# The heavy metal content of Gaborone secondary sewage effluent in Botswana

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## ABSTRACT

The objective of this study was to determine the heavy metal content of the Gaborone secondary effluent in Botswana before its discharged to the Notwane river. Secondary effluent water was sampled every month for one year, from a breather pipe on the pivot irrigation system at the Botswana College of Agriculture, Notwane Farm, Gaborone, using USEPA procedures and guidelines. The results showed that the heavy metals of most widespread concern to human health Hg, Cd, Pb and As were below detectable limits, 5.75, 4.83 and 5.7 parts per billion ($\mu g L^{-1}$), respectively, and were below concentrations that could pose pollution of the environment and were within the recommended limits for irrigation water by FAO and the Botswana guidelines for irrigation water. The other trace elements Be, Ti, V, Cr, Co, Cu, Ga, Ge, Se, Sr, Ba, Ce, Bi, Al, Li, Mn, Mo and Fe were all below the recommended limits for irrigation water by FAO and the Botswana guidelines for irrigation water. Most of the trace elements were in concentrations of parts per billion. The current results suggest that the Gaborone secondary effluent is suitable for unrestricted irrigation of field, fodder and horticultural crops. However, heavy metal levels should be monitored continuously either by the Gaborone City Council or any other government institution in order to make sure the treated secondary sewage effluent meets the recommendations for irrigation water, and prevent environmental pollution and reduce health hazards that may be caused by pollutants to the end users of this scarce resource.

**Keywords:** Secondary effluent, mercury, cadmium, lead, trace elements, Gaborone Botswana.

## INTRODUCTION

Pollution is the undesirable change in the physical, chemical or biological characteristics of air, land and water that may be harmful to the human life, living conditions and cultural assets, or that may or will waste, or deteriorate raw natural resources. Pollution of the environment with toxic metals has increased dramatically since the beginning of the industrial revolution.

Industries are major sources of pollution in all environments. Based on the type of industry, various levels of pollutants can be discharged into the environment directly or indirectly through public sewer lines. Pollutants include disease causing micro-organisms (pathogens such as bacteria and viruses), organic pollutants (pesticides), plant nutrients (fertilizers, detergents), organic matter (sewage), solids, oil, high concentration of dissolved salts, heavy metals (cadmium, lead and mercury), colour, foam, heat, toxic chemicals (cyanide), casinogenic compounds (arsenic) and radioactive materials (nuclear reactor waste).

There is considerable evidence that some heavy metals and organochlorines may be harmful to human and animal health at levels higher than what is recommended in water, air and foods. Some of the pollutants are not broken down, or are broken down over a long period of time and they become permanent additions in air and aquatic environment. They accumulate in plant and animal tissues, and may biomagnify in food chains (Mason, 1996). The major uptake route for many acquatic organisms is directly from the water so that, to a certain extent, tissue concentrations reflect concentrations in water. Carnivores at the top of the food chain, however, such as birds and mammals, including humans, obtain most of their pollutant burden from aquatic ecosystems by ingestion, especially of fish, so there exists the potential for considerable biomagnification. Mason (1996) reported that 730 people and a large number of animals ( cats, dogs and pigs) died of Hg poisoning in Minamata Bay, Japan, in the early 1950s due to eating fish with high concentration of Hg. The Hg was released into Minamata Bay through sewage from a factory. Mercury poisoning affects the nervous system ( speech disturbances, delirium and walking difficulties).

In acquatic environment, inorganic Hg is converted by micro-organisms to the highly toxic methyl Hg, which is more readily taken up by tissues. Some 95% of methyl Hg is absorbed by the gut and most of it is retained in the body, less than 1% is excreted. Over 90% of the body burden in fish is in the form of methyl Hg (Mason, 1996; Zilloux *et al*., 1993). While cadmium poisoning in human beings is characterized by severe back and joint pains, kidney lesions, protein and sugar in the urine and a decalcification of the bones, leading sometimes to multiple fractures, enhanced lymphocyte count, slight anaemia and changes in the concentration of potassium and magnesium in the blood (Larsson *et al*., 1985). Nriagu (1988) reported that over one billion human beings are currently exposed to elevated concentrations of toxic metals and metalloids in the environment and several million people may be suffering from subclinical metal poisoning. Heavy metals suppress the immune system, leading to increased susceptibility to disease in animals. Heavy metals may also be carcinogenic (Peakall, 1991).

