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Effectiveness of water Hyacinth (*Eichhornia crassipes*) in remediating polluted water: The case of Shagashe river in Masvingo, Zimbabwe

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ABSTRACT

The aim of this study was to investigate the effectiveness of water hyacinth (Eichhornia crassipes) in remediating a polluted river. Triplicate samples were collected on three different points designated SR1, SR2 and SR3 along the Shagashe River. The course of the river stretching from SR1 to SR3 was covered by over 95% water hyacinth during the period of study. SR1 was located on the upper stream, SR2 centrally and SR3 furthest downstream. Analysis for electrical conductivity, total dissolved solids (TDS), sulphates, phosphates, total hardness, pH, nitrates, nitrites and total nitrogen on all samples was done. Statistical analysis was done to check if there was a significant reduction of the parameters moving downstream. The results indicate that water hyacinth was remediating the river as noted by the significant reduction of electrical conductivity (25% decrease), total dissolved solids (TDS) (26%), sulphates (45%), phosphates (33%) and total hardness (37%) between the sample points SR1 and SR3. Statistical analysis showed no significant changes for the other parameters.

Keywords: Water hyacinth, bioremediation, physico-chemical parameters, pollution, phytoremediation

INTRODUCTION

Water pollution is a major environmental nuisance confronting modern day society which could lead to the uptake and accumulation of pollutants by edible plants and fish posing a risk to human and animal health [1]. Every day, 2 million tons of sewage, industrial and agricultural waste is discharged into the world's water [2]. Rapid urban growth characterised by an increase in human population and industrialisation has seen most municipalities failing to cope with the corresponding rise in waste material they have to handle. In most developing countries this is more often exacerbated by limited municipal budgets [3]. In Zimbabwe, inconsistent electricity supply has worsened the situation. This in some cases has forced some municipalities to adopt unconventional means in handling waste such as dumping raw sewer into water bodies [4]. In developing countries, water pollution accounts for close to 14 000 deaths per day due to consumption of water contaminated by raw sewage [5]. Some studies have shown a link between sewer pollution and an increase in bloody diarrhoea amongst five year old children in Zimbabwe [6]. The effects of water pollution are far outreaching not only having implications on health, but also disruption of aquatic ecosystems [7-9].

There are a numerous types of pollutants found in water. Of major concern in developing countries is the presence of raw sewage waste material, a source of nitrates and phosphates. Nutrients from sewage such as nitrates and phosphates in excess may lead to the process of eutrophication [10]. This is the exponential growth of aquatic plants such as phytoplankton stimulated by an excess concentration of phosphates and nitrates in water leading to what is commonly referred to as an "algal bloom". As the plants die and decompose, there is oxygen depletion to lower levels resulting in the death of aquatic organisms such as fish. Some algae are also toxic to both plants and humans in some cases leading to mortality of animals [11]. Heavy metal pollution has become a problem which according to Kara [12] can be toxic to both humans and animals even at very low concentrations. This has become more pronounced due to the accumulation and concentration of the heavy metals in organic matter at sewage treatment works [12] and their ability to persist in environments for a long time [13].

Water hyacinth is a perennial, floating aquatic macrophyte [14] world renowned as a nuisance weed which invades polluted rivers, lakes and dams [15-16]. It has a fast reproduction rate forming a thick "carpet" on the surface of water bodies. While in most literature it has been cited for its negative impacts, it has also been scientifically shown to have positive impacts in remediating polluted water [17-19]. Water hyacinth has been reported to have accumulated and concentrated zinc, nickel and copper in their roots to levels 20 000, 1200 and 1300 more than its concentration in a river (growth media) respectively [18]. Rommens [19] report on the potential benefits of water hyacinth in Lake Chivero, Zimbabwe. They discovered that vegetated portions of the lake covered with water hyacinth had significantly lower concentrations of phosphates and ammonium compared to unvegetated regions. This they attributed to the ability of hyacinth to use these nutrients which they estimated to have a daily removal capacity of 1.5% ammonium load of the lake [19].

