International Journal of Chemistry and Materials Research
2014 Vol. 2, No. 5, pp. 36-47
ISSN(e): 2311-763X
ISSN(p): 2312-0991

HEAVY METAL AND NUTRIENT LOADING OF RIVER RWIZI BY EFFLUENTS FROM MBARARA MUNICIPALITY, WESTERN UGANDA

Moses Egor[1] --- Jolocam Mbabazi[2] --- Muhammad Ntale[3]*

[1]*Department of Chemistry, Busitema University, Tororo, Uganda*

[2,3]*Department of Chemistry, Makerere University, Kampala, Uganda*

ABSTRACT

This study, carried out in the wet annual April seasons during the period 2010-2011, was geared towards the quantification of heavy metal and nutrient levels in the surface water of River Rwizi, the main Mbarara municipal drainage system. The effect of Mbarara municipal effluents on heavy metal and nutrient (phosphate, nitrite, nitrate and ammonium) loading of River Rwizi was investigated along with the changes in some basic water quality parameters, i.e., pH, conductivity and hardness. The filtered water samples were digested with a perchloric acid/nitric acid/hydrochloric acid mixture. Total heavy metals Cu, Zn, Cd and Pb were determined by flame atomic absorption spectrophotometry. Nutrients were determined by standard Wagtech methods. The results showed that there was a significant difference in concentration of lead ($p = 0.047$) and zinc ($p = 0.018$) between 2010 and 2011, with average concentrations being higher downstream. The concentrations of lead and cadmium were much higher than the WHO guideline values in drinking water (0.01 $\mu g\ ml^{-1}$ and 0.003 $\mu g\ ml^{-1}$, respectively). There was no significant difference in concentration of cadmium in 2010 along River Rwizi around Mbarara Township ($p = 0.180$). Nutrient loading in the domestic water source also indicated a gradual annual increase - hence a call for early pollution control measures by the relevant authorities.

Keywords: Heavy metals, Nutrients, Drinking water, River rwizi, Mbarara municipality, Uganda.

Contribution/ Originality

This study documents an early warning to the relevant policy makers in the country as to the rapidly growing urban population and the attendant domestic water problems leading to an ill-health population. This would in turn lead to undue annual medical expenditures that drain heavily on the national financial resources.

1. INTRODUCTION

The population of Mbarara Municipality has more than doubled since the 1970s, currently estimated to stand at 83,700 [1]. As the population increases, so do the domestic and industrial

---

† Corresponding author

activities, leading to increased volumes of wastewater as well as anthropogenic pollution. Mbarara Municipality draws its piped water from River Rwizi and despite the purification processes, some pollutants such as heavy metals remain in the final running water. Some of the poor people even draw water from the river banks and use it directly for domestic use. The water in this stream has a permanent dirty-brown colour and carries a not too pleasant smell. It is feared that the increasing volume of untreated municipal effluent discharge finds its way, directly or indirectly, into the river. Knowledge of the current state of the quality of water at specific points in the town is therefore essential, especially with regard to the soluble and invisible inorganic pollutants, notably heavy, or trace metals. Some of the heavy metals most commonly linked to human poisoning are lead, copper, zinc and cadmium. There is increasing evidence that lead poisoning causes permanent neurological, developmental [2] and behavioral disorders, particularly in children [3] and it poisons thousands of people in urban areas annually [4].

The leaching of the heavy metals from the drainage systems into the river may cause a serious deterioration of its water quality [5, 6] and a probable poisoning of the aquatic life [7] such as the marketed mud fish caught from the banks of the river. Consequently, there was need to initiate systematic studies to evaluate the levels of the more likely heavy metal pollutants Cu, Cd, Zn and Pb in the river water system in an effort to establish the full extent of the problem. The results from the study are considered to be an indirect but confirmatory indicator of pollution in the waterway, from which Mbarara Municipality draws its water for domestic and industrial use yet there is limited information on the state of purity of this water in terms of metal and nutrient loading. Such studies may prove of great value in matters of public health, and help instigate the putting of early counter-measures in place [8].

The general objective of this study was to assess the extent of heavy metal concentration as well as the nutrient levels of the waters of River Rwizi, with the specific objectives of determining the physical water parameters; pH, hardness and electrolytic conductivity of River Rwizi water as indicators of pollution due to the Mbarara municipal settlements and other human activities along the river valley, as well as the concentrations of lead, copper, cadmium and zinc in River Rwizi waters before and after flowing through Mbarara Municipality. It was also deemed necessary to measure the levels of nutrients, *i.e.*, nitrite, nitrate, ammonium and phosphate in the waters of River Rwizi before and after drainage through Mbarara Township. It is also hoped that the data herein provided on the trace metal loading of River Rwizi shall be used as a benchmark for decision-making on pollution control. The results of this study would also enrich the existing database on the extent of heavy metal pollution of surface water in Uganda.

