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BIOREMEDIATION WITH THE WATER HYACINTH (*EICHHORNIA CRASSIPES*): A PANACEA FOR RIVER POLLUTION IN THE CITY OF MASVINGO (ZIMBABWE)?

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ABSTRACT

River pollution poses a major threat to Zimbabwe's natural water courses, especially those that pass through urban centres. This study examines the effectiveness of the water hyacinth (*Eichhornia crassipes*) in remediating the Shagashe River, which has been heavily polluted by raw sewage from Masvingo City's sewage treatment works. It is based on surveys, which were conducted between August and October 2012 as well as data from the Environmental Management Agency (EMA), a watch dog of Zimbabwe's environment. Although laboratory experiments indicate that the weed is an effective agent of wastewater bioremediation, results from this survey show that under natural conditions this may not be the case probably due to the continuous flow of water downstream, which does not provide the weed with adequate contact time for bioremediation. For this reason, the weed does not provide a remedy for the polluted river. The paper suggests alternative solutions for the problem of river pollution in the city so that sustainable development (SD) can be achieved.

Keywords: River Pollution, Water Hyacinth, Bioremediation, Sustainable Development, Phytoremediation

INTRODUCTION

Rapid rates of urbanization are major characteristics of most developing countries (Auret, 1995). In 1990, the most urbanized countries in southern Africa were: South Africa (59%), Zambia (50%) and Tanzania (33%), respectively (Chenje & Johnson, 1994). Although Zimbabwe had a modest figure of 28% compared to a regional average of 42.7%, in more recent years, it has been rapidly catching up with the rest of its neighbours as shown by a 40% urban population in recent years (Chimhowu, Manjengwa, & Feresu, 2010). As urban centres grow spatially and demographically, they are confronted by waste disposal problems, which result in water or river pollution (Mapira, 2011). Chenje and Johnson (1996) define this form of pollution as:

'*the degradation of natural systems by the addition of detrimental substances such as sewage, heavy metals, pesticides and detergents. It is generally associated with industrial and agricultural development, and the rapid increase of human population densities. Economic growth leads to larger discharges of wastewater and solid waste per capita*'.

They also identify the main sources of the pollution such as:

a) Industrial and municipal waste, which is either bio-degradable or otherwise, solid or liquid
b) Agro-chemical pollution, a product of the application of pesticides, herbicides or fertilizers, which are widely used in southern Africa
c) Pollution emanating from health control measures such as the spray of mosquitoes, spiders, mites and other parasites
d) Oil spills during transportation or use, and
e) Industrial emissions (gaseous) and dust fall.

A major symptom of river pollution is the proliferation of the water hyacinth, a weed that thrives under conditions of contaminated water (Moyo, 1997). Rivers which pass through some urban centres of Zimbabwe have been heavily polluted by wastewater resulting in *eutrophication*, a condition that promotes the growth and proliferation of the water hyacinth (Mapira & Mungwini, 2005). As the weed spreads in dams, along river channels and other water bodies, it clogs them and destroys other forms of aquatic life such as: frogs, turtles and fish. According to Moyo (1997), Lake Chivero, a major source of water for the city of Harare is now '*dead*' due to the high level of *eutrophication* and the proliferation of the water hyacinth.

Although the weed is often viewed negatively due to its damaging effects on some water sources, laboratory experiments suggest that it has a healing impact as it absorbs nutrients such as nitrates, phosphates and other pollutants (Reddy & Tucker, 1983; Rogers, Breen, & Chick, 1991; Sooknah, 2000). Consequently, the aim of this study is to assess the bioremediation impacts of the weed on the Shagashe River in the city of Masvingo. Through an analysis of nine physico-chemical parameters of samples drawn from two sample points (Table 1), the study addresses the following research questions:

a) What are the main causes and sources of river pollution in the city of Masvingo?
b) What implications do they have on the city's water quality and sustainable development?
c) How effective is the water hyacinth in the remediation of Shagashe's water?
d) What solutions can be suggested for the achievement of environmental sustainability?

DESCRIPTION OF STUDY AREA

Samples for this study were collected from two points designated A and B 6km apart along the Shagashe River, which flows through the city of Masvingo. Masvingo is the provincial capital of Masvingo Province in Zimbabwe (Figure 1). It is located in the south-easterly part of the country within the dry low-veld area. A decade ago, the city had a population of 69 993 while the province had approximately 1 300 000 people (CSO, 2002). However, recent municipal estimates peg the city's population figure at about 90 000 (Munganasa, 2008). Covering an area of 6 835 hectares, the city has been encroaching on surrounding agricultural land since the colonial era (Scott, 1991).

