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Assessment of human impact on water quality along Manyame River

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Abstract

Human activities such as urbanization, agriculture, sewage treatment and industrialization are affecting water resources both quantitatively and qualitatively. The impact of these activities were studied by measuring and determining the concentration and values of eight selected water quality parameters namely nitrates, phosphates, copper, iron, biochemical oxygen demand (BOD), dissolved oxygen (DO), pH and turbidity along Manyame River, in the Manyame Catchment. Thirty five sites were sampled from the source of the river which is at Seke Dam, along Manyame River and on the tributaries (Ruwa, Nyatsime, Mukuvisi and Marimba) just before they join the river. The 35 sites were categorized into 5 groups (A, B, C, D and E) with group A and E being the upstream and downstream of Manyame. The analysis of results was undertaken using a simple one-way ANOVA with group as the only source of variation. Turbidity values, nitrate and phosphate concentrations were found to be higher than the Zimbabwe National Water Authority (ZINWA) maximum permissible standards for surface waters. DO saturation in the downstream groups was less than 75% (ZINWA standard). Agricultural and urban runoff and sewage effluent were responsible of the high nutrient levels and turbidity, which in turn, reduced the dissolved oxygen (DO).

Keywords: Agriculture, Pollution, Sewage, Urbanization, Water quality

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1. Introduction

The study was conducted on a stretch along Manyame River from the source, Seke Dam, up to Lake Chivero to determine the impact of human activities prevalent in the catchment on the river water quality. Lake Chivero is also a water supply for the City of Harare and Chitungwiza. The study was carried out to investigate the problems that were being experienced in the catchment. The problems included high incidence of water borne diseases like cholera and diarrhoea, increases in the cost of purifying water for domestic use, and the presence of the alien invasive water hyacinth in Manyame River. All these problems indicated that Manyame River and its tributaries (Ruwa, Nyatsime, Mukuvisi and Marimba) were polluted. Water pollution is a global problem and does not respect national boundaries. Pollution is by far the most critical factor affecting the sustainability of the availability of water resources in southern Africa (Masundire and Mackay, 2002).

Water pollution is defined, by the ZINWA as the discharge of any liquid, solid, gaseous, pathogenic organisms or other substances into the water as will or is likely to create a nuisance or to render such water harmful, detrimental or injurious to the health, safety or welfare of the public and the environment. Much of water pollution results from human activities such as agriculture, mining, manufacturing industries and poor management of urban waste. This hampers the use of water for downstream purposes and increases the cost of treatment. Manyame catchment is the most urbanized of the seven catchment of Zimbabwe, as it contains two major cities: Harare and Chitungwiza and two small towns, namely Norton and Ruwa. As expected, human activities that cause pollution to the environment are legion. The sources of pollution were identified as sediments, industrial effluent, sewage effluent and urban runoff (carrying significant amounts of sediment, nutrients and organic materials resulting in the increase in suspended and deposited sediments and these have a serious impact on the aquatic environment (Munzwa, 1982; Moyo and Mtetwa, 2002).

The effects of disposing untreated sewage in aquatic systems cause depletion of DO due to oxidation of organic matter and increases nutrients such as nitrogen and phosphorus. Alien invasive species like the water hyacinth, also causes a reduction in DO and light levels in water, is a major threat in Manyame River (Masundire and Mackay, 2002). The water hyacinth weed has caused a decline in fish catches in Lake Chivero. The water hyacinth can also increase evaporative water losses from reservoirs and water bodies by as much as 3.5 times (Davies and Day, 1998), representing an enormous economic loss, in terms of water available for economic production for example irrigation. Water quality degradation is one of the most serious of all environmental problems because it can affect human health and economic activities as well as biotic communities (Turpie and van Zyl, 2002). With population growth and economic growth in the Manyame Catchment, surface and groundwater quality is increasingly being degraded by industrial and agricultural activities, and domestic sewage. Mukuvisi River which runs into Harare's drinking water supply was found by Chenje and Johnson (1996) to contain high concentrations of nutrients, sulphates, calcium, magnesium, fluoride, aluminium and iron largely from industrial dumps along the river banks.