The application of plants to remove pollutants from the environment is known as phytoremediation [20]. Phytoremediation comes in different forms which include amongst others rhizofiltration and phytodegrdation (phytotransmition). Rhizofiltration is the uptake of metals by plants in water while phytodegrdation involves the uptake, storage and degradation of organic pollutants [20]. In the last few decades there has been great interest in the application of phytoremediation in the treatment of polluted water bodies [21]. This is may be attributed to the fact that the technology application comes at a lower cost [22] compared to conventional methods.

While the ability and effectiveness of water hyacinth in the removal of pollutants under experimental conditions has been widely documented and demonstrated, there is not much that has been done to investigate this under its natural habitat conditions. The major variance being that under most experimental conditions, the water is static while in rivers it is flowing. Consequently, contact time could possibly be short under such circumstance leading to less effectiveness in nutrient removal. The current study seeks to investigate on its ability and effectiveness to remove pollutants in Shagashe River. The river is polluted by the discharge of raw sewer into it [23]. The study seeks to build on the research done by Moyo and Mapira [24] specifically improving on the experimental design to accurately assess the effectiveness on the water plant. Unlike the previous study in which data for a period of four years was examined, the current study only utilises data collected in one month covering three sample points and not two as was done by Moyo and Mapira [24].

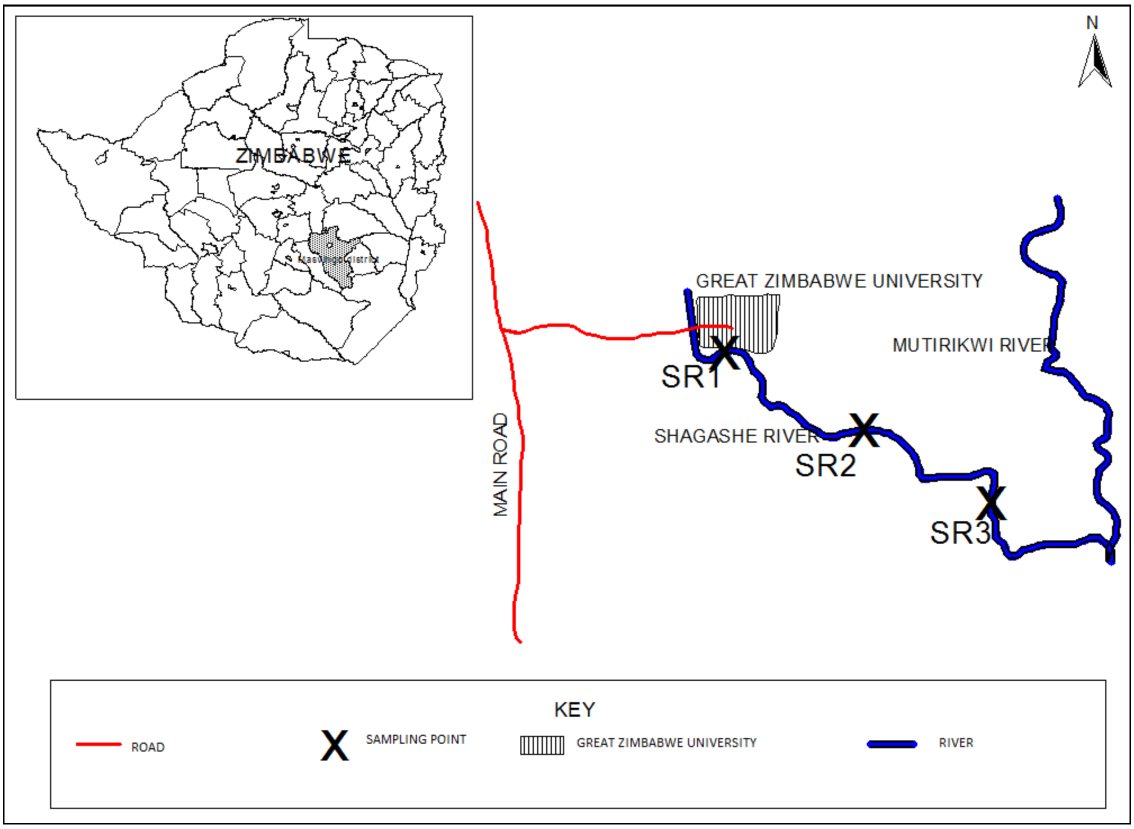

Fig 1: Study area, Shagashe River in Masvingo

MATERIALS AND METHODS

Study Area

Water samples were collected from three different points along the Shagashe River, in the City of Masvingo which is located in the south-easterly province of Masvingo in Zimbabwe (Fig 1).