2. EXPERIMENTAL

2.1. Study Area

Mbarara Municipality is the largest urban centre in Western Uganda with a population of about 83,700 people [1], one of the fastest growing towns in Uganda. It is located approximately 270 kilometres, southwest of Kampala, Uganda's capital city. The coordinates of the municipality are 00° 36'S, 30° 36'ERiver Rwizi is a tributary of Lake Victoria transecting five districts of

Mbarara, Bushenyi, Ntungamo, Isingiro and Kiruhuura. It is the source of domestic water supply and drainage system of Mbarara Municipality [9].

2.2. Water Sampling

Sampling was done twice, in March 2010 and April 2011. Surface water samples were collected from twelve different locations. Four samples from sites 2 km upstream, labelled U1, U2, U3 and U4 (figure 1); in the town area (mid-town, labelled M1, M2, M3, M4) and 2 km downstream (D1, D2, D3, D4), the sampling sites were 200 m apart along River Rwizi on the southern outskirts of Mbarara Municipality (Figure 1). The samples were collected using 10-litre plastic containers. At each sampling site the containers were cleaned with detergent solution, rinsed several times with dilute nitric acid solution to avoid metal contamination, and finally rinsed with distilled deionised water, before use. The collected water was filtered within a few hours of sampling, transferred to 5-litre polythene containers and stored at room temperature (25°C) until analysis.

2.3. Analytical Procedures

All the chemicals named and used in this study, including the deionised water, were supplied by British Drug Houses (BDH), Wagtech and were of analytical reagent grade (AnalaR).

2.3.1. Determination of Heavy Metals Cu, Zn, Pb and Cd

These were investigated using different methods for comparison and completeness. Water samples were digested using the following methods:

a) The filtered water samples were analysed directly [10] for copper, zinc, cadmium and lead, using a flame atomic absorption spectrophotometer, FAAS (Perkin-Elmer GmbH, Uberlingen, Germany, Model 2380).

b) To 500 ml of the filtered water samples was added 10 ml of concentrated hydrochloric acid (analytical reagent grade) and evaporated under gentle heat to 50 ml. The concentrate was quantitatively transferred to a 100 ml volumetric flask and made up to the mark with distilled deionised water.

c) 500 ml of the water samples from each site were evaporated to near dryness. To the residue, concentrated nitric acid (10 ml) and hydrochloric acid (4 ml) were added. This was then be evaporated to near dryness. The final residue was reconstituted with 2 ml of 2M hydrochloric acid, transferred to a 25 ml volumetric flask and made up to the mark with distilled water.

d) 1 litre of the water samples from each site was evaporated to dryness. To the residue, the triple acid system, *viz.* concentrated nitric acid (10 ml), perchloric acid (2 ml) and hydrofluoric acid (4 ml), was added. Then this was reheated to dryness. The final residue was reconstituted in 2 ml of hydrochloric acid (2*M*), transferred to a 25 ml volumetric flask and made up to the mark with distilled, deionised water.

The resultant aqueous solutions were analysed for each of the heavy metals Zn, Cu, Cd and Pb using a Flame Atomic Absorption Spectrophotometer, FAAS (Perkin-Elmer GmbH, Uberlingen, Germany, Model 2380). In each case a read-out from the screen was taken as the concentration of the selected metals.

2.3.2. Determination of Nutrient Loading

Nutrients were determined by a standard Wagtech procedure using the CP1000 Physico-Chemical Kit as described in the Wagtech manual, that has been specifically designed for testing a wide range of physical and chemical water quality parameters, including phosphate, nitrate and nitrite. The kit contained a carefully selected range of high quality digital instruments that made it suitable for field work. The kit was used in conjunction with the Photometer 7100, capable of analysing over 40 different chemical parameters.

The total hardness in the water was determined by EDTA titration as follows. 50 ml of sample was put into a 250 ml conical flask followed by 1 ml of ammonia buffer solution of pH 10 and two drops of Eriochrome black T indicator. The mixture was titrated with 0.01M EDTA solution until the colour changed from red- wine to blue. Hardness was subsequently calculated using the formula [11]:

$$\text{Hardness} = \frac{\text{volume of EDTA X 1000}}{\text{volume of sample}}$$

2.3.3. Statistical Analysis

The results were subjected to one way ANOVA, Kruskal-Wallis test, independent samples *t*-test or Mann-Whitney U-test, using SPSS version 17 and Minitab version 14 statistical software with confidence interval of 95%.