There has been high incidence of waterborne diseases in areas of Chitungwiza and Norton as a result of untreated sewage finding its way into drinking water sources. This, in turn, was caused by overburdening of the sewage systems as a result of the ever increasing volume of wastewater generated by an increase in the population of Harare (Moyo and Mtetwa, 2002), whilst the sewage treatment facilities are not increasing at the same rate. The population of Harare, according to the 2002 national census was 1,444,534 and Chitungwiza had a population of 321,782 (CSO, 2003). The Firle Sewage Works treats half of Harare's sewage and was designed to treat 72,000 m^3 of wastewater, but now the plant receives flow in excess of 100,000 m^3 of wastewater per day (Moyo and Mtetwa, 2002).

Industrial pollution in the catchment is associated with contamination of water by heavy metals. According to JICA (1997), there are more than 45 different types of industries in the Upper Manyame basin which have become pollution sources as they discharge untreated and partially treated substandard effluent into municipal sewer system of Harare. Industrialization is associated with contamination of surface waters by heavy materials. Another non-point source of pollution is peri-urban agriculture being practiced by urban dwellers in Harare, Norton and some parts of Chitungwiza and is responsible for loading nutrients like nitrates and phosphates in rivers leading to eutrophication. The aim of this study was to assess the impact of non-point and point source pollution on the quality of water along Manyame River and to investigate whether the quality was deteriorating as distance from the upstream control point increases; in terms of nitrates, phosphates, copper, iron, dissolved oxygen, biochemical oxygen demand, turbidity and pH. To accomplish the study objectives, water samples were taken along Manyame River and were analyzed at the National Water Quality Laboratory (NWQL) for the eight selected physical and chemical water parameters.

2. Methodology

2.1. Site description

The study was carried out on a stretch of Manyame River, from the source, which is, at Seke dam to Lake Chivero, in Manyame Catchment, one of the seven catchments of Zimbabwe. A sketch map of the study area is shown in Fig 1. The catchment is the most urbanized in Zimbabwe, and it contains two major cities: Harare and Chitungwiza and two small towns, namely Norton and Ruwa. As expected, human activities that cause pollution to the environment are legion. The study area stretches from Seke Dam (source of Manyame river), situated to the North West of Chitungwiza up to Lake Chivero. It lies at latitude 17^o 56′ S of the Equator and longitude 30^o 34' E of the Greenwich. The study area is situated in Natural Region II, which is the main cropping region of Zimbabwe, and receives moderate to high rainfall (700 mm to 1000 mm), most of the which, if not all, falls in the summer season. The area experiences warm to high summer temperatures (22 to 27 ^oC). High temperatures are experienced in the summer season. The winter season is cool (16 to 18 ^oC). The soils are sandy loams that are well drained and are derived from granite. Manyame catchment is located in the Highveld of Zimbabwe, which stretches from the Southwest to the Northeast and lies between 1220 and 1525 m above mean sea level. This relief region forms a watershed between the Zambezi (to the north) and Limpopo (to the south) and has the middleveld on either side.