The river is one of two which discharge into the country's largest in-land lake, Lake Mutirikwi. The lake supplies water to the Masvingo City Council and sugar irrigation plantations in Chiredzi district. Lake Mutirikwi is of economic value to the province as not only does it provide irrigation water, it is also a popular tourist spot and a source of water for wildlife in the Kyle National Park. Study area extended for about 4.5 km in distance stretching along the river. Sample points were equidistant 1.5 km apart with point SR1 located upstream near Great Zimbabwe University, SR2 centrally and SR3 downstream. Coordinates (X and Y) for the location of the points were as follows; X – 0276160, Y – 7775423 for SR1, X – 0277659, Y – 7774739 for SR2 and X – 0279013, Y – 7773754 for SR3. During the period of study, approximately 95% surface water on the river was covered by the Water Hyacinth.

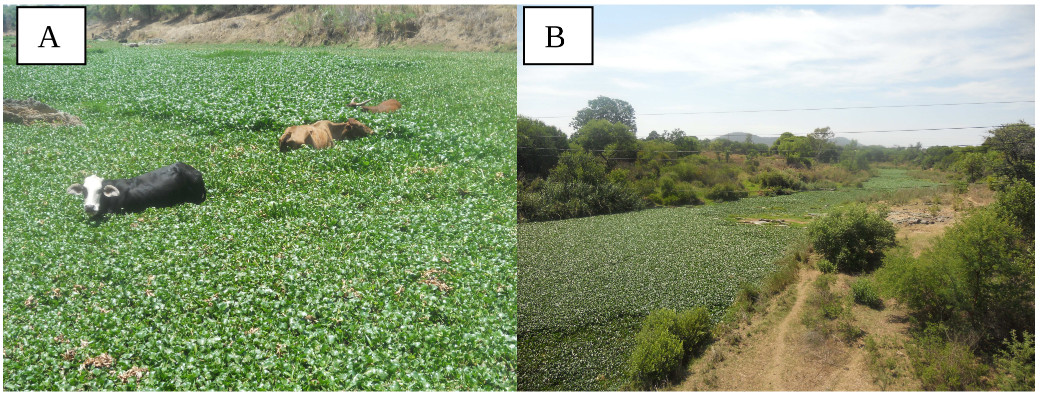

Fig 2: Photo A and B were taken during the period of study during the month of October. Photo is located next to sample site SR1 while B is next to SR2. Significant water hyacinth "carpet" is observed from each point

River Water Sampling and Analysis

Water samples were collected using standard procedure as outlined in APHA Manual [25]. Seven hundred and fifty millilitre surface water samples were collected into 1 litre polyethylene containers. Three samples were collected per point, two from both sides of the river banks and one centrally. All water samples were collected in the month of October 2012. This was prior to the onset of the rainy season with warm prevailing temperatures and generally shallow water depth in the river. Depth per each point was measured using a standard meter ruler while velocity was determined using a float and stop watch. Water analysis was done using standard methods as described by the following reference laboratory standard operating procedure manuals for fresh and waste water quality:

I. WHO Guidelines for Drinking-Water Quality. Second Edition, Vol 3.
II. APHA, Standard Methods For The Examination Of Fresh Water And Waste Water, Including Bottom Sediments and Sludges, 11th Edition.
III. Adams, V. Dean. 1991. Water and Waste Water Examination Manual. Lewis Publishers, Inc. USA.
IV. University Of Zimbabwe, Biological Sciences Laboratory Manual For Water Quality Research, 2011.
V. University Of Zimbabwe, Institute Of Mining and Research, Atomic Absorption Spectroscopic Methods, 2011.