3. RESULTS AND DISCUSSION

Tables 1and 2 show the mean total of heavy metal levels (±SD) at various sites along River Rwizi during the wet seasons of 2010 through 2011, as analysed using the four sample pre-treatment procedures (a), (b), (c) and (d). In general, the total concentration, in μg ml^{-1}, of the metals in all the samples decreased in the order: Zn > Pb > Cu >> Cd.

3.1. Zinc

Comparison of Zn concentration upstream, in mid-town area and downstream in 2010 using Kruskal-Wallis test indicated a significant difference ($p = 0.018$). In 2011, one way ANOVA of zinc levels in the different locations also indicated a significant difference ($p = 0.000$). Comparison of Zn concentration upstream, mid-town and downstream in 2010 versus 2011 using independent samples *t*-test and Mann-Whitney *U*-test indicated no significant difference ($t = 0.399$, $DF = 6$, $p = 0.767$), ($t = -0.135$, $DF = 6$, $p = 0.897$), ($U = 6.5$, $n = 4$, $p = 0.663$), respectively. There was a general increase in the concentration of zinc along River Rwizi around Mbarara town, with average concentration highest in the town area. Zinc-coated corrugated iron sheets, the commonest roofing material in the country, on corrosion release considerable amounts of zinc as its oxide or sulphide into the soil [12], the leaching of which concentrates the metal in the water body via surface run-off and other processes. High demand for wall and roof paints, most of which are zinc-based, adds to the problem [13]. Zinc is also extensively used in the manufacture of dry cells that are commonly used as chemical sources of electrical energy.

3.2. Lead

Comparison of Pb concentration upstream, mid-town and downstream for 2010 and 2011 using one way ANOVA indicated a significant differences ($F = 4.369$, $DF = 11$, $p = 0.047$) and ($F = 7.105$, $DF = 11$, $p = 0.014$) respectively, with figures notably higher in the town area and downstream. When the amount of Pb upstream in 2010 and 2011 were compared using independent samples t test, there was no significant difference ($t = 0.177$, $DF = 6$, $p = 0.865$). The differences in mid-town ($t = .005$, $DF = 6$, $p = 0.996$) and downstream ($t = -0.336$, $DF = 6$, $p = 0.748$) were not significant at 95% confidence interval. Average concentration of 1.321 µg ml^{-1} upstream, 0.75 µg ml^{-1} in the town area and 1.5 µg ml^{-1} downstream, showed an average increase in lead downstream. The average lead level in the river waters was found to be 0.5–2.0 µg ml^{-1}.

Continued use of lead-based paints and their inappropriate disposal [14]; car washing and emptying of old lead-acid accumulators regularly takes place directly along the streams and channels leading to the river. The lower levels lead in the town area could as a result of adsorption, chelation and sedimentation, making it less available in the filtered water, but rather in the sediment.

$$M^{n+}(aq) + z(\text{High RMM organic anions}) \longrightarrow [M(\text{organic anion})_z]^{n+} \longrightarrow \text{Sediment}$$

Generally, the concentration of lead was highest downstream, which also showed an average increase from 2010-2011, while remaining fairly constant in town area and downstream.

3.3. Copper

The concentration of Cu upstream, mid-town and downstream for 2010 and 2011 were compared using Kruskal-Wallis test. The tests showed a significant difference ($H = 9.33$, $DF = 2$, $p = 0.009$) in 2010 and ($H = 8.80$, $DF = 2$, $p = 0.012$) in 2011. Comparison of Cu in upstream for 2010 versus 2011 using Mann-Whitney U test gave no significant difference ($U = 6.5$, $n = 4$, $p = 0.659$), while in mid-town for 2010 and 2011 using Mann-Whitney *U*- test, Cu levels showed no significant difference ($U = 6.0$, $n = 4$, $p = 0.538$). The levels of Cu were relatively constant upstream, but steadily increased in town area and downstream in 2011 (Tables 1 and 2).

There was a visible increase in concentration going downstream with average concentrations of 0.0437 µg ml^{-1}, 0.0699 µg ml^{-1}and 0.13986 µg ml^{-1} going downstream. The increased usage of imported electrical copper wire and cables in the town leaves on a daily basis a considerable amount of waste metal in the form of bits, choppings and cut-offs. Metallic copper washed down in the run-offs subsequently dissolves in the fluctuating acidities and alkalinities of the effluent.