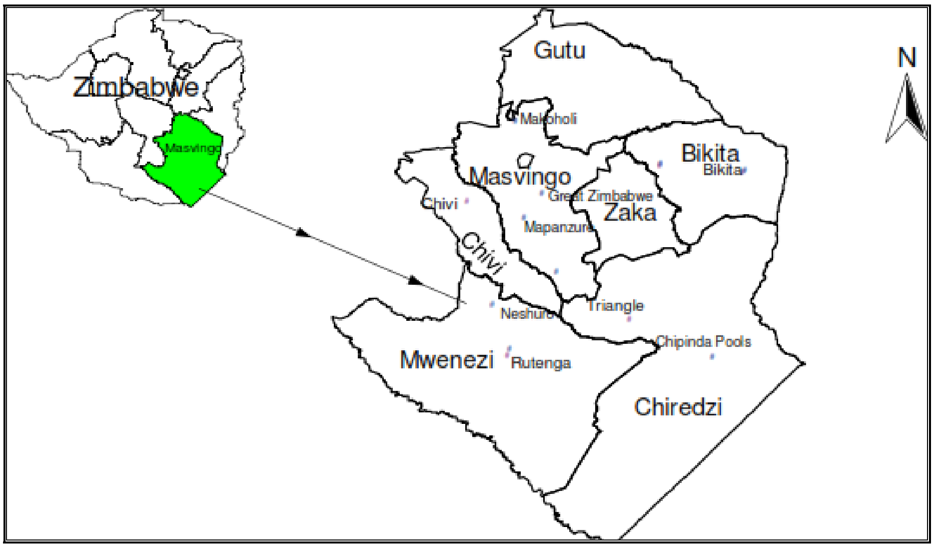

Figure 1: Location of Masvingo Province (Adapted from: Simba et al., 2012)

The city of Masvingo was established on the 13th of August in 1890 by the British South Africa Company (BSAC) Pioneer Column who had been contracted by Cecil John Rhodes to colonize Zimbabwe (Bulpin, 1968). Originally, Fort Victoria (its colonial name) was located at the Providential Pass, some 8km south of the present site. However, due to water scarcity, the fort later shifted to the confluence of the Mucheke and Shagashe Rivers where it has survived up to the present day (Figure 2). In 1894 the first form of local government (the Sanitary Board) was established. In 1926 it acquired town status and by 2002, it had become a city to join other urban centres of its age (City of Masvingo Annual Report, 2002).

As the city expands spatially, demographically and industrially, it exerts a considerable impact on the environment, resulting in pollution and land degradation in general. Since the last two decades, the Mucheke and Shagashe Rivers have been heavily polluted by raw sewage from industrial, commercial, residential and institutional sources (Mapira & Mungwini, 2005). This pollution has impacted negatively on water quality in Lake Mutirikwe, which is located some 30km downstream. It has also raised water treatment costs at the adjacent Bushmead water treatment plant (Masvingo City Engineer's Annual Report, 2002). The Mucheke is a tributary of the Shagashe, which in turn drains into Mutirikwe River on which the Lake lies. Mucheke River flows through industrial, residential, commercial and institutional areas before eventually joining the Shagashe on the outskirts of the city (Figure 2).

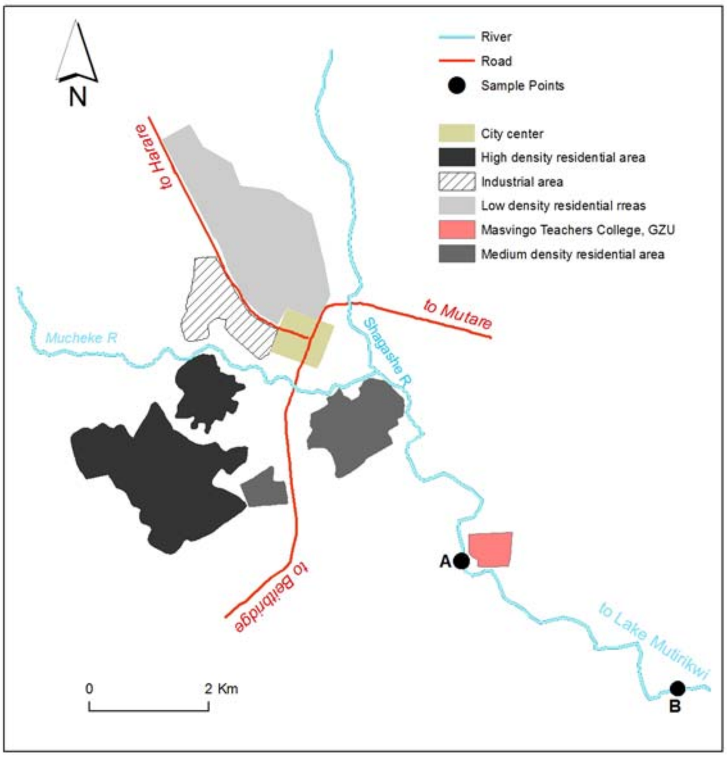

Figure 2: Map of Masvingo city showing the Shagashe River and its tributary, Mucheke. Sample point A is adjacent to Masvingo Teacher's College and Great Zimbabwe University campus while B is located 6km downstream.