Water resources in Botswana are limited due to low erratic, unreliable and poorly distributed rainfall, plus high temperatures, making water to be the most limiting factor to agricultural production (Emongor et al., 2005). Municipal wastewater is a resource that can be used beneficially. Currently in Botswana, treated secondary effluent is discharged into ephemeral rivers but not recycled, despite the semi-arid and arid nature of the country. Droughts are common and adversely affects the fragile food and agricultural situation in the country and seriously impairs the rural economy and socio-cultural structures.

The benefits of using recycled wastewater include conservation of drinking water, creation of an alternative water source for irrigation, and reducing fertilizer costs, because wastewater is rich in both macro-and micro-nutrients essential for plant growth and development (Emongor et al., 2005). However, the effects of continuous irrigation with secondary sewage effluent on soil and leachate water quality needs to be evaluated to avoid ground water pollution. The objective of this study was to determine the heavy metal content of Gaborone secondary effluent before it is discharged into Notwane river in Botswana.

## MATERIALS AND METHODS

Secondary effluent water samples were collected every month for a period of 12 months from a breather pipe on the central pivot irrigation system at Notwane Farm, Botswana College of Agriculture, using USEPA (United States Environmental Protection Agency) procedures and guidelines. The water samples were digested as follows. 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 80YC 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 water sample measurements were determined in triplicate per variable analysed per sampling.

The elements aluminium (Al), manganese (Mn), zinc (Zn), molybdenum (Mo), 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 researchers.

## RESULTS AND DISCUSSION

Apart from salinity and sodium hazards, pH, alkalinity, specific ions ($Cl^-$, $SO_4^{2-}$, $NO_3^-$, B) and microbiological contaminants that determine the quality of irrigation water, heavy metal concentrations is an important criteria while evaluating irrigation water quality. Evaluation of heavy metal content in irrigation water is important in order to avoid environmental pollution and potential hazards to human and animal health through biomagnification in the food chain. Peakall (1991), reported that heavy metals suppress the immune system, leading to increased susceptibility to disease in animals and they are also carcinogenic. Cadmium is reported to accumulate in the human body with a half-life exceeding 10 years and is linked to a number of health problems including renal tubular dysfunction, pulmonary emphysema, significant kidney damage and osteoporosis (Mudassir et al., 2005). In 1993, the International Agency for research on Cancer (IARC) classified Cd and compounds containing Cd as human carcinogens (Nyamgababo and Hamya, 1986).

The results of the current study showed that the treated secondary sewage effluent (water) had on average a Hg, Cd, Pb and As concentrations of below detection limits, 5.75, 4.83 and 5.7 $\mu gL^{-1}$, respectively (Table 1). The concentrations of Hg, Cd, Pb and As were below the recommended limits by

FAO and Botswana government guidelines for irrigation water quality. These metals (Hg, Cd, 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 were 1.07, 118, 71.5, 5.84, 2.2, 37.5, 3.65, 3.3, 3.17, 73.2, 20.2, 1.25, and 9.53 $\mu gL^{-1}$, respectively (Table 1). These trace elements were all below the recommended limits by FAO and Botswana government guidelines for irrigation water quality. The low levels of heavy metal content in the Gaborone secondary effluent indicates that the sewage is lowly contaminated with heavy metals and/or the activated sludge treatment plant is working effectively. Nkegbe et al. (2005), reported that the Gaborone activated sludge treatment plant reduced pollutants in the sludge by 81.4 to 99% depending on the pollutant. Chang (1980), reported that metals such as Cd, Cu, Pb and Zn are removed substantially (greater than 70%) during activated sewage treatment. D'Itri et al. (1981), also observed that

Table 1. Heavy metal and trace element content of treated secondary effluent from Gaborone (Botswana) sewage treatment plant.