Statistical analysis was done to compare the average means of the physico-chemical parameters for samples collected from the different points along the river. This was performed using the one-way Analysis of Variance (ANOVA). Statistical significance was accepted at a level $p < 0.05$. Statistical Package for Social Scientists (SPSS 16.0) software was used in doing the one-way ANOVA test.

RESULTS AND DISCUSSION

Table 1 shows that there was no significant difference in depth of the water in the river and cover of water hyacinth amongst the three different sample points. The depth of water related to total surface area covered by the roots may possibly impact on the effectiveness of the aquatic macrophyte to remove pollutants. While not scientifically proven and documented, for water hyacinth, it can be assumed that the larger the surface area covered by the roots in water, the higher is the removal rate of the pollutants. In their study on the comparative uptake of nutrients by plants, Ying

[26], showed a positive correlation in the accumulation of nitrogen and phosphorus with root surface area. Moving downstream, there was a significant decrease in the velocity of river water. The rates for SR2 and SR3 were approximately half that of SR1. This implies plants further down the river have more contact time with water than they do upstream. Consequently, this could lead to marked increase in the removal rate of pollutants downstream compared to upstream. However, Davis [27], present evidence to the contrary in their study on the application of bioaccumulation in removal of heavy metals by plants. In their study they showed that flow rate had no impact on the removal of heavy metals by vegetation. The high coverage of the study areas with water hyacinth is an important factor in the current study as the observed removal of the physico-chemical parameters being removed can be confidently attributed to the phytoremediation action of the plant. This cannot be easily done in environments where the plant is dominated by other vegetation species.

Table 1: Sampling points SR1, SR2 and SR3 on the Shagashe River

Sample Point	Coordinates	Elevation (m)	**Average** Depth (m)	**Average** River water velocity (m/s)	Water Hyacinth Cover (%)
SR1	X – 0276160, Y – 7775423	1044	0.15	0.12	95
SR2	X – 0277659, Y – 7774739	1041	0.13	0.05	95
SR3	X – 0279013, Y – 7773754	1028	0.14	0.06	98

Electrical Conductivity (E. Conductivity): Fig 3 shows that there was a significant reduction in E. Conductivity between the points SR1 and SR2 from 624 µS/cm to 500 µS/cm respectively a 19% decrease. Minimum and maximum conductivity values for SR1 were 582 and 648 µS/cm while for SR2 it was 322 and 589 µS/cm respectively. Between SR2 and SR3 there was a slight change lowering down to 477 µS/cm a mere 6.7% variance between the two points. Minimum and maximum E. Conductivity values for sample point SR3 were 426 and 532 µS/cm. Overall there was a 25% decrease in E. Conductivity between SR1 and SR3. Statistical analysis showed this to be a significant difference between the two points. This observed change in E. Conductivity suggests that the water hyacinth is remediating the river with respect to ions present.

E. Conductivity is a parameter used in the measure of pollution which provides an estimate of the concentration of ions and salts in water samples. The higher the value, the greater the concentration of the pollutants. Reduction in the measure, as was observed in this study, indicates remediation action by the plant. Mahmood [28] suggest that remediation action is achieved by assimilation of the pollutants by the plant. This has been documented in different studies. Moyo and Mapira, [24] in their study noticed a decrease in E. Conductivity between two points along the Shagashe River which however, was not significant. Other researchers who have conducted lab experiments in which water samples were treated have also shown water hyacinth to reduce the E. Conductivity. Mahmood [28] noted a 55% decrease in conductivity in textile waste samples treated by hyacinth within a 96 hour period. In their study on the removal of nutrients by water plants from dairy manure waste, Sooknah and Wilkie [29], report on the high reduction of E. Conductivity on samples treated by water hyacinth. The different in the total reduction between SR1 to SR2 (19% removed) and SR2 to SR3 (only 7% removed) could be attributed to the increase in water velocity moving down stream. This ultimately leads to less contact time between nutrients and plant downstream hence leading to less removal rate.