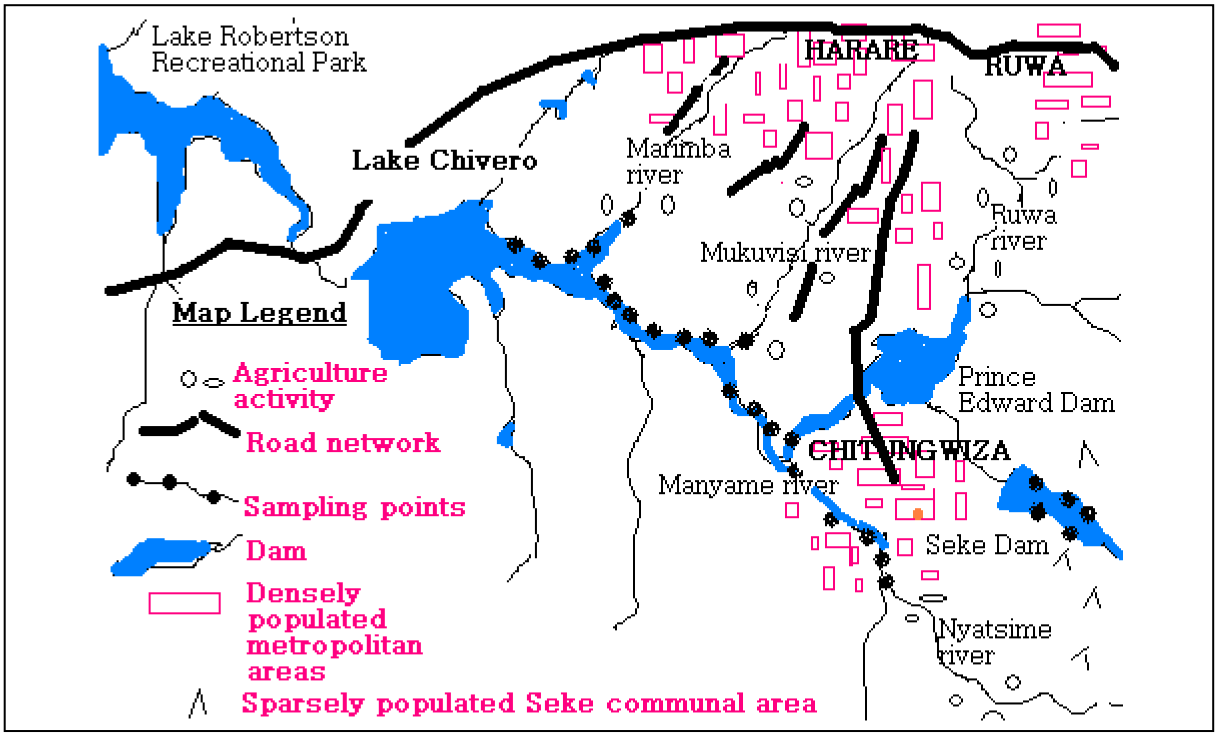

Figure 1. Sketch of the field situation

2.2. Methodology

2.2.1. Sampling

Thirty-five sites were sampled along Manyame River and stratified random sampling technique was used during selection of points to sample, to eliminate bias by catering for all tributaries that feed into Manyame River. This was achieved by taking three duplicate samples per sampling point after every tributary had joined the main river (Manyame) as shown in Fig 1. Sampling was undertaken in accordance to NWL/SAZ: 558: 1999/22/05 (sampling from surface waters), which stipulates that samples should be taken at points where water is flowing, and sampling bottles used should be sterilized, among other precautions.

2.2.2. Layout of the experimental design

A completely randomized design was used for analysis, with the thirty-five sampling sites divided into five groups of seven sites each, as shown in Table 1.

Table 1. Grouping of sampling sites

Sites in group A	Sites in group B	Sites in group C	Sites in group D	Sites in group E
CP I	RUW 1	NYA 1	MUK 1	1-Mar
M1	M7	M13	M19	M25
M2	M8	M14	M20	M26
M3	M9	M15	M21	M27
M4	M10	M16	M22	M28
M5	M11	M17	M23	M29
M6	M12	M18	M24	M30

CP 1 – Control point (Seke Dam); RUW 1 - Site on Ruwa-Manyame confluence; NYA 1 - Site on Nyatsime-Manyame confluence; MUK 1 - Site on Mukuvisi-Manyame confluence; MAR 1 - Site on Marimba-Manyame confluence; M1 to M30 - Sites along Manyame River

The analyses of results were undertaken using a simple one-way ANOVA with group as the only source of variation for each of the eight water quality parameters. Group A consisted of the control point and the next six sites. Group B consisted of RUW 1 and the next six sites. The same applies for other groups which start at NYA 1, MUK 1 and Mar 1 respectively. Group A is upstream followed by groups B, C, D and E (E is located downstream).

