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Effect of sewage disposal on the water quality in Marimba River and Lake Chivero: The case of Crowborough grazing land of Harare, Zimbabwe

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ABSTRACT

The potential impact of effluent (from treated and semi-treated sewage) discharged from Crowborough Sewage Treatment Works on water quality of Marimba River and Lake Chivero was investigated. This was done by monitoring levels of selected physical and chemical water quality parameters in sewage and its effluents sampled over a period of eight months (from January to August). Samples were collected from: raw sewage; digesters; seepage effluent (final effluent from farm to the river), and pond effluent. The sewage quality parameters monitored were ammonia, phosphates, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Sodium Absorption Ratio (SAR) and selected heavy metals: lead (Pb); zinc (Zn); copper (Cu); cadmium (Cd), and chromium (Cr). The variation in mean levels of these pollutants in sewage sludge and seepage effluent were computed using one way Analysis of Variance ($p < 0.05$). The overall quality status of the sewage effluents was evaluated by comparison with the water and wastewater regulations of the Government of Zimbabwe that were set in line World Health Organization (WHO) standards. The concentrations of heavy metals in sewage sludge were higher than in seepage effluent. The concentrations of Cr, Cu and Pb of 0.26, 0.29 and 0.12 mg l⁻¹, respectively, in raw sewage sludge were higher than the recommended limits. The mean concentration of Cr and Pb in digested sludge of 0.34 mg l⁻¹ and 0.16 mg l⁻¹, respectively, also exceeded the standards of limits. Ammonia and phosphate mean concentrations from seepage effluent with 9.36 mg l⁻¹ and 2.74 mg l⁻¹ respectively, were also higher than the recommended standard limits. The mean sodium absorption ratio of 9.00 (meq l⁻¹)^{0.5} in pond effluent exceeded the FAO recommended limits for irrigation wastewater. Effective treatment to tertiary level should be a pre-requisite prior to disposal or else find alternative ways of sewage disposal rather than irrigating pastures since it is indirectly polluting Marimba River, a feeder stream to Lake Chivero which is the major water supplier to Harare residents.

Key words: Crowborough grazing land, sewage quality, receiving water bodies, heavy metals

1. INTRODUCTION

Wastewater treatment facilities have become *sin quo non* in ensuring the discharges of high quality wastewater effluents into receiving water bodies and consequence, a healthier environment (Okoh *et al.*, 2007). Surface and ground water supplies are used to irrigate crops, to provide industrial and drinking water and to act as a sanitation system. Although we as humans recognize this fact, we disregard it by polluting our water resources due to addition of persistent and recalcitrant xenobiotics (Prabu, 2009). The disposal of wastewater should be considered as a matter of urgency across the world. For example, the Thames River in England was once regarded as the 'sewer' of Europe because treated sewage effluent was being discharged directly into Thames causing disastrous effects on the natural water ecosystem (Wells, 1975). In Canada, St Mary's River was listed as one of 43 areas of concern in the Great lakes due to high levels of pollutants discharged from industries and wastewater treatment plants. These elevated levels of pollutants wreaked havoc to the natural ecosystem leading to: loss of fish species richness and diversity, loss of wildlife habitat and eutrophication (Ripley, 2009).

Harare, the capital of Zimbabwe is facing serious water and wastewater management problems (Parawira and Khosa, 2009). Problems of eutrophication have been experienced in Lake Chivero, which was built in 1952 as the principal water supply for the City of Harare (Moyo, 1997). The lake is located downstream from the city, which discharges sewage effluent into three of its tributaries the Mukuvisi, Marimba and Manyame Rivers. It is suspected that eutrophication in the lake is caused by discharge of semi-treated sewage effluent either indirectly through

irrigation on Crowborough grazing land or directly into feeder streams of the lake. A study carried out on nutrient levels in Marimba River has indicated high nitrogen and phosphorous concentration values that exceeded acceptable limits (Nhapi and Tirivarombo, 2004). This excess of plant nutrients results in eutrophication exhibited by overgrowth and decay of water hyacinth (*Eichhornia crassipes*) and aquatic algae (Mathuthu *et al.*, 1997). The processes reduce dissolved oxygen of water to lower levels that cannot sustain life of higher order aquatic animals such as fish.

In developed nations, treatment and discharge systems of sewage can sharply differ between countries and between rural and urban users, with respect to socio-economic income (Doorn *et al.*, 2006). Crowborough sewage treatment works (CSTWs) treats sewage of both domestic and industrial origin (Mathuthu *et al.*, 1995). Domestic wastes are mostly organic solids from toilets and laundry detergents. It is mainly comprised of human wastes, detergents and small trace amounts of laundry and household necessities such as shampoos and pastes. The sewage is also rich in inorganic plant nutrients such as phosphates, potassium and nitrates from domestic and industrial wastes. A number of companies including electroplating and food processing companies located in Western Industrial sites of Harare have their wastewaters treated at the plant (Baggs *et al.*, 2001). The industrial activities of all companies result in wastewaters enriched in trace heavy metals, oils, detergents and other organic species (Mathuthu *et al.*, 1995). Crowborough Irrigation farm has 305 hectares of irrigated pastures for cattle grazing in Marimba sub-catchment area (Nhapi *et al.*, 2002). The pastures are flood irrigated either with effluent alone or effluent mixed with sewage sludge from CSTWs (Nhapi, 2008). Disposal of effluent through pasture irrigation presents a number of problems on receiving Marimba R and L. Chivero. Some of the effluent from the farm is disposed as surface run-off in Marimba R. Cumulative loading of wastewater pollutants on soils leads to groundwater pollution and subsequent leaching into the lