The major cations and trace elements in Notwane river, Botswana and its suitability for irrigation

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ABSTRACT

Notwane river in Botswana, is a perennial river in which the treated secondary or tertiary sewage effluent from Gaborone activated sludge treatment plant is discharged to. The objective of this study was to evaluate the major cations and trace elements in the water of Notwane river for irrigation purposes. Six sites were used for the study. The results of the study showed that the major cations and heavy metal concentration differed significantly ($P \leq 0.0001$) among the sampling sites, but the concentrations of the heavy metals were far below the recommended limits for effluent discharge guidelines to perennial or ephemeral rivers and irrigation water quality. The concentration of Ti, V, Cr, Mn, Fe, Co, Cu, Zn, As, Se, Sr and Pb ranged between 95-131.54, 41.03-89.50, 4.47-10.0, 7.26-42.04, 390-1000.10, 2.0-2.87, 2.46-5.26, 11.96-16.24, 5.14-6.44, 3.01-5.48, 76.51-78.61 and 3.38-8.56 $\mu g\ L^{-1}$, respectively. The SAR values of the Notwane river water ranged between 3.57 to 3.64, which is within the maximum recommended (<9) for irrigation water by FAO. Based on major cation content, SAR and heavy metal concentration in the water of Notwane river along the sampled sites, the water is suitable for irrigation of field, fodder, horticultural crops and drinking water for livestock.

Keywords: Secondary effluent, perennial river, sodium adsorption ratio, heavy metals, irrigation water quality.

INTRODUCTION

Effluent irrigation has been practiced for centuries throughout the world (Shuval *et al.*, 1986). It provides farmers with a nutrient enriched water supply and society with a reliable, inexpensive, sustainable and ecological system of wastewater management and disposal (Emongor *et al.*, 2005). Wastewater has been used for forage crop production because of their long growing season, high evapotranspiration demand and removal of large quantities of nutrients from the biosystem (Feign *et al.*, 1991). Forages are not consumed directly by human beings, therefore the transfer of diseases is unlikely (Bole and Biederbeck, 1979).

Many trace elements are micronutrients essential for the growth of animals and plants. Several trace elements have no known physiological functions (Page and Chang, 1984). At high concentrations all trace metals, regardless of whether they are essential or non-essential, become toxic to animals and man. Unlike pathogens whose transmission relies entirely on direct contact, trace elements introduced into soil may be translocated into plant tissue through absorption from soil by plant roots (Emongor, 2007). Through land application of wastewater, the input of trace metals to soil is not likely to result in any immediate and acute toxicity. However, excessive accumulation of certain trace elements such as lead, cadmium, mercury, arsenic and selenium in plants, can expose consumers to potentially hazardous levels. There is also a possibility of long-term build up of trace elements with long-term application of wastewater into soils leading to phytotoxicity. The Gaborone activated sludge treatment plant discharges the treated secondary effluent into the Notwane river. The Notwane river used to be seasonal, but due to discharge of secondary effluent has become permanent. The water quality for irrigation purposes of the Notwane river has not been determined and yet farmers are using it for irrigation and livestock plus wildlife drink in it. The objective of this study was to evaluate the major cations and trace elements in the water of Notwane river for ir rigation purposes

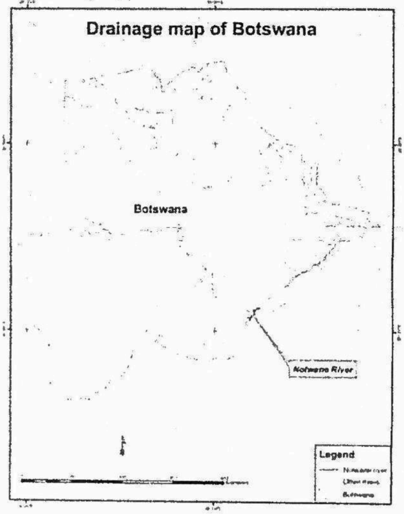

Figure 1a. A map of Botswana showing the Notwane river

MATERIALS AND METHODS

Six sites were used for the study (Phakalane secondary effluent reservoir ponds, Oodi, Matebele, Belabela, Morwa and Mochudi) as shown in Figures 1a and 1b. The sampling sites were on average at 5 km interval [measured using the Global Positioning System (GPS)] along the Notwane river, starting from the source (Phakalane secondary effluent reservoir ponds). The secondary effluent from the Phakalane reservoir ponds is discharged to the Notwane river.