2.2.3. Determination of water quality parameters

Determination of nitrates, phosphates, Cu, Fe, DO, BOD, turbidity and pH were undertaken using methods according to the SAZ and National Water Quality Laboratory (NWL). Turbidity was determined by the Turbidimeter (NWL/SAZS: 478:1995), DO by the Winkler method as described by NWL/SAZS: 573: 1997, BOD by the 5 day-incubation at 20 ^{o}C as described by NWL/SAZS: 496:1995 and pH by the method described by NWL/SAZS: 459: 1993. Nitrates were analyzed using the spectrometric method as described by NWL/SAZS: 481:1996, phosphates by NWL/SAZS: 603:1996 and iron using atomic adsorption spectrometry described by NWL/SAZS: 486:1997.

3. Results

3.1. Human activities

It was observed that the main human activities taking place in the study area was agriculture, light and heavy manufacturing industries and some mining activities. These activities together with untreated and partially treated sewage effluent were noted to be responsible for polluting Manyame River and its tributaries. These activities were similar to those found by Mudozori and Kusangaya (2005) that intensive urban and commercial agriculture along the long profile of Manyame and its tributaries contributes to pollution by agro-chemicals. Agriculture in form of both, commercial and uncontrolled subsistence agriculture was found to be the main human activity along Nyatsime and Mukuvisi Rivers. There were very little agricultural activities taking place along Marimba and Ruwa Rivers. There were some mining activities taking place along Mukuvisi River, which was also receiving untreated and partially treated sewage from Mabvuku and surrounding residential areas. Chitungwiza was experiencing sewage treatment problems and bursting of sewage pipes, was responsible for sewage effluent finding its way in Nyatsime River. Norton City Council had similar concerns, which led to untreated sewage finding its way into the environment. The increase in population of the Harare, Chitungwiza and Norton due to urbanization is responsible for the overburdening of the sewerage systems as they were not designed to cater for the current populations. The light industries around Chitungwiza, Norton and Harare were also releasing untreated and partially treated effluent to the environment. Ruwa was experiencing high developments including massive building and construction in industry and housing during the study period. The area around the control (Seke Dam) had minimum human activities and was sparsely populated.

3.2. Nitrates and phosphates

The concentrations of nitrate increased as the distance from Seke Dam (control point) increased. The concentrations of nitrates ranged between 9.92 mg/l (upstream) to 15.69 mg/l (downstream) as shown in Table 2. Generally, the increase in the concentrations of nitrate is as a result of the contribution of the joining tributaries, with Nyatsime River contributing the highest nitrate load as shown by the resultant increase in nitrate concentration immediately after Nyatsime joined Manyame River. The source of nitrates and phosphates could be from untreated sewage and uncontrolled agricultural activities along Nyatsime River. Phosphate concentrations increased at a constant rate as distance from the upstream control point increased, from 2.46 mg/l to 5.80 mg/l at the downstream (group E), implying almost equal contributions of all the tributaries.

3.3. Copper and iron

The lowest concentrations of copper were recorded in the upstream group, A (0.017 mg/l), whilst that of iron were recorded in the third group (0.043 mg/L). The mean copper concentration for the third group, C (0.029 mg/l) is much lower than that of the second group, B (0.041 mg/l) as shown in the Table 3. This implies that Ruwa and Mukuvisi Rivers contributed the highest concentrations of copper as shown by the mean concentrations soon after joining Manyame River. The least concentrations of iron were recorded for the middle group C (0.43 mg/l), although there were no significant differences between the mean concentrations of iron for the first 3 groups (A, B and C). The upstream (group A) had higher concentrations of iron than Group B and C. Samples taken soon after Nyatsime River joined Manyame indicate that Nyatsime had a much lower iron concentration compared to other tributaries. This could be attributed to the dilution effect that resulted after Nyatsime River had joined the main river. Successive addition of stream water from polluted and unpolluted tributaries (Figure 1) into the main river, Manyame, with running water has the effect of reducing pollutant concentration by dilution. However, the greatest concentrations for both iron and copper were recorded downstream (group E).