3.4. Cadmium

The amount of Cd was fairly constant upstream and in the town area (with the unusually high level of up to 0,044 µg ml^{-1} in site D3). An increase was noticed downstream over the two years. Comparison of Cd in upstream, mid-town and downstream for 2010 using Kruskal-Wallis test indicated no significant difference ($p = 0.180$). The concentration of Cd is higher than the

WHO guideline value in drinking water (0.003 μg ml^{-1}), which poses a threat to living organisms using this water directly. The relatively high level of cadmium in the municipality effluent waters may be attributable to the activities of small-scale metal works in the town, which process even scrap metal and run their untreated effluent directly into the drainage channels [15]. Also increased use and poor disposal of rechargeable batteries [16], cathode ray tubes of colour TVs and photocopier drums poorly disposed, corrode and get washed down the river [17]. Cadmium is widely used in paints [18]; and owing to the booming construction in the town, there is a considerable release of the metal into the environment via the associated painting and face-lifting of buildings.

3.5. Nutrients

Phosphate was the most predominant of the nutrients considered, followed by nitrates and fluctuating low amounts of ammonium and nitrite nutrients (Figures 2 &3). The elevated nutrient level is due to sewage and domestic wastewater as well as effluents from food processing factories (milk and bakeries) and from runoffs from surrounding farmland where fertilizers are used in banana plantations. Too much nutrient in domestic water might encourage the growth of toxic bacteria [19]. The high amount of nitrogen nutrients (ammonium, nitrates and nitrites) is attributed to a number of cattle farms at several points along the river, notably Mbarara High School farm among others. Excreta from these animals are an obvious source of nitrogen that is directly washed down to the river. At the point where treated sewage is channelled back to the river, we also expect a considerable amount of nitrogen fertilizer loading into river water. Surface runoff from the town and surrounding villages contains raw sewage, wastewater and fertilizers from gardens that contribute to nitrogen loading [20].

Most nitrogen in River Rwizi water occurs as nitrates, whose concentration also increased downstream throughout the sampling period (Figures 2 and 3), giving no significant concentration difference in the sampling sites in 2010 (p = 0.062) and a significant difference in 2011 (p = 0.022). There was also a slight increase in nitrate levels in 2011 (0.233-0.577 μg ml^{-1}) as compared to 2010 (0.119-0.54μg ml^{-1}) (Figure 2). A slight decrease in nitrite levels can be attributed to biochemical (bacterial) conversion to nitrates, evidenced by increase in nitrate levels. In all sites, the levels of nitrites were higher in 2011 (Figure 3).

These nutrients cause an increase in production and biomass of phytoplankton, attached algae and macrophytes [19], shift in habitat characteristics due to change in assemblage of aquatic plants, replacement of desirable fish by less desirable species, production of toxins by certain algae [21], deoxygenation of water, especially after collapse of algal blooms [22]. Loss of recreational use of water due to slime, weed infestation and noxious odour from decaying algae is an impediment to navigation due to dense weed growth [23].

The main source of phosphate could be raw sewage and wastewater from that drain in the river. Increased use of detergents as a result of relative hardness detected could accelerate the problem. Phosphorus nutrient pollution causes enormous blooms of the algae, a form of cyanobacteria, which can produce neurotoxins and hepatotoxins [24].

3.6. Hardness, ph and Conductivity

Hardness of River Rwizi water remained fairly unchanged over the study period, the water not so heavily loaded with Ca and Mg ions, but tables 3 and 4 show significantly high quantities of these ions. There are no limestone rocks in Mbarara area, but possibly runoffs from areas as far as Bunyaruguru, with plenty of calcium rocks, contribute to the observed relative hardness in the water.

The pH of the filtered water samples at 25°C was in the range 6.6 - 6.8 (Tables 3 and 4), indicative of the relative neutrality, despite the direct seepage of the untreated municipal effluent, of the river waters. The slight reduction in pH can be attributed to the increase in the levels of metallic cations discussed earlier.

4. CONCLUSIONS

Our results show that the levels of heavy metals in the river water are on the rise, which is reflective of the growing anthropogenic pollution problem in Mbarara Municipality. This poses a big threat to the only reliable source of fresh water for domestic and industrial use. It is therefore imperative upon the relevant municipal authorities to stress the need for treatment of effluent at the source before release into the environment. In addition, tougher laws should be put in place as a deterrent against direct channelling of industrial effluents and dumping of wastes into River Rwizi. Nutrient levels are rising, with phosphates being the most predominant. Nitrogenous nutrients occur mainly as nitrates and a combination of all these seem to be the sole cause of the dirty-brown appearance of the water and the subsequent growth of algae observed at stagnant points along the river.