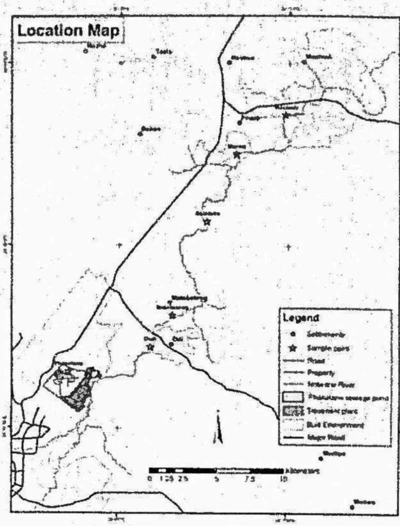

Figure 1b. Map showing sampling areas. Sewage treatment plant, Phakalane sewage ponds and Notwane river

The Gaborone potable water was used as the control because it is the same water that becomes secondary effluent. Water at different sites was sampled nine times (once a month) starting from March 2004 to March 2005, using the United States Environmental Protection Agency procedures and guidelines.

The cations Na^+, K^+, Ca^{2+} and Mg^{2+} were determined using undigested water samples. While the other cations were determined using digested water samples. The water samples were digested according to Hach (2002). The samples were acidified with concentrated nitric acid (55%) at the time of collection by adding 5 mL of acid per litre of sample. Then 100 mL of well-mixed sample was transferred to 250 mL-beaker. Then 5 mL of distilled water 1:1 hydrochloric acid was added. The samples were then heated in a water bath maintained at 80°C until the volume reduced to 20 mL. The samples were then filtered to remove any insoluble material. The sample pH was adjusted to a pH of 4 by adding 5.0 N NaOH a drop at a time while mixing and checking the pH after each drop of NaOH. Then the samples were quantitatively transferred to a 100 ml volumetric flasks and diluted with deionized water.

The alkali metals, Na^+ and K^+ were determined using a flame photometer (Corning 410) where the emission intensities were proportional to the concentration of the metals. All measurements were done against a reagent blank solution containing the same amount of nitric acid as the sample. While Ca^{2+} and Mg^{2+} were determined using flame atomic absorption spectrometer (GBC 908AA). The sodium adsorption ratio was calculated using the formula below (Ayers and Westcot, 1985).

$$SAR = [Na] / [(Ca + Mg)/2]^{1/2}$$

Where: Na = sodium in me L^{-1}, Ca = calcium in me L^{-1}, Mg = magnesium in me L^{-1}

The elements aluminium (Al), manganese (Mn), zinc (Zn), molybdenum (Mo), phosphorus (P) and iron (Fe) were determined using a microprocessor-controlled, LED-sourced filter photometer (Hach DR/850, USA). The heavy metals beryllium (Be), titanium (Ti), vanadium (V), chromium (Cr), cobalt (Co), copper (Cu), gallium (Ga), germanium (Ge), arsenic (As), selenium (Se), strontium (Sr), barium (Ba), cerium (Ce), lead (Pb), bismuth (Bi), cadmium (Cd) and mercury (Hg) were determined using Inductively Coupled Plasma Emission (ICP)- Mass Spectroscopy.

Data collected was subjected to analysis of variance using the general linear models (Proc GLM) procedure of the statistical analysis system program package. Proc Univariate procedure was carried out on residuals to support the assumptions of normality made by the researcher.