RESEARCH METHODOLOGY

The objective of this study was to test for the effectiveness of the water hyacinth in phytoremediating Shagashe River as observed by the reduction or lack of in physico-chemical parameters analysed for points A and B (Table 1). This was followed by a statistical analysis to test if the observed differences in parameters were significant. The raw data used was solicited from the Environmental Management Agency (EMA), Masvingo Provincial office. EMA is a government body which has the responsibility to safeguard the environment and enforcing laws in an endeavour to try and preserve the natural resources of Zimbabwe (Mapira, 2011). Data collected was for physico-chemical parameters for samples collected from the 2 points (A and B) mentioned previously. A is an upstream point while B is located 6km further downstream. The portion of the river between these two points along the river has been infested by the water hyacinth (Figures 2 and 3). The invasive aquatic macrophyte has become a permanent feature of the river for over a decade (Mapira & Mungwini, 2005). The physico-chemical analysis results were for a four year period stretching between 2009 and 2012. Only results for the cool dry season, September to April, were used for the study. This was done because the weed favours raw sewage which prevails during this season when river discharge is at its lowest level (Mapira, 2011).

Figure 3: Water hyacinth infestation in the Shagashe River below the bridge on a stretch between points A and B adjacent to the Great Zimbabwe University campus in Masvingo city.

Physico-chemical parameter analysis

Table 1 depicts physico-chemical parameters analysed from samples that were collected from points A and B.

Table 1: Physico-chemical parameters analysed for samples collected from sample points A and B.

Parameter	**Analytical method**
pH	Electrode
Nitrates	Spectrophotometry
Phosphates	Spectrophotometry
Chemical oxygen demand (COD)	Spectrophotometry
E. Conductivity	Electrode
Total hardness	Titrimetric
Dissolved oxygen (DO)	Electrode
Chloride	Titrimetric
Total dissolved solids (TDS)	Gravimetric

(Source: EMA, Masvingo Province Branch.)

Statistical analysis

Raw data collected from EMA was statistically analysed with results shown as mean ± standard error. For comparison of mean concentrations of physico-chemical parameters analysed for the two points A and B, the independent samples t-test was used. Statistical significance was defined as $p < 0.05$. The Statistical Package for Social Scientists (SPSS 16.0) software was used in administering the t-test.

RESULTS AND DISCUSSION

Figure 4 shows that there was a slight or marginal (3.5%) increase in the concentration of nitrates (NO_3^-) as water moved downstream from sample point A (1.13 mg/l ± 0.18) to B (1.17 mg/l ± 0.63). Statistically, there was no significant difference ($p < 0.05$) between the mean concentrations of nitrates analysed for samples collected from the two points. Values for nitrate concentration ranged between 1.00 and 1.63 mg/l and 0.79 to 2.37 mg/l for samples collected from A and B respectively.

Nitrates

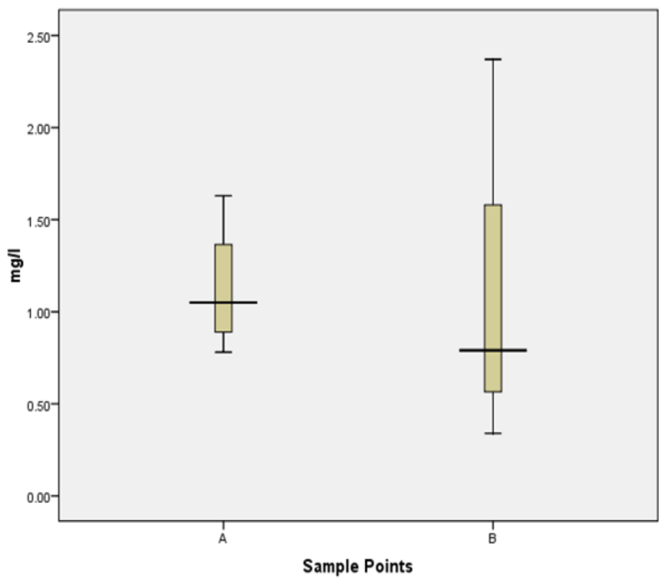

Figure 4: Nitrate concentration for two sample points along the Shagashe River.

The water hyacinth removes nitrates by assimilating them from water (Rogers et al., 1991). The weed utilises the nutrients in its metabolic processes such as protein and nucleic acid synthesis. These are subsequently used for growth and other functions. The rate of nitrate uptake is influenced by factors such as: growth rate, temperature and the density of water hyacinth (Reddy & Tucker, 1983; Sooknah, 2000). As these parameters increase so does the rate of nitrate uptake.