REFERENCES

[1] UBOS, "Estimated population of Mbarara town in 2011. Uganda Bureau of Statistics, Kampala, Uganda 2011." Available http://en.wikipedia.org/wiki/Mbarara#cite_note-4, 2011.

[2] A. Chen, K. N. Dietrich, X. Huo, and S. M. Ho, "Developmental neurotoxicants in E-Waste: An emerging health concern," *Environ. Health Perspect*, vol. 119, pp. 431-438, 1994.

[3] M. A. S. Laidlaw, H. W. Mielke, G. M. Filippelli, D. L. Johnson, and Gonzales, "Seasonality and children's blood lead levels: Developing a predictive model using climatic variables and blood lead data from Indianapolis, Indiana, Syracuse, New York, and New Orleans, Louisiana (USA)," *Environ. Health Perspect*, vol. 113, pp. 793-798, 2005.

[4] M. Saeedi, M. Hosseinzadeh, A. Jamshidi, and S. P. Pajooheshfar, "Assessment of heavy metals contamination and leaching characteristics in highway side soils, Iran," *Environ.l Monit. Assess*, vol. 151, pp. 231-241, 2009.

[5] B. Chiswell and M. B. Mokhtar, "The speciation of manganese in fresh waters," *Talanta*, vol. 33, p. 669, 1986.

[6] B. B. Naziriwo, S. O. Wandiga, and M. J. G. Gatari, "Use of TXRF and convectional energy dispersive X-ray fluorescence analysis (EDXRF) to determine trace metal concentrations in waters of Nakivubo channel and Lake Victoria," *Lakes & Reservoirs: Res. Manage.*, vol. 15, pp. 101–110, 2010.

[7] P. M. Linnik, "Zinc, lead and cadmium speciation in dnieper water-bodies," *Lakes Reservoirs Res. Manage.*, vol. 5, pp. 261-70, 2000.

[8] J. Mbabazi, G. Bakyayita, J. Wasswa, A. Muwanga, H. Twinomuhwezi, and J. Kwetegyeka, "Variations in the contents of heavy metals in arable soils of a major urban wetland inlet drainage system of Lake Victoria, Uganda," *Lakes & Reservoirs Res. Manage*, vol. 15, pp. 89–99, 2010.

[9] C. M. Mukwaya and R. Mugabe, "Cooperation in management of water resources in the Rwizi catchment, South Western Uganda," *Kampala*, Available http://www.inweb.gr/twm4/abs/MUKWAYA%20Christine.pdf [Accessed 05 June 2014], 2008.

[10] D. S. Kisamo, "Environmental hazards associated with heavy metals in Lake Victoria Basin (East Africa)," *African Newsletter on Occupational Health and Safety*, vol. 13, 2003.

[11] F. Kruis, "Environmental chemistry, Selected analytical methods," *The Netherlands: International Institute for Infrastructural Hydraulic and Environmental Engineering*, 1992.

[12] J. M. B. Lippard, *Principles of bioinorganic chemistry*. CA: Mill Valley, 1994.

[13] B. Muyssen, A. Schamphelaere, C. Karel, and R. Janssen, "Mechanisms of chronic waterborne Zn toxicity in Daphnia Magna," *Aquatic Toxicol*, vol. 77, p. 393, 2006.

[14] T. R. Crompton, *Battery reference book*. Oxford, England: Newnes, 2000.

[15] N. B. D. M. Skrbic, "Chemometric interpretation of heavy metal patterns in soils worldwide," *Chemosphere*, vol. 80, pp. 1360-1369, 1991.

[16] C.-H. Lee and C. S. Hsi, "Recycling of scrap cathode ray tubes," *Environ. Sci. Tech.*, vol. 36, pp. 69-75, 2002.

[17] L. S. Muller and J. B. Mullin, *Crystalline cadmium sulfide. Electronic materials: From silicon to organics*. New York: Plenum Press, 1991.

[18] A. M. Lansche and Arnold, *Minerals year book 1956*. Cadmium: United States Geological Survey, 1956.

[19] G. W. A. Nyakairu, C. B. Nagawa, and J. Mbabazi, "Assessment of cyanobacteria toxins in freshwater fish: A case study of Murchison Bay (Lake Victoria) and Lake Mburo, Uganda," *Toxicon*, vol. 55, pp. 939-946, 2010.

[20] W. H. P. Campbell, G. G. Song, and Barbier, "Nitrate reductase for nitrate analysis in water," *Environ. Chem. Letters*, vol. 4, pp. 69-73, 2006.