RESULTS AND DISCUSSION

Major cations

Table 1 shows major cations (P^{3+}, K^+, Na^+, Ca^{2+} and Mg^{2+}) concentration in the Notwane river (Table 1). The P concentration along the Notwane river in the study area ranged between 1.10 to 2.55 mg L^{-1} (Table 1). The water at Oodi and Matebele had significantly higher P concentration than either Phakalane reservoir ponds, Belabela, Morwa, or Mochudi (Table 1). The P concentration increased by between 124 to 420% compared to P concentration in the potable water (Table 1). Phosphorus concentration in the Notwane river was above the recommended concentration for irrigation water by FAO (< 2 mg L^{-1}) and discharge guidelines to the environment (<1 mg L^{-1}) in Botswana (Ayers and Westcot, 1985; Nkegbe et al., 2005). The high P concentration in the Notwane river and secondary sewage effluent compared to potable water is due to P discharge from homes. Phosphorus is a building block for soap, soap powders and detergents and also a major source of nutrient in human diet. The high P concentration (> 1 mg L^{-1}) in the secondary sewage effluent discharged into Notwane river has caused a significant growth of algae (eutrophication) in the river and the Phakalane reservoir ponds. The growth of algae has been stimulated by an interaction between nitrogen and phosphorus. Nitrogen and phosphorus has been reported to interact and produce large standing crops of algae (Fang and Liu, 2001; Metcalf, 1991). Phosphorus concentration was much higher at Oodi and Matebele than other sampling sites possibly due to addition of phosphorus into the Notwane river through surface fertilizer run off from farms in these areas. The concentration of K^+ in the Notwane river did not differ significantly among the sampling sites (Table 1). However, the K^+ concentration was high in the Notwane river and Phakalane reservoir ponds (secondary sewage effluent) compared to potable water (Table 1). The increase in K^+ concentration in the secondary effluent and Notwane river compared to potable water can be explained by the decomposition of organic matter during sludge treatment and in the settling and reservoir ponds. Potassium in wastewater and irrigation water is not known to cause adverse health and crop effects.

The Na^+ ion concentration in the Notwane river did not significantly differ in the sampling sites, but it was significantly higher (7 fold) than that in potable water (Table 1). The increase Na^+ ion concentration in the secondary effluent and Notwane river is due to high Na in the sludge and wastewater. The SAR followed same trend as Na (Table 1). There was no significant difference in the SAR among the sampling sites along Notwane river, but it was significantly higher in the Notwane river water than potable water (Table 1). Excessive Na in irrigation water increases the SAR if the concentration of Ca and Mg is low. Excessive Na in irrigation water also promotes soil dispersion and structural breakdown if Na exceeds Ca by more than a ratio of 3:1 (Ayers and Westcot, 1985). Irrigation water with a high SAR value is detrimental to the soil physical properties. Ca flocculates, while Na disperses the soil particles. Dispersed soils crust and have poor infiltration and permeability (Ayers and Westcot, 1985). The SAR values of the Notwane river water ranged between 3.57 to 3.64, which is within the maximum recommended (<9) for irrigation water by FAO (Ayers and Westcot, 1985). Classification of irrigation water based on SAR values, the Notwane river water could be classified as low sodium hazard water.

Calcium concentration in the Notwane river water did not vary significantly among the sampling sites (Table 1). However, the Ca concentration in Notwane river water was significantly high compared to potable water (Table 1). The Mg concentration in the Notwane river did not vary significantly along the river, with exception at Phakalane reservoir ponds (Table 1). However, the Mg concentration in Notwane river water was significantly high compared to potable water (Table 1). The Ca and Mg concentrations in the Notwane river are within the recommended limits for irrigation water quality (Ayers and Westcot, 1985). Calcium is a non-toxic mineral nutrient, even in high concentration, and it is very effective in detoxifying high concentrations of other mineral elements in plants (Hanson, 1984). The functions of Mg in plants are related to its mobility within cells, its capacity to interact with strongly nucleophilic ligands (phosphoryl groups) through ionic bonding, and to act as abridging element and/or form complexes of different stabilities (Marschner, 1986). Calcium and Mg in irrigation water play an important role in counteracting the dispersing effects of Na and reducing infiltration problems (Ayers and Westcot, 1985).