Table 2. Mean nitrate and phosphate concentrations for the five groups

Group	Mean nitrate concentration (mg/l)	Mean value ± SD	Mean phosphate concentration (mg/l)	Mean value ± SD
A	9.92^{a}	9.92±0.78	2.46^{a}	2.46±0.38
B	14.53^{b}	14.53±1.62	3.06^{b}	3.06±0.35
C	16.41^{c}	16.41±1.58	4.00^{c}	4.00±0.41
D	15.07^{b}	15.07±0.91	4.97^{d}	4.97±0.60
E	15.69^{bc}	15.69±1.21	5.80^{e}	5.80±0.56
L. S.D $p < 0.05$	1.68		0.58	

Key *The Group means with the same superscript letter indicates that p>0.05 (not significantly different).*
Means with different letters indicates that p<0.05 (significantly different). L.S.D – least significant difference.
SD – standard deviation

3.4. Dissolved oxygen and biochemical oxygen demand

DO decreased downstream where as BOD increased downstream. This is so because unpolluted river water has a high DO level and low BOD level. Highest DO concentrations were observed in the upstream group and the lowest DO concentration was found in the fourth group, D (3.81 mg/l), which is also statistically different from the average for other groups as shown in Table 4. This indicates that Mukuvisi River contributed water containing high oxygen demanding waste, which could have diluted the DO concentration from 6.06 mg/l, before joining the main river. High concentrations of BOD were found in the last 3 downstream groups, all having a mean above 6.00 mg/l, with the highest concentration (7.16 mg/l) recorded after the joining of Mukuvisi River. The lowest concentrations of BOD were noted at the upstream.

Table 3. Mean concentrations of copper (Cu) and iron (Fe) for the five groups

Group	Mean Cu levels (mg/l)	Mean value ± SD	Mean Fe levels (mg/l)	Mean value ± SD
A	0.017^{a}	0.017±0.03	0.059^{ab}	0.059±0.02
B	0.041^{c}	0.041±0.06	0.054^{ab}	0.054±0.02
C	0.029^{b}	0.029±0.04	0.043^{a}	0.043±0.01
D	0.057^{d}	0.057±0.06	0.066^{b}	0.066±0.03
E	0.060^{d}	0.060±0.07	0.094^{c}	0.094±0.05
L.S.D $p<0.05$	0.0098		0.024	

Key *The Group means with the same superscript letter indicates that p>0.05 (not significantly different).*
Means with different letters indicates that p<0.05 (significantly different).
L.S.D – least significant difference.
SD – standard deviation

Table 4. Mean concentrations of DO and BOD for the five groups

Group	Mean DO levels (mg/l)	Mean value ± SD	Mean BOD levels (mg/l)	Mean value ± SD
A	9.74^{d}	9.74±0.39	2.75^{a}	2.75±0.11
B	7.38^{c}	7.38±0.30	4.91^{b}	4.91±0.28
C	6.65^{c}	6.65±0.24	6.01^{c}	6.01±0.34
D	3.81^{a}	3.81±0.16	7.16^{d}	7.16±0.48
E	5.06^{b}	5.06±0.21	6.33^{c}	6.33±0.44
L.S.D $p<0.05$	0.674		0.727	

Key *The Group means with the same superscript letter indicates that p>0.05 (not significantly different).*
Means with different letters indicates that p<0.05 (significantly different).
L.S.D – least significant difference.
SD – standard deviation