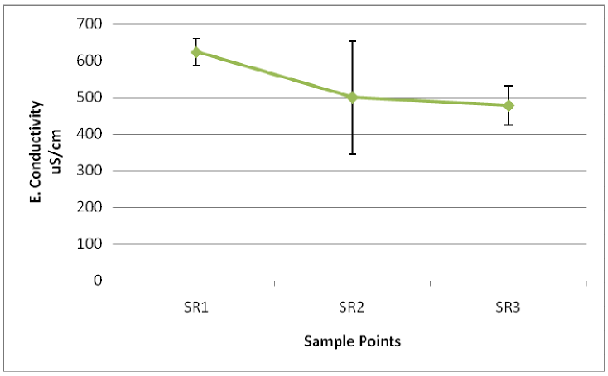

Fig 3: Changes in E. Conductivity on the three points on Shagashe River in Masvingo. SR1 is upstream, SR2 central while SR3 is furthest downstream. All points are equidistant from each other 1.5km apart

pH: There was no drastic change in pH between SR1 and SR2 (Fig 4). The pH slightly increased from 6.80 to 6.86 between the two respective points. Minimum and maximum values recorded were 6.70 and 6.90 for SR1 while for SR2 it was 6.70 and 7.00 respectively. Mean pH value for SR2 and SR3 were equal with minimum and maximum values of 6.8 and 6.9 for the latter point respectively. Statistically the increase was shown not to be significant. This increase is contrary to most results presented by other scholars who have shown pH reduction in water samples treated with water hyacinth [28, 30-31]. However, MacDonald and Wolverton, [32] present data showing pH which remained constant in their study on comparison of physico-chemical parameters in a lagoon covered with water hyacinth and without water hyacinth.

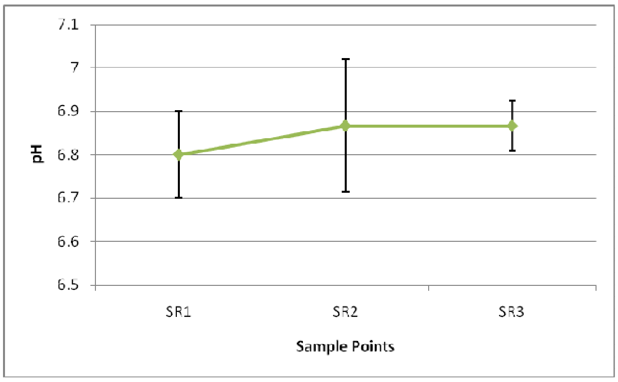

Fig 4: Changes in pH on the three sample points

Total Dissolved Solids (TDS): Figure 5 shows that there was a significant decrease in TDS between the upstream and downstream points SR1 and SR3 respectively. TDS decreased from an average value of 378 mg/l at SR1 to 281 mg/l on SR3, a 26% change. Statistical analysis showed this to be a significant change. The decrease moving down stream was almost constant changing from 378 mg/l at SR1 to 328 mg/l at SR2, a difference of 50. It further decreased from 328 mg/l at SR2 to 277 mg/l at SR3 a difference of 47 between the two points. Removal of solids in water by hyacinth is achieved by way of entrapment on the roots and through metabolic action of bacterial films on plant roots [33]. The decrease in TDS is in parallel to a study carried out by Shah [17] who observed a 10 to 38% decrease in dye-effluent waste water treated by the aquatic macrophyte. In closely related studies documented by different scholars, water hyacinth is reported to have significantly reduced total suspended solids [32] and total solids [28].