The ability of the water hyacinth to remove nitrates from water has been demonstrated in different studies (Akinbile & Yusoff, 2012; Dar, Kumawat, Singh, & Wani, 2011; Shah, Kumawat, Singh, & Wani, 2010). In a study carried out by Akinbile and Yusoff (2012), water hyacinth was used to treat wastewater samples from a fish farm. This was set up in plastic dishes containing both the aquatic macrophyte and wastewater. Nitrate concentration was significantly reduced by as much as 90.72% within a four week period (Akinbile & Yusoff, 2012). Using a laboratory set up in which water hyacinth was used to remediate municipal wastewater samples in plastic troughs, the concentration of nitrates was reduced to levels just over 50% the initial concentration within a 15 day period (Dar et al., 2011). In an experimental set up similar to that used by Dar et al. (2011), water hyacinth was used to treat dye-wastewater samples. Nitrates were reduced to concentrations ranging from 10 to 38% in the different conditions employed within a 15 day period (Shah et al., 2010).

Results from the present study suggest that the water hyacinth may have not removed nitrates from the river between the two sample points A and B. There is evidence that the macrophyte preferential uses ammonia over nitrates as a nitrogen source (Reddy & Tucker, 1983; Sooknah, 2000). In their study, Reddy and Tucker (1983) showed that water hyacinth was more efficient in utilising ammonia than nitrates when both the nitrogen sources were supplied in equal proportions. The water hyacinth may be utilising ammonia in the river in preference to the nitrates hence the insignificant change in its concentration between the two points. Analysis of water samples further downstream may provide a clearer picture on the ability of the plant to reduce nitrates in the river.

Most documented experiments in which water hyacinth has significantly reduced nitrates concentration have been done in conditions in which water being treated was static. This translates to a high contact time between the plant roots and the nitrates in the water consequently leading to more effective removal of the nitrates by the plant. Conditions for the current study are much different as the water in the river was flowing implying there was less contact time between it and the roots evidently leading to less effectiveness in the removal of nitrates. The impotence of water hyacinth to significantly reduce nitrate concentration in a river has been reported by Ndimele (2012). In the study, water samples were collected from three hyacinth infested rivers and one control (had no hyacinth). Statistical analyses showed there was no significant difference in nitrate concentration among the different sample points (Ndimele, 2012). In another study seeking to the examine the efficiency of water hyacinth to remove nutrients from municipal wastewater samples, Kutty, Ngatenah, Isa, and Malakahmad (2009) reported the plant to have failed to significantly reduce nitrate levels when compared to a control.

Phosphates

Phosphate concentration for point B (3.43 ± 0.80 mg/l) was found to be slightly higher than for A (3.11 ± 0.86 mg/l) as illustrated on Figure 5. This was approximately a 10% margin difference between the two points. However, this disparity is not significant as was shown by statistical analysis ($p < 0.05$). The minimum and maximum concentration values for phosphates on the upstream point A were 0.03 and 7.66 mg/l respectively. For point B, these were 0.11 and 6.30 mg/l, respectively.

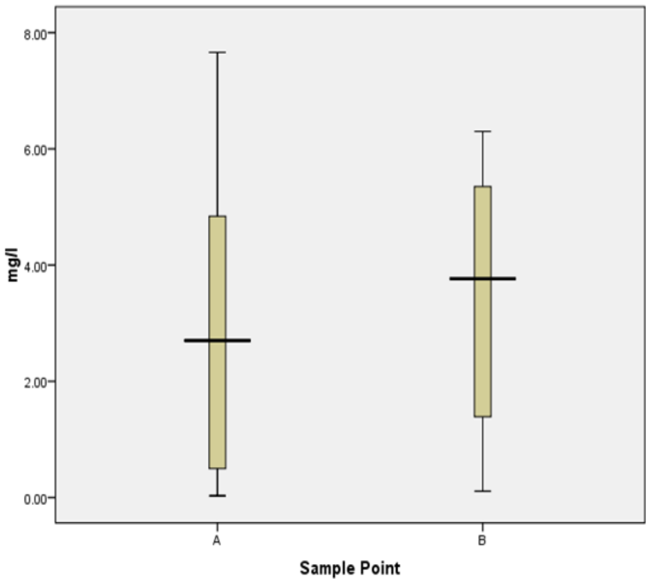

Figure 5: Phosphate concentration for two sample points along the Shagashe River.

Plants take up phosphates through assimilation by roots, into the xylem and shoots (Lambers & Colmer, 2005; Sooknah, 2000). In this study, the water hyacinth does not seem to be removing phosphates from water. These results are in agreement to those presented by Ndimele (2012) who discovered that concentration of phosphates from a non water hyacinth infested river were not statistically significantly different from those that were chocked with the plant. However, in an experiment done by Akinbile and Yusoff (2012) evidence to the contrary was shown. In their study, the water hyacinth reduced phosphate levels by as much as 85%. The increase in phosphate concentration has been reported by Akinbile and Yusoff (2012). Phosphate concentration was shown to increase after four weeks in the treatment containers. This they attributed to the accumulation of the plant detritus (Akinbile & Yusoff, 2012).