[21] S. B. R. Williams, "Avoid blue-green algae, people told bacteria that closed beach can make fatal toxins," *Wisconsin State Journ.*, Available http://www.highbeam.com, vol. 10, 2004.

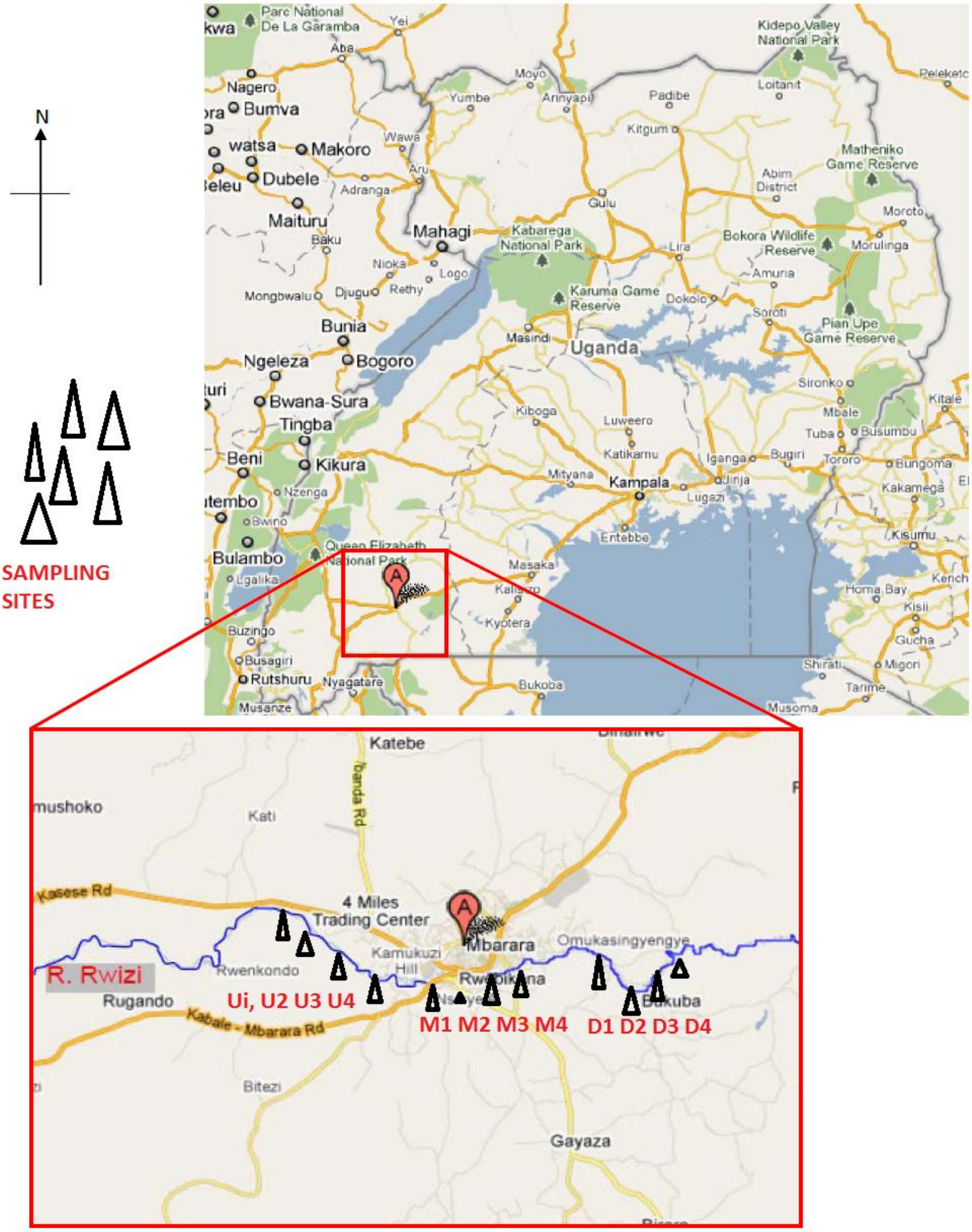
[22] B. C. Kross, G. R. Hallberg, D. R. Bruner, K. Cherryholmes, and J. K. Johnson, "The nitrate contamination of private well water in Iowa," *Amer. Journ. Public Health*, vol. 83, pp. 270-272, 1993.

[23] EPA, "Is your drinking water safe?," *In US-EPA 570 9-91-005: EPA*, 1991.

[24] C. S. Bruning-Fann and J. B. Kaneene, "The effects of nitrate, nitrite, and N-nitroso compounds on human health: A review," *Vet. Human Toxicol*, vol. 35, pp. 521-538, 1993.