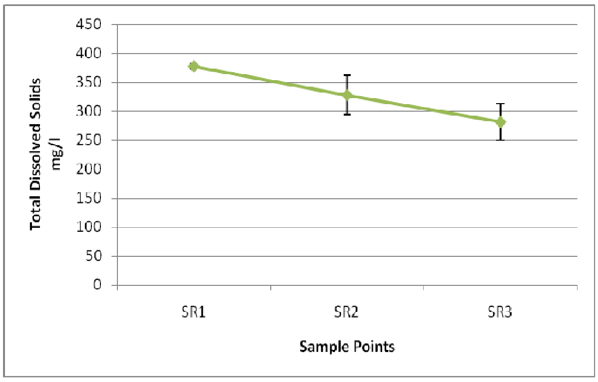

Fig 5: Changes in TDS on the three sample points

Nitrates (NO_3^-), Nitrites (NO_2^-) and Total Nitrogen (Total Kjedahl Nitrogen): Comparatively, there seems to be a similarity in the removal of nitrates and nitrites on the three different points of study. Between SR1 and SR2 there is a reduction of both nitrates and nitrites. The concentration of these nutrients marginally increases between SR2 and SR3. On the contrary, total nitrogen increases going downstream from SR1 to SR2 and SR3. Between SR1 and SR2 nitrates decreased from 28.9 to 24.6 µg/l and then slightly increasing to 26.1 µg/l. Between SR1 and SR3 the overall change in nitrates is a 9.7% decrease statistically shown to be insignificant. Nitrites as seen on Fig 6 decrease from 191 to 145 between SR1 and SR2 respectively. The nitrite concentration then increases from 145 to 165 µg/l between SR2 and SR3 respectively. Total nitrite reduction between SR1 and the furthest downstream sample point SR3 is 26 µg/l a 13.6% decrease which was shown to be statistically insignificant. Total nitrogen concentration rose from 0.46 to 0.50 µg/l a mere 0.04 µg/l increase which can be concluded to have been constant.