Electrical Conductivity

The average value of E. Conductivity for samples collected from point A (484.70 µS/cm ± 60.43) was marginally higher than for those for B (437.00 µS/cm ± 64.01). The upstream point, A, value was 10% slightly greater than that for the downstream point, B. However, statistical analysis showed that there was no significant difference in the conductivity values for samples collected from A and B (Figure 6). Values for A had the largest range value of 590 with minimum and maximum values of 190 and 780 µS/cm, respectively. Point B on the other hand had a range of 473 with minimum and maximum values of 200 and 673 µS/cm, respectively.

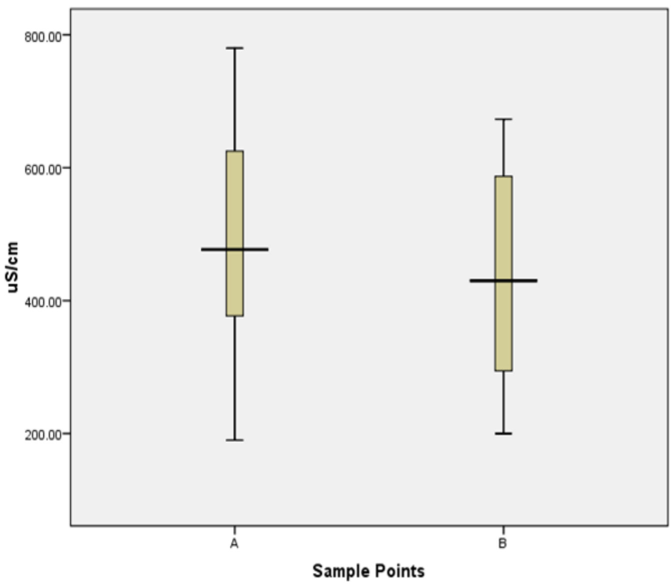

Figure 6: E. Conductivity values for two sample points along the Shagashe River.

Electrical Conductivity gives an estimate measure of salt or ion concentration in water. It is directly proportional to total solids and salinity (Uka & Chukwuka, 2007). From the current study, the water hyacinth has reduced the conductivity levels in the river. This is consistent with work that has been documented by other researchers. Dar et al. (2011) reported in their study that the water hyacinth had decreased conductivity by as much as 40% in some of their experiments. In a study carried out by Shah et al. (2010) the plant is reported to have treated dye-wastewater reducing the conductivity by as much as 38%. The decrease in conductivity could be due to the assimilation of salts and ions by water hyacinth.

Chemical oxygen demand

From Figure 7 it is evident that there was a decrease in the chemical oxygen demand (COD). Moving downstream from A (60.28 ± 9.96 mg/l) to B (44.00 ± 1.50 mg/l) the concentration decreased by nearly 27%. Despite the observed variations in the average concentration of COD for the two points, statistical analysis showed that there was no significant difference between them. The range for A and B were 69 and 5 respectively. Minimum and maximum concentrations for A were 20 and 89 mg/l while for B it was 42 and 49 mg/l.

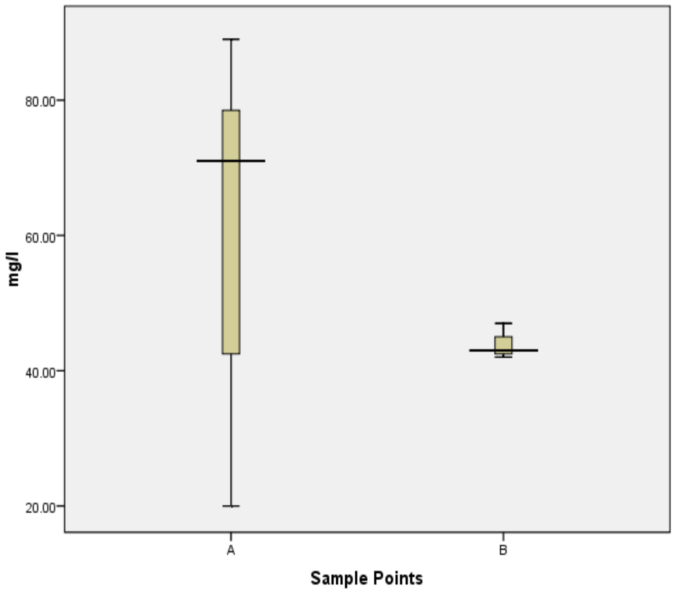

Figure 7: Chemical oxygen demand concentration for two sample points along the Shagashe River.

COD is a test used for the analysis of water for organic compounds, in most cases being pollutants. Water hyacinth employs different techniques in removing the organic compounds from water. Dissolved solids are removed by way of oxidation by bacteria immobilised on the plant roots (Sooknah, 2000). The plant root acts as an inert solid matrix onto which microorganisms are attached. Another mechanism in which they are removed is by way of phytodegradation and uptake. Suspended solids on the other hand are reduced through entrapment on plant roots, subsequently accumulating into a large particulate and settling at the bottom of water bodies (Sooknah, 2000). These are potential mechanisms by which the water hyacinth has reduced COD levels in the current study. These results are in agreement with those that have been presented by other researchers. In a constructed wetland, the water hyacinth was used to treat nutrient rich wastewater. It reduced the COD level by 64% (Lu, Fu, & Yin, 2008). In another study done by Gamage and Yapa (2001), the plant reduced COD of textile factory sample wastewater by over 80%. Water hyacinth in the present study has treated the river to some extent though not significantly so with regards to COD levels.