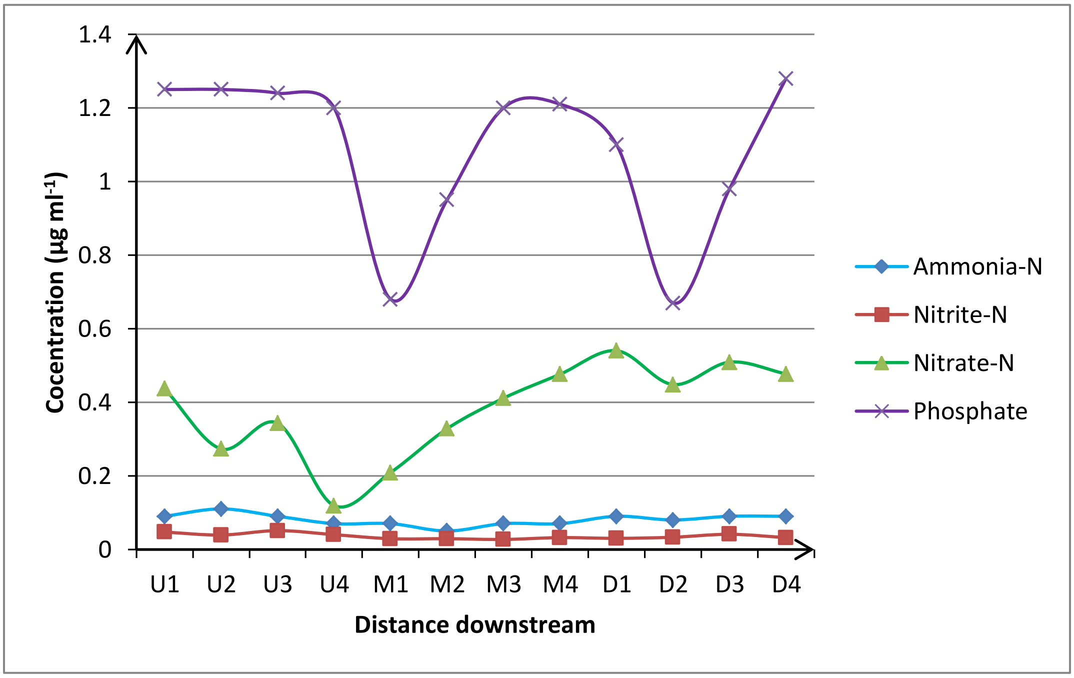
FIGURES

Figure-1. Map of Uganda showing location of Mbarara Municipality and sampling sites on River Rwizi



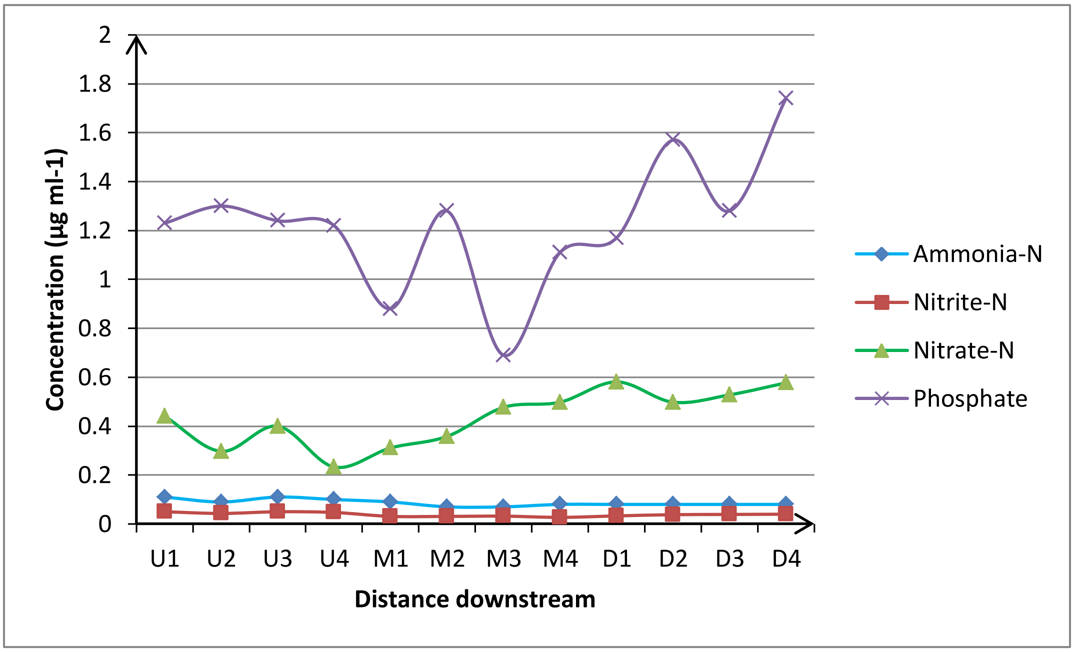
(**Source:** Google maps/Uganda)