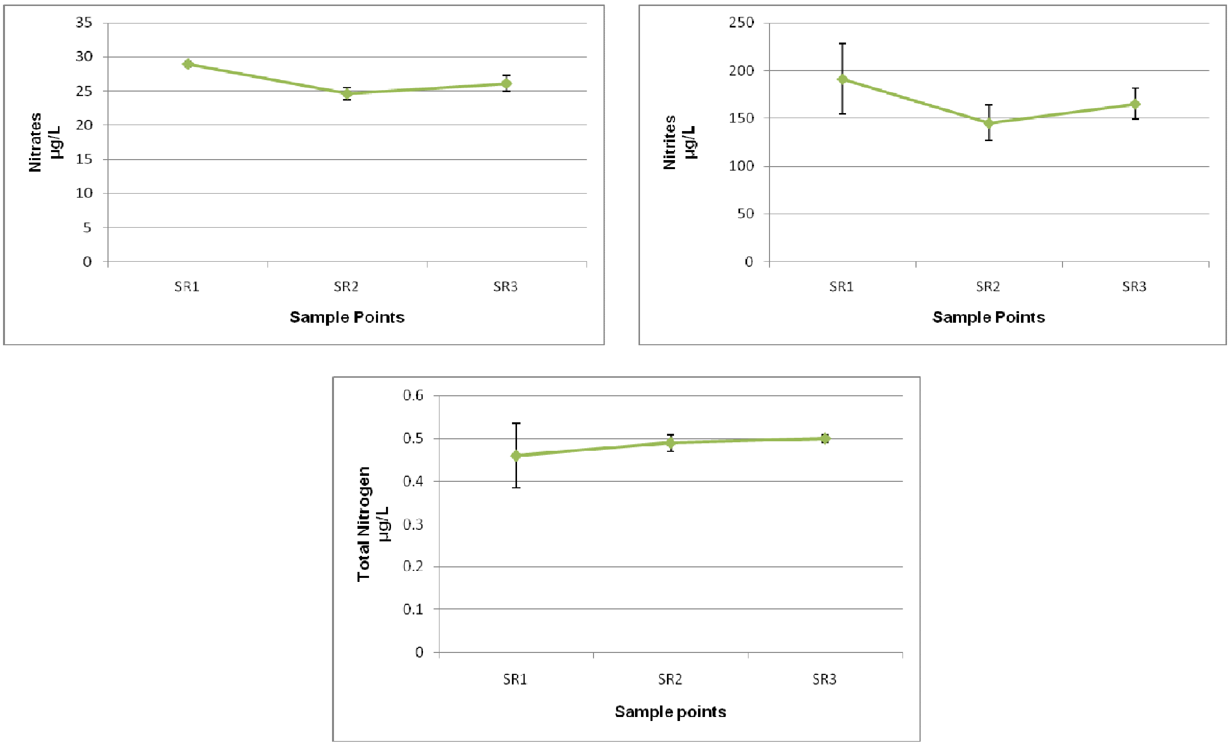

Fig 6: Changes in Nitrates, Nitrites and Total Nitrogen on the three sample points

Nitrogen is a critical nutrient assimilated by plants [34] either as ammonia or nitrates and used in the production of biological macromolecules such as amino acids and nucleotide bases. Water hyacinth is not so different from other plants taking up nitrogen as either ammonia or nitrates. The observed decrease in the concentration of nitrates on Fig 6 may be attributed to assimilation by the plant or could also be due to the process of denitrification in which nitrates are reduced to molecular nitrogen gas (N_2) [33]. The corresponding decrease of nitrites could be due to the nitrification process in which it is being converted to nitrates by a microbial mediated process. Similarly, the increase in nitrite concentration could be as a result of a number of processes all which constitute the nitrogen cycle. One such process could be nitrification in which ammonia is oxidised to nitrites. The resulting highly unstable nitrites are quickly oxidised to nitrates resulting in an observed increase in the concentration of both ions.

The current observed pattern of nitrates and nitrites reduction is similar to that presented in other studies [22, 31, 35]. Slight increase in total nitrogen has been reported by Akinbile and Yusoff, [35] an observation which they cite may be due to decomposition leading to an increase in organic nitrogen within the water. This they indicate occurred during the late stage (fourth week) of an experiment which they had setup to treat waste water samples. Earlier on in the first three weeks of the same experiment water hyacinth was shown to significantly reduce the total nitrogen by as much as 89% [35].

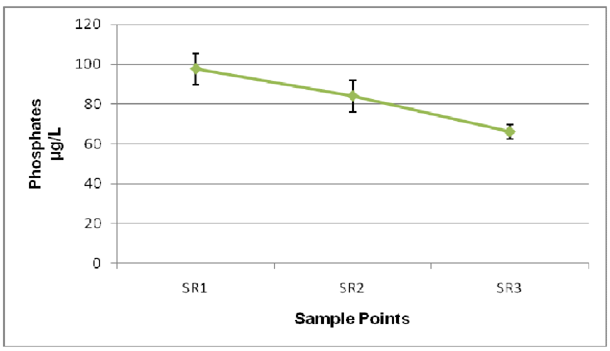

Fig 7: Changes in Phosphates on the three sample points

Phosphates: Phosphate concentration is observed to be decreasing moving downstream from SR1 to SR3. There was a reduction of phosphates from an average 98 to 84 µg/l between SR1 and SR2 a 14% change. This was to further lowered down between SR2 and SR3 decreasing from 84 to 66 µg/l. Between the upstream point SR1 and the furthest downstream point SR3, total decrease in phosphates was 32 µg/l a 33% variance statistically shown to be significant. Phosphates are a critical nutrient required by plants which they assimilate through their roots [33]. The current observed trend of the decrease in their concentration is in agreement to those presented in other studies [35-37].