Total dissolved solids

Figure 8 shows the concentration of total dissolved solids (TDS) for samples collected from the different sample points A and B. There was a reduction in the concentration of solids moving downstream from A (281.88 ± 33.03 mg/l) to B (217.88 ± 31.24 mg/l). This was a 23% decrease in concentration statistically shown to be insignificant ($p < 0.05$). Minimum and maximum values of TDS concentration for A were 193 and 459 mg/l while for B it was 98 and 351 mg/l respectively. The range for A was 266 and B slightly lower at 253. Reduction of the total solids has been reported by Shah et al. (2010). The hyacinth reduced TDS by just over 10%.

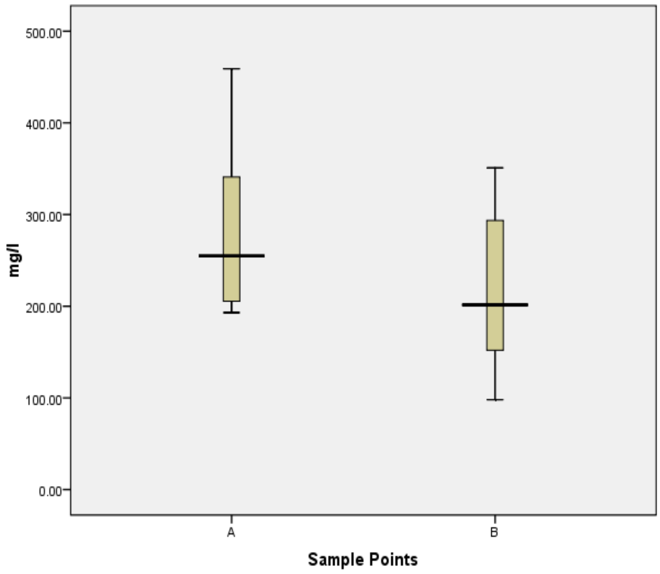

Figure 8: Total dissolved solids concentration between two sample points along the Shagashe River.

Dissolved oxygen

There was an increase in the dissolved oxygen (DO) levels between A (49.13 ± 9.75 % saturation) and B (59.87 ± 7.03 % saturation) as shown in Figure 9. This was a marginal difference of 22%. Statistical analysis showed the variation between the levels of DO between the two points was insignificant ($p < 0.05$). The range for the levels of DO for A and B were 74.4 and 49.2 respectively. Minimum and maximum levels were 16.8 and 91.2 for A and 30.2 and 79.4 for B. Such an increase in the level of DO is in agreement with work done elsewhere. In a study done by Dar et al. (2011), the water hyacinth doubled the level of DO in water. In another study, the level of DO increased from 3.83 to 5.23 mg/l an approximately 37% rise (Shah et al., 2010). This they suggest may be due to the fast growth rate of the hyacinth releasing oxygen into the water.

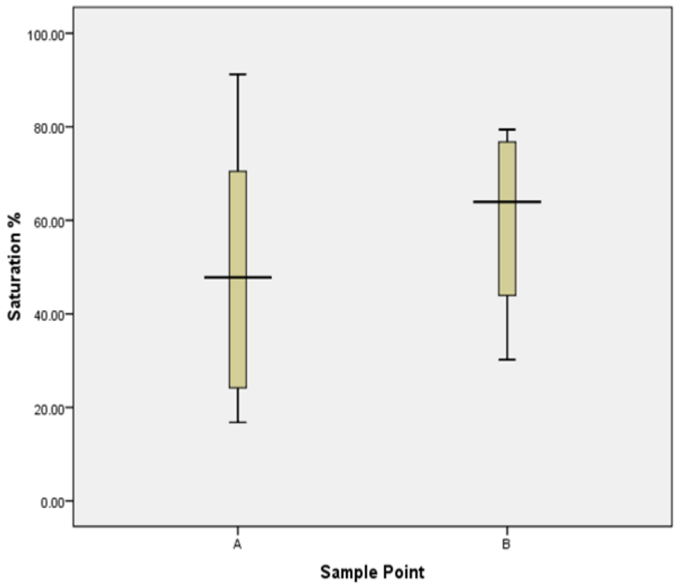

Figure 9: Dissolved oxygen concentration for the two sample points along the Shagashe River.

Chlorides

There was a decrease in the concentration of chlorides as water moved from upstream to downstream between the two points A (50.30 ± 5.55 mg/l) and B (44.55 ± 6.85 mg/l). The difference between the mean values for concentration of chlorides was 11 %. Statistical analysis of chloride concentration at 5% level of significance indicated that there was no significant difference in the concentration of samples collected from the two different points on the river. The range was almost similar at 52 and 55 for A and B respectively. Minimum and maximum figures were marginally different. For A these were 21 and 73 mg/l while for B it was 20 and 75 mg/l respectively. The ability of the water hyacinth to remove chlorides has been demonstrated in a study done by Gamage and Yapa (2001). It was significantly reduced by as much as 36%.