Table 1. Major cations in Notwane river

Site	P mg L^{-1}	K mg L^{-1}	Ca mg L^{-1}	Mg mg L^{-1}	Na mg L^{-1}	SAR
Potable water	0.49d	6.37b	9.70b	8.61c	12.8b	0.72b
Phakalane ponds	1.84b	25.62a	23.70a	18.30a	95.2a	3.57a
Oodi	2.55a	25.54a	23.68a	16.47b	94.3a	3.64a
Matebele	2.49a	25.03a	23.57a	16.52b	93.5a	3.61a
Belabela	1.10c	24.96a	23.73a	16.62b	93.2a	3.58a
Morwa	1.74b	25.32a	23.72a	16.50b	93.3a	3.60a
Mochudi	1.30c	25.79a	23.72a	16.68b	93.2a	3.58a
Significance	****	****	****	****	****	****
LSD	0.427	2.45	4.73	2.01	4.35	0.422

**** Significant at $p = 0.0001$.
Means separated by the Least Significant Difference (LSD) at $p = 0.05$; means within columns followed by the same letter(s) are not significantly different.

Table 2a. The trace element content of Notwane river

Site	Be μg L^{-1}	Al μg L^{-1}	Ti μg L^{-1}	V μg L^{-1}	Cr μg L^{-1}	Mn μg L^{-1}	Fe μg L^{-1}	Co μg L^{-1}	Cu μg L^{-1}	Zn μg L^{-1}
Potable water	0.00g	37.34g	95.00g	83.90c	6.14d	2.76g	0.04g	1.63e	20.31a	176.97a
Phakalane ponds	1.07e	44.81e	118.26f	71.61d	5.71e	42.04a	0.39e	2.00d	2.46g	17.84b
Oodi	0.91f	57.42c	131.54a	69.26e	10.09a	16.55c	0.22f	2.32c	2.89f	11.96g
Matebele	69.96a	53.67d	129.06c	41.03e	4.47g	26.81b	0.72d	2.57b	4.32d	16.24c
Belabela	11.96b	44.14f	127.16e	60.38f	5.43f	14.16d	0.93c	2.82a	4.53c	14.59e
Morwa	2.27d	93.89b	128.23d	89.50a	7.49c	7.26f	1.10a	2.61a	4.29e	16.02d
Mochudi	8.00c	188.84a	129.55b	88.52b	9.45b	13.29e	1.00b	2.87a	5.26b	12.84f
Significance	****	****	****	****	****	****	****	****	****	****
LSD	0.0616	0.3574	0.1919	0.0855	0.0725	0.077	0.0206	0.1681	0.0267	0.0183

**** Significant at $p = 0.0001$.
Means separated by the Least Significant Difference (LSD) at $p = 0.05$; means within columns followed by the same letter(s) are not significantly different.

Table 2b. The trace element content of Notwane river

Site	Ga μg L^{-1}	Ge μg L^{-1}	As μg L^{-1}	Se μg L^{-1}	Sr μg L^{-1}	Mo μg L^{-1}	Ba μg L^{-1}	Ce μg L^{-1}	Pb μg L^{-1}	Bi μg L^{-1}
Potable water	3.653d	2.45d	4.61g	2.89b	106.70a	1.22d	51.29a	1.06f	3.36g	8.50bc
Phakalane ponds	3.680c	2.51c	5.72c	3.20b	72.65f	3.22c	20.47f	1.20e	4.31e	9.62bc
Oodi	3.713a	2.49cd	5.41e	3.92ab	78.61b	3.39c	28.45d	1.43c	6.39c	6.35c
Matebele	3.603e	2.02f	5.14f	5.48a	76.44e	3.78ab	18.49g	1.42c	8.56a	48.49a
Belabela	3.700ab	2.16e	5.52d	4.07ab	76.87c	3.91a	36.94b	1.31d	3.38f	11.42b
Morwa	3.693bc	2.61b	6.22b	3.01b	76.58d	3.23c	26.99e	2.01b	6.32d	8.53bc
Mochudi	3.697b	2.67a	6.44a	3.82ab	76.51de	3.62b	33.40c	3.06a	6.89b	8.90bc
Significance	****	****	****	****	****	****	****	****	****	****
LSD	0.0136	0.0501	0.0174	1.9449	0.082	0.2213	0.049	0.0535	0.0152	3.488

**** Significant at $p = 0.0001$.
Means separated by the Least Significant Difference (LSD) at $p = 0.05$; means within columns followed by the same letter(s) are not significantly different.