Figure-2. Relative nutrient levels in 2010



Source: (this work)

Figure-3. Relative nutrient levels in 2011



Source: (this work)

TABLES

Table-1. Mean total heavy metal levels in River *Rwizi* water in 2010

April , 2010	**Concentration (µg ml^{-1})**			
Sampling site	**Zn**	**Cu**	**Cd**	**Pb**
U1	1.469±0.001	0.037±0.003	0.029±0.004	1.428±0.004
U2	1.704±0.004	0.068±0.001	0.029±0.005	1.428±0.006
U3	1.453±0.004	0.036±0.003	0.029±0.003	1.283±0.006
U4	1.353±0.003	0.034±0.005	0.029±0.006	1.142±0.008
M1	2.503±0.003	0.069±0.005	0.029±0.007	0.552±0.005
M2	2.587±0.003	0.069±0.007	0.029±0.007	0.716±0.005
M3	2.394±0.006	0.107±0.006	0.044±0.006	0.545±0.006
M4	2.630±0.006	0.104±0.006	0.029±0.005	1.421±0.005
D1	2.017±0.005	0.139±0.007	0.029±0.005	1.427±0.005
D2	0.777±0.005	0.105±0.007	0.029±0.006	1.031±0.005
D3	1.855±0.005	0.139±0.004	0.029±0.005	2.058±0.006
D4	2.066±0.005	0.138±0.003	0.043±0.004	1.573±0.002
Average	1.901±0.007	0.087±0.00	0.0314±0.006	1.217±0.006

Source: (this work)

Table-2. Mean total heavy metal levels in River *Rwizi* waters in 2011

April, 2011	**Concentration (µg ml^{-1})**			
Sampling site	**Zn**	**Cu**	**Cd**	**Pb**
U1	1.447±0.002	0.035±0.004	0.029±0.002	1.429±0.005
U2	1.605±0.004	0.068±0.003	0.029±0.003	1.423±0.006
U3	1.447±0.004	0.036±0.004	0.029±0.002	1.218±0.007
U4	1.369±0.006	0.703±0.005	0.029±0.002	1.140±0.006
M1	2.546±0.003	0.069±0.001	0.029±0.004	0.545±0.002
M2	2.535±0.005	0.069±0.002	0.029±0.004	0.716±0.003
M3	2.408±0.003	0.120±0.002	0.044±0.004	0.545±0.003
M4	2.665±0.005	0.126±0.003	0.029±0.003	1.422±0.004
D1	2.060±0.004	0.191±0.004	0.029±0.004	1.427±0.005
D2	1.689±0.004	0.099±0.007	0.029±0.004	1.385±0.004
D3	1.855±0.006	0.179±0.006	0.029±0.006	2.005±0.005
D4	2.269±0.008	0.132±0.005	0.029±0.001	1.615±0.005
Average	1.991±0.007	0.096±0.005	0.030±0.001	1.239±0.004

Source: (this work)

Table-3. Hardness, pH and conductivity of *R. Rwizi* water in 2010

Sample	**Hardness (mg/L as $CaCO_3$)**	**pH**	**Conductivity ($\Omega^{-1}cm^{-1}$)**
U1	48	6.8	105.1
U2	48	6.8	107.4
U3	47	6.8	106.5
U4	44	6.8	105.7
M1	48	6.7	105.7
M2	46	6.7	104.2
M3	46	6.6	105.9
M4	46	6.7	106.7
D1	52	6.7	108.8
D2	46	6.6	109.5
D3	46	6.6	110.1
D4	49	6.6	107.6

Table-4. Hardness, pH and conductivity of *R. Rwizi* water in 2011

Sample	Hardness (mg/L as $CaCO_3$)	pH	Conductivity ($\Omega^{-1}cm^{-1}$)
U1	47	6.8	106.1
U2	43	6.8	107.8
U3	46	6.7	105.6
U4	44	6.8	105.6
M1	49	6.7	106.6
M2	45	6.7	105.5
M3	44	6.6	105.7
M4	48	6.6	106.9
D1	53	6.7	109.3
D2	48	6.6	109.1
D3	55	6.6	109.1
D4	47	6.7	109.3

Source: (this work)