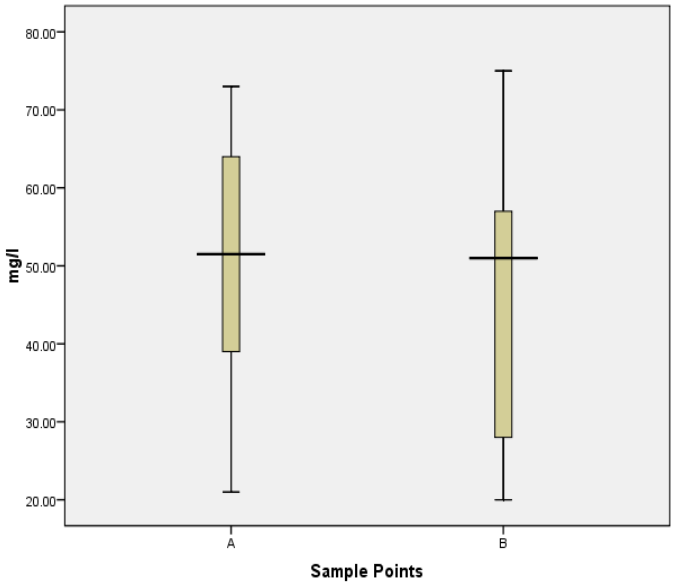

Figure 10: Chlorides concentration for the two sample points along the Shagashe River.

Total hardness

The total hardness concentration slightly increased from 95. 42 mg/l ± 15.80 to 97.33 mg/l ± 11.85 between A and B respectively. Statistical analysis of the different concentrations of total hardness at 5% level of significance showed that there was no significant difference in the concentration of hardness between the two points. The range values were 99 and 82 for A and B respectively. B had marginally higher minimum and maximum values for total hardness of 56 and 138 mg/l compared to A whose values were 34 and 133 mg/l respectively.

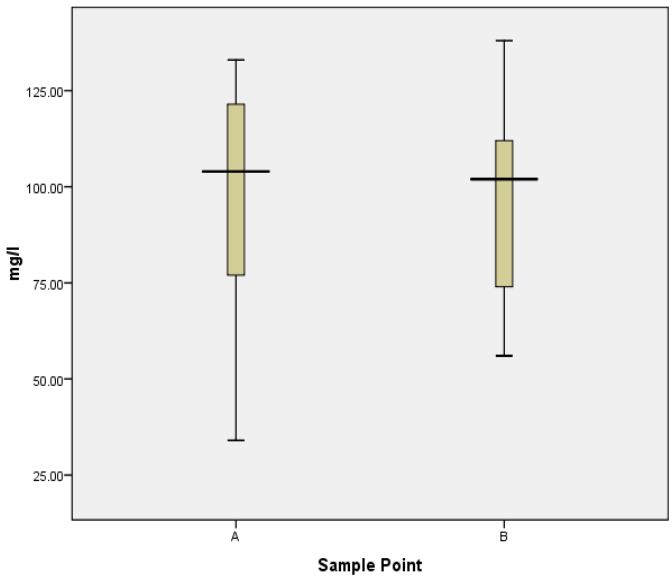

Figure 11: Total hardness concentration for two sample points along the Shagashe River.

Hardness is the measure of the concentration of multivalent metallic ions such as Ca^{2+}, Mg^{2+} and Fe^{2+} (Shah, et al., 2010). Plants remove these ions from water through the process of phytoextraction (Hammad, 2011). They do so assimilating the metals through roots and transporting them to the stem and shoots. In the present study there was a slight increase in hardness. This is in variance with some studies in which metal concentration has been reduced by water hyacinth (Dune & Ezeilo, 2012; Hammad, 2011; Hussain, Mahmood, & Malik, 2010).

pH

pH level decreased between the two points from 7.33 ± 0.22 at A to 7.23 ± 0.17 at B. This was not a statistically significant ($p < 0.05$) reduction. Minimum and maximum pH levels for A were 6.39 and 8.48 respectively with a range of 2.09. For B these were 6.49 and 8.00 respectively with a range of 1.51. Slight decrease in pH values have been reported by Dune and Ezeilo (2012) and Dar et al. (2011).