Trace elements

Table 2a and 2b shows the trace elements (Be, Al, Ti, V, Cr, Mn, Fe, Co, Cu, Zn, Ga, Ge, As, Se, Sr, Mo, Ba, Ce, Pb and Bi) concentration in the Notwane river (Tables 2a, 2b). The concentration of the trace elements varied significantly along the Notwane river, but were below the recommended concentrations for discharge to the environment and irrigation water quality according to (Tables 2a, 2b). The results of the current study showed that the treated secondary sewage effluent (Phakalane reservoir ponds) and Notwane river water had on average a Hg, Pb and As concentrations of below detection limits, 3.38-8.56 and 5.14-6.44 μgL^{-1}, respectively (Table 2a). The concentrations of Hg, Pb and As were below the recommended limits by FAO and Botswana government guidelines for irrigation water quality (Table 3). These metals (Hg, Pb and As) are of widespread concern to human health (Nriagu, 1988). Metals like Hg, Cd, Pb, As, Zn and Ni are the important metals near urban areas due to industries and automobiles. These metals may accumulate in soil, sewage sludge and effluent, plants and the atmosphere, therefore causing pollution of the environment.

The concentrations of Be, Ti, V, Cr, Co, Cu, Ga, Ge, Se, Sr, Ba, Ce, and Bi ranged between 1.07-69.96, 118.26-131.54, 41.03-89.5, 4.47-10.09, 2.0-2.87, 2.46-5.26, 3.60-3.71, 2.02-2.67, 3.01-5.48, 72.65-78.61, 18.49-33.4, 1.2-3.06, and 8.53-48.49 μgL^{-1}, respectively (Tables 2a, 2b). These trace elements were all below the recommended limits by FAO and Botswana government guidelines for irrigation water quality (Table 3). The low levels of heavy metal content in the secondary effluent and the Notwane river indicates that the sewage is lowly contaminated with heavy metals and/or the activated sludge treatment plant is working effectively. The Gaborone activated sludge treatment plant reduces pollutants in the sludge by 81.4 to 99% depending on the pollutant (Nkegbe *et al.*, 2005). Metals such as Cd, Cu, Pb and Zn are removed substantially (greater than 70%) during activated sewage treatment (Chang, 1980). It has also been reported an effective primary and secondary sewage treatment, removes 85 to 90% of the major pollutants in raw sewage water (D'Itri *et al.*, 1981). Toxic chemicals are removed from the sewage effluent during treatment, adsorbing on particular matter and ending up in sludge hence only traces of chemicals and metals are found in wastewater (Straus, 2000). In the wastewater, trace metal elements tend to form metal hydroxide, phosphate, carbonate, and other precipitates, which get adsorbed on the sewage solids, and co-precipitate with other constituents in the wastewater.

The concentration of Fe, Mo, Mn, Zn, Al and Li in the secondary effluent and Notwane river ranged between 0.39-1.10, 3.22-3.91, 7.26-42.04, 11.96-17.84, and 44.14-188.84 μgL^{-1}, respectively (Table 2a). The concentration of these micronutrients were below the recommended limits for irrigation water quality by FAO and Botswana government guidelines for irrigation water quality. The concentration of aluminum is related to the clay materials and although it is also a part of other minerals (White, 1986). Aluminum has been reported to be inert in aquatic environment (Chapman, 1992). The trace elements in the secondary effluent and Notwane river water are micronutients which are beneficial or essential for growth and development of certain crops. Therefore, the use of secondary effluent and Notwane river water for irrigation will supply both macro- and micro-nutrients needed for plant growth and development, and hence reduce fertilizer costs.

In conclusion, the treated secondary sewage effluent discharged to Notwane river is suitable for irrigation purposes and Notwane river is not heavily polluted due to the low heavy metals including Hg, Pb and As in the river which are of concern to human health when they accumulate in the environment.

REFERENCES

Ayers, R. S. and Westcot, D. W. (1985). Water quality for irrigation. *FAO Irrigation and Drainage* 29: 1-130.