3.5. Turbidity and pH

The pH results did not show much variation. The pH ranged from 6.26 to 7.27 and hence lies within the WHO range of 6.5 to 8.5 for effluent and river water standards save for the upstream group, which is also slightly acidic. Nutrient enriched waters are characterized by high pH values (Chapman, 1996). Turbidity increased with distance from the upstream from 21.16 NTU (group A) to 30.33 NTU (group E) as shown in Table 5. Nyatsime River contributed acidic water than all the other tributaries, as indicated by a drop in the pH after it had joined the main river. Ruwa River had the greatest load of suspended solids than the other tributaries as evidenced by the increase in turbidity in Manyame River after it had joined. The turbidity for the three middle groups was almost the same implying a similar turbidity load from Nyatsime and Mukuvisi Rivers.

Table 5. Mean pH and turbidity values for the five groups

Group	Mean pH values	Mean value ± SD	Mean turbidity values (NTU)	Mean value ± SD
A	6.26^{a}	6.26±0.56	21.16^{a}	21.16±1.29
B	7.02^{bc}	7.02±0.58	28.29^{b}	28.29±1.34
C	6.63^{ab}	6.63±0.50	28.26^{b}	28.26±1.35
D	7.27^{c}	7.27±0.63	28.80^{b}	28.80±1.41
E	7.23^{c}	7.23±0.64	30.33^{b}	30.33±1.65
L.S.D	0.484		2.55	
P<0.05				

Key *The Group means with the same superscript letter indicates that p>0.05 (not significantly different).*

Means with different letters indicates that p<0.05 (significantly different).

L.S.D – least significant difference.

SD – standard deviation

4. Discussion

The concentrations of nitrates in groups B, D and E were significantly higher than from those in group A (upstream). This implies that the quality of water in terms of nitrates is deteriorating downstream. The concentrations of phosphates in all the groups were statistically different, with the highest concentration in the group E (downstream). The increase in the concentrations of nitrates and phosphates as the distance from upstream increased was as a result of the contribution of the tributaries (Ruwa, Nyatsime, Marimba and Mukuvisi) and the increase in agricultural and industrial activities (fertilizer manufacturing, steel making, mining refineries) taking place along and upstream of the tributaries. Only the upstream group was found to have nitrate concentration below the ZINWA concentration of 10 mg/l for domestic supplies, with the rest mean concentrations exceeding the recommended value. The highest concentration of nitrates, noted for group C, after the joining of Nyatsime River (16.41 mg/l) is more 65% greater the ZINWA recommended concentration. Mean phosphate concentrations recorded for all the groups were way above the recommended concentration of 0.5 mg/l, with the lowest concentrations found at the upstream (2.46 mg/l) and the highest concentration noted for the downstream group (5.8 mg/l). The highest phosphate concentration was found to be 11.6 higher than the recommended concentration. This phosphate concentrations were also noted in a study by Hranova et al. (2002) in Marimba River where the mean concentrations of ammonia and phosphates were 3.5 and 4.4 mg/l respectively which were exceeding the ZINWA regulation by 7 - 9 times. The nitrates and phosphates, which are also responsible for the eutrophication, were likely to be coming from agricultural lands located in parts of Chitungwiza and Norton as well as sewage effluent emanating from the sewage outbursts that characterized Chitungwiza during the study period. This again echoed the findings by Hranova et al. (2002) where the sources of nitrates and phosphates were associated with the operational problems of the treatment facilities and non-point sources of pollution from pastures irrigated with effluent as well as urban storm water. Nyatsime River contributed the highest load of nitrates while the highest phosphate concentrations were contributed by Marimba River.

Statistically the copper concentration in the first three groups (A, B and C) were not different, whilst the two last groups downstream was different ($p<0.05$). This is attributed to the heavy industrial activities nearby, where the companies are not treating their effluent to the standards required by the ZINWA. The first three upstream groups contain statistically the same levels of iron although the least levels were recorded in the third group (group C), which is soon after the joining of Nyatsime River. This can be due to the dilution effect, whereby the high concentration of iron (upstream) was reduced after mixing with water containing lower iron concentration, from Nyatsime River. The higher levels of iron at the upstream are as a result of pollution arising from the some light industrial activities upstream. This might be an indication of upstream contamination with iron-rich effluent. However, the concentrations of both copper and iron were found to below the recommended concentrations by ZINWA of 0.1 mg/l and 0.3 mg/l respectively.