| Property (mg/L) | Secondary effluent mean ± SD[Y] | Botswana irrigation water quality | FAO[Z] irrigation water quality |
|---|---|---|---|
| Mercury (Hg) | BDL | 0.002 | 0.001 |
| Cadmium (Cd) | 0.00575 ± 0.0033 | 0.01 | 0.01 |
| Lead (Pb) | 0.00483 ± 0.0036 | 0.1 | 5 |
| Arsenic (As) | 0.0057 ± 0.00003 | 0.1 | 0.1 |
| Beryllium (Be) | 0.00107 ± 0.001 | 0.1 | 0.1 |
| Titanium (Ti) | 0.118 ± 0.0007 | - | - |
| Vanadium (V) | 0.0715 ± 0.0005 | 1.0 | 2.0 |
| Chromium (Cr) | 0.00584 ± 0.0001 | 0.1 | 0.1 |
| Cobalt (Co) | 0.0022 ± 0.00025 | 0.05 | 0.05 |
| Copper (Cu) | 0.0375 ± 0.004 | 0.2-1.0 | 0.2-1.0 |
| Gallium (Ga) | 0.00365 ± 0.00008 | - | - |
| Germanium (Ge) | 0.0033 ± 0.0014 | - | - |
| Selenium (Se) | 0.00317 ± 0.00006 | 0.02 | 0.2 |
| Strontium (Sr) | 0.0732 ± 0.00058 | - | - |
| Barium (Ba) | 0.0202 ± 0.001 | - | - |
| Cerium (Ce) | 0.00125 ± 0.00005 | - | - |
| Bismuth (Bi) | 0.00953 ± 0.00012 | - | - |
| Iron (Fe) | 0.623 ± 0.29 | 5.0-20 | <5.0 |
| Molybdenum (Mo) | 0.044 ± 0.005 | 0.05 | <0.01 |
| Manganese (Mn) | 0.28 ± 0.16 | 0.2 | <0.2 |
| Zinc (Zn) | 0.25 ± 0.07 | 2.0-10 | <2.0 |
| Aluminum (Al) | 0.073 ± 0.006 | 5.0 | <5.0 |
| Lithium (Li) | 0.038 ± 0.004 | - | - |

SD[Y] Standard deviation. FAO[Z] Ayers and Westcot (1994). Dash means no standard developed. BDL Below detection limits.

effective primary and secondary sewage treatment, removes 85 to 90% of the major pollutants in raw sewage water. 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 (Strauss, 2000; USEPA, 1981). In the wastewater, trace metal elements tend to form metal hydroxide, phosphate, carbonate, and other precipitate 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 Gaborone secondary effluent was 0.623, 0.044, 0.28, 0.25, 0.073 and 0.038 $mgL^{-1}$, respectively (Table 1). 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 heavy metals in the Gaborone secondary effluent are micronutients which are beneficial or essential for growth and development of certain crops. Therefore, the use of the Gaborone treated secondary effluent for irrigation will supply both macro- and micro-nutrients needed for plant growth and development, hence reducing fertilizer costs, conservation of drinking water, creation of an alternative water source for irrigation especially in a semi-arid and arid country like Botswana, and its an ecological way of effective wastewater management.

## CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the Gaborone treated secondary effluent is suitable for irrigation of agronomic and horticultural crops. The secondary effluent discharged by Gaborone City Council to Notwane river is low in heavy metals including Hg, Cd, Pb and As which are of concern to human health when they accumulate in the environment. It is recommended that the Gaborone City Council and/or any other government institution should continuously monitor the heavy metal content in the secondary effluent discharged to Notwane river to avoid biomagnification of the pollutants in plant and animal tissues because farmers down stream are using this water for irrigation and watering livestock, and fishing is done along Notwane river and the Phakalane secondary effluent reservoir ponds.

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## REFERENCES

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

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

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 Sciences* 5(3): 451-454

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.

Larsson, A., Haux, C. and Sj¯beck, M .L. (1985). Fish physiology and metal pollution: results and experiences from laboratory and field studies *Ecotoxicological and Environmental Safety* 9: 250-281.

Mason, C. F. (1996). Biology of Fresh Water Pollution. 3rd Edition. England, Longman, 166-356 pp.

Mudassir, I. Z, Aban ,A., Arsala, M. and Farooqui, M. A .(2005). The heavy metal concentration along roadside trees of Quetta and its effects on public health. *Journal of Applied Sciences* 5(4): 708-711.

Nkegbe, E., Emongor, V. E. and Koorapetsi, I. (2005). Assessment of effluent quality at Glen Valley wastewater treatment plant. *Journal of Applied Sciences* 5(4): 647-650.

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

Nyamgababo, J. T. and Hamya, J.W. (1986). The deposition of lead, cadmium, zinc and copper from motor traffic Brachiara enimi and soil along a major Bombo road in Kampala City. International *Journal of Environmental Studies* 27: 1-3.

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

Peakall, D. (1991). Animal Biomarkers As Pollution Indicators. 1st Edition, London, Chapman and Hall, 291 pp.

USEPA. (1981). Process design manual for land treatment of municipal wastewater EPA 625 (1): 13-81 .

Zillioux, E. J., Porcella, D. B. and Benoit, J. M. (1993). Mercury cycling and effects in freshwater wetland ecosystem. *Environmental Toxicology and Chemistry* 12: 2245-2264.