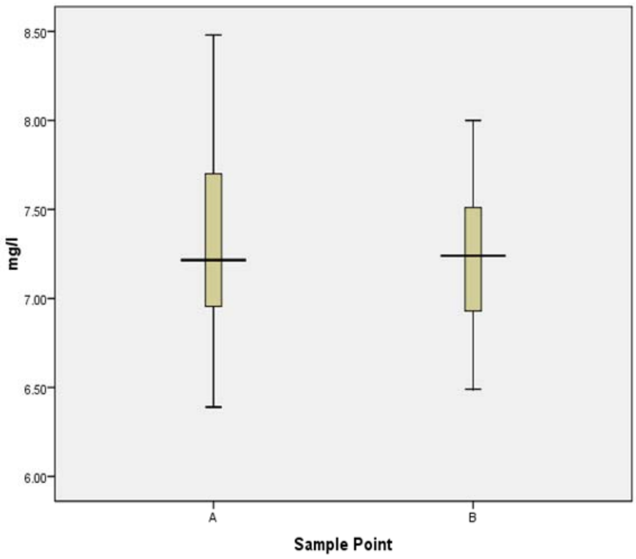

Figure 12: pH level for two sample points along the Shagashe River.

BIOREMEDIATION EFFECTIVENESS

An analysis of the parameters that were tested in this study has yielded interesting results. For example, most of them reflect the ineffectiveness of the water hyacinth in the remediation of the river. This is surprising since laboratory experiments conducted elsewhere tell a different story. A possible explanation of this contradiction could be the shorter contact time between the weed and the river water as it flows downstream. If it were static, it would have a longer contact period with the weed thereby increasing its bioremediation effectiveness. Since this is not the case, more research is necessary in order to find alternative solutions to the problem of river pollution in the city. A major weakness of this study was the lack of more sample points, which could have provided detailed information on the remediation of the Shagashe River water. Consequently, this paper recommends the launching of another study, which takes this point into consideration.

IMPLICATIONS FOR SUSTAINABLE DEVELOPMENT

This study has shown that the water hyacinth is ineffective in the bioremediation of the Shagashe River. What implications does this have for sustainable development? Since 1990, the demand for treated water in the city has been on the increase. For example, between 2001 and 2002, it increased by 3.1% (City Engineer's Annual Report, 2002). The Bushmead Water Treatment plant at the Lake Mutirikwe has been kept under pressure in order to meet increasing demand for treated water. Furthermore, frequent breakdowns of sewage treatment works in the city have worsened the problem. For example, in 2002, the municipal sewage plant experienced break downs of the following parts:

a) Two diaphragm pumps
b) One clarifier
c) Three pumps
d) Aerator conductors
e) Three mixer gear boxes

Although they were later repaired, raw sewage had already spilled into the Shagashe River. The Teacher's College treatment works also broke down and has not been repaired since then due to lack of funds. The frequent dumping of raw sewage into the river has led to several repercussions, which undermine sustainable development in the city, including:

a) Increased river pollution levels of river pollution

b) Death of aquatic creatures such as: frogs, fish, turtles and crabs

c) Increased costs of water treatment at the Bushmead Water Purification plant

d) Proliferation of the water hyacinth, which is a threat to the river's natural ecosystems

e) Increasing health risks to downstream communities, livestock and wildlife, which depend on the river for survival. For example, cattle from the Morningside area feed on the weed thereby exposing themselves to numerous health risks including tuberculosis and some water borne diseases. People who conduct fishing and washing in the river also risk their health in similar ways (Mapira & Mungwini, 2005).

POSSIBLE SOLUTIONS

In order to avert the prevailing environmental crisis, there is need to repair the sewage treatment works that are contributing to the pollution of the Shagashe River. Recently, the Environmental Management Agency (EMA) sued Masvingo City Council for polluting the river. According to *The Mirror*, 21 September 2012 page 3: EMA

'*alleged that council polluted Shagashe River by releasing untreated sewage into the river during times of electrical cuts*'.

In this way, it was violating the Environmental Management Act Chapter 20:27 Section 57 (1), which prohibits the pollution of water sources. The court found the city council guilty and ordered it to pay for the damage as well as the costs of litigation.

A recommendation emanating from the court case was that the sewage treatment works should be connected to an un-interrupted power supply cable. Other solutions suggested by EMA were '*purchasing generators to supply power to the treatment works during these periods or better still construct holding ponds*' (*The Mirror*, 21 September 2012, page 3). Time will tell whether this court verdict will force the city council to curb the pollution of the river which has persisted for more than a decade.

CONCLUSIONS

This paper has examined the problem of river pollution in the city of Masvingo with a view to suggesting alternative solutions. Specifically, it investigated the effectiveness of the water hyacinth as a possible panacea for river pollution. The analysis of sampled data shows that it is not a viable solution to the problem. The topic needs to be further examined by looking into a different experimental approach. This will include having more sample points, measuring the river water velocity and depth per each sample point along the course of the river. The paper makes several recommendations for the achievement of sustainable development at city level. These include: the regular maintenance of the sewage treatment works, purchasing of power generators, constructing holding ponds and providing un-interrupted power supply to the sewage treatment works. The Masvingo City Council is also advised to look into the option of constructing artificial wetlands. These would further treat sewer coming from the sewage treatment plant ensuring that all pollutants are reduced to very low levels. More research should also be conducted in order to find effective alternative solutions to the problem of river pollution in the city.

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