Sulphates: There was a significant decrease in the concentration of sulphates moving downstream (Fig 8). Sulphate concentration was reduced from 0.11 to 0.09 mg/l from SR1 to SR2 respectively. The concentration further decreased to an average value of 0.06 mg/l at sample site SR3. Total sulphate concentration reduction between SR1 and SR3 was 0.05 mg/l a 45% change. Statistical analysis showed this to be a significant change. Like in most plants, sulphur is a vital nutrient chiefly required for the synthesis of the amino acids cysteine and methionine along with other important organic compounds such as glutathione and ferrodoxin [38]. It is assimilated by plants via roots by so doing reducing its concentration from the source which in this study is the river water, hence remediating it. Evidence of sulphate reduction has been presented in a study carried out by Ndimele [39]. In the study sulphate concentration were compared between three water bodies infested with the aquatic macrophyte and a control which was free of the plant. Sulphate concentration was shown to be significantly lower in the three water hyacinth infested bodies compared to the control. Sulphate reduction by water hyacinth has also been demonstrated in a study done by Dune and Ezeilo, [30].

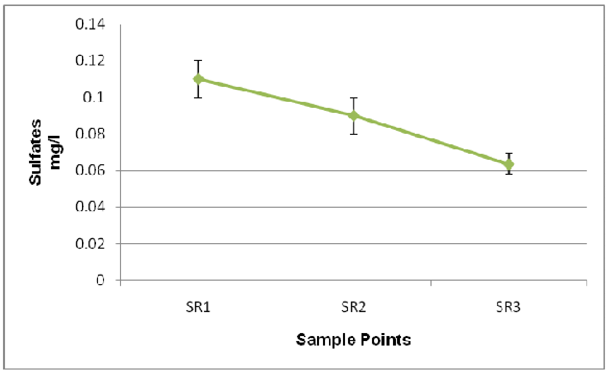

Fig 8: Changes in Sulphates on the three sample points

Total Hardness: Total hardness concentration decreased from 89 to 56 mg/l between sample points SR1 and SR2 respectively (Fig 9). This was 37% reduction. The concentration was to further lower down to 46 mg/l on sample point SR3 implying a total 43 mg/l decrease constituting 48% decline from the SR1 concentration. Statistically this was shown to be a significant change. The water hyacinth in this present study seems to be removing multivalent metallic ions in the river water by the process of phytoextraction. The current presented results are in tandem to those demonstrated and documented elsewhere [17, 30, 39].

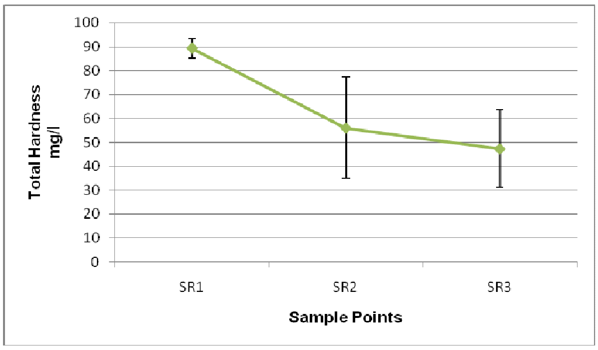

Fig 9: Changes in Total Hardness on the three sample points

CONCLUSION

The study presents evidence showing that water hyacinth could be remediating the river. This was observed by the statistically significant reduction of sulphates, TDS, electrical conductivity, phosphates and total hardness moving downstream from sample point SR1 to downstream point SR3. The evidence presented is however not conclusive as there may be natural purification processes that may also be purifying the river. Having a control experiment without hyacinth vegetation cover could help provide more conclusive evidence. Results of physico chemical parameters with and without hyacinth for samples on the three different points could be compared to see if there are any significant differences. However, the bioremediation abilities of the water weed have also been confirmed by other studies carried out under different environmental settings [17-19, 28-30, 32, 35, 39-42]. Thus, water hyacinth can be managed and used effectively to control pollutant levels in water bodies for example water hyacinth farms can be proposed along river channels, with the possibility of harvesting it as animal feed. Ideally the farms, will serve to slow down the velocity of the water implying an increased contact time between the roots and pollutants in the river water ensuring more effective remediation. However, results have shown that there is little potential for the remediation of pH, nitrates, nitrites and total nitrogen. This is subject to further study.

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