The highest DO concentration found in the upstream group indicate less pollution in the upstream compared to the downstream which had low DO concentration (Nhapi and Tirivarombo, 2004). This can be attributed to the fewer potential causes of pollution at the upstream compared to downstream (Lake Chivero) where the intensity of human activities (agriculture, mining, and heavy industries) will have contributed oxygen demanding wastes in river. BOD analyses were used to determine the strength of oxygen demanding materials and from the results it was shown that the strength was higher on the downstream compared to that at the upstream. Only the last two downstream groups (D and E) mean DO concentrations were found to be less than the 75% saturation permitted for domestic water supplies by ZINWA. The depletion of DO downstream was a result of the untreated sewage from the city centre and Chitungwiza residential areas. The other possible explanation for DO depletion in oxygen demanding waste is the increase in temperature of wastewater. All the mean concentration of BOD noted were less than the ZINWA recommended concentration of 15 mg/l.

Mean values of turbidity in all the groups except the first group (upstream) were statistically not different ($p<0.05$). The high values of turbidity are attributed to non-point pollution including soil erosion, runoff from residential areas containing debris left after the clean-up (*Murambatsvina*) operation of 2005, excess nutrients and, various waste and pollutants. The action of bottom feeding organisms which stir sediments up into the river could have also contributed to high turbidity values. The suspended solids in the water, including silts, clays, industrial wastes and sewage are responsible for causing surface waters to be turbid. Nhapi and Tirivarombo (2004) found that high turbidity values were noted in Marimba River after sewage discharge mainly due to residential and urban agricultural runoff, pond overflow and pasture runoff.

Pollution of the water was found to be responsible for the fluctuating pH values in Manyame River. The standard optimum pH for surface waters like Manyame River is around 7.4. Mining activities in the catchment were found to be responsible for slightly acidic conditions in Nyatsime River. The pH values found in the study was within the ZINWA maximum allowable limit for domestic supplies of 6.5 to 9. The water acidity would have probably been increased by acid rain (due to heavy industrialization in the study area) but would have almost certainly been kept in check by the buffer limestone. The buffer limestone dissolved in a stream adds carbonate and bicarbonate ions that have the ability to neutralize acid. Extremes in pH can make a river inhospitable to life. Low pH is especially harmful to immature fish and insects. Nyatsime River contributed water with a lower pH (more acidic) than the other tributaries, as shown by the lower pH in group C. Acidic water also speeds the leaching of heavy metals harmful to fish. This was confirmed by the lowest corresponding mean iron concentration for group C (0.043 mg/l) recorded for the acidic group C.

5. Conclusions

- The quality of water in Manyame River was generally decreasing downstream. Both point and non-point sources pollution (soil erosion runoff from agricultural lands containing nutrients, industrial wastes and sewage) were possibly responsible for the deteriorating quality of water along the Manyame River.
- The upstream is less polluted due to minimal human activities like agriculture and industrialization, which were increasing as distance from the upstream increased.
- Agricultural runoff and sewage contributed to the nutrients concentration in the receiving waters that drains into Manyame River.
- Industrial effluents contributed metal (copper and iron) concentrations into the river; however the concentrations for both copper and iron, in all the sections of river, were found to be below the recommended concentrations for domestic supplies by ZINWA.
- Generally high population growth rates in Harare and Chitungwiza had adverse effects on water resources. The population influx in these urban centres is greater than the sewerage capacity meaning untreated sewage effluent may be discharged into water bodies (Moyo and Mtetwa, 2002).

- Of the eight selected water quality parameters, turbidity, nitrates, phosphates and dissolved oxygen were greater than the ZINWA maximum allowable concentrations.

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