Bole, J. B. and Biederbeck, V. O. (1979). Soil and plant response to wastewater irrigation: Nutrient uptake and plant productivity. In: Effluent Irrigation Under Prairie Conditions. A Technology Transfer Conference. Regina, Saskatchewan, January 24-25th

Chang, R. L. (1980). Health risks associated with toxic metals in municipal sludge. In: Bitton, G. Damron, B. L., Edds, G. T. and Davidson, J. M. (Eds.), Sludge-Health Risks of Land Application, Ann Arbor Science Publishers Inc., pp: 166-181.

D'ltri, F. M., Aquirre-Martinez, J. and Athie-Lambarri, M. (1981). Municipal Wastewater In Agriculture. London, New York, Academic Press, 476pp.

Emongor, V. E. (2007). Biosorption of lead from aqueous solutions of varied pH by kale plants (*Brassica oleraceae* var acephala). *Journal of Agricultural, Food, and Environmental Sciences* 1(2): 1-8.

Emongor, V. E., Khonga, E. B., Ramolemana, G. M., Marumo, K., Machacha, S. and Motsamai, T. (2005). Suitability of treated secondary sewage effluent for irrigation of horticultural crops in Botswana. *Journal of Applied Science* 5: 451-454.

Fang, H. P. and Liu, y. (2001). Anaerobic wastewater treatment in sub-tropical regions. In: Matsuo, T., Hanaki, K., Takizawa, S. and Satoh, H (Eds.), Advances in Water and Wastewater Treatment Technology: Molecular Technology, Nutrient Removal, Sludge Reduction and Environmental Health, Elsevier, Amsterdam, London, New York, Oxford, Paris, Shanon, Tokyo, pp: 285-294.

Feign, A., Ravina, I. and Shalhevet, J. (1991). Irrigation with treated Sewage Water. Management for Environmental Protection. Advanced Series in Agricultural Sciences 17. Springer-Verlag, 224pp.

Hach (2002). Water Analysis Handbook: Photometric Procedures, Titration procedures, Ion-selective procedures, Microbiological Procedures, Chemical procedures Explained and Digesting Liquids, Oils and Solids. 4th Edition. Loveland, Colorado, USA, Hach Company, 1259 pp.

Hanson, J. B. (1984). The function of calcium in plant nutrition. In: Tinker, P. B. and Läuchli, A. (Eds.), Advances in Plant Nutition, Praeger, New York, pp: 149-208.

Marschner, H. (1986). Mineral Nutrition in Higher plants. Academic Press, Harcourt Brace Jovanovich, Publishers, London, Orlando, San Diego, New York, Toronto, pp 484-523.

Metcalf, E. (1991). Wastewater Engineering. 3rd Edition, McGraw-Hill, Inc., pp: 394-426.

Nkegbe, E., Emongor, V. E. and Koorapetsi, I. (2005). Assessment of effluent quality at Glen Valley wastewater treatment plant. *Journal of Applied Science* 5: 647-650.

Nriagu, J. O. (1988). A silent epidemic of environmental metal poisoning? Environmental *Pollution* 50: 139-161.

Page, A. L. and Chang, A. C. (1984). Fate of wastewater constituents in soil and groundwater: Trace elements. In: Pettygrove, G. S. and Asano, T. (Eds), Irrigation with Reclaimed Municipal Wastewater, California State Water Resources Control Board, Sacramento: *A Guidance Manual*, 13: 1-16

Shuval, H. I., Adin, A., Fattal, B., Rawitz, E. and Yekutiel, P. (1986). Wastewater Irrigation in Developing Countries: Health Effects and Technical Solutions. World Bank Technical Paper 51, Washington, D.C., 325pp.

Strauss, M. (2000). Reuse of urban wastewater and human excreta, EAWA/Sandec, Duebenderf, Switzerland. *strauss@eawag.ch*.

White V. N. (1986). Handbook on Chlorination, Second Edition, Van Nostrand Reinhold, New York, pp: 35 – 129.

Chapman, B. (1992). Water quality Assessment, A guide to use of Biota, Sediments and water in Environmental monitoring, Chapman and Hall, pp 55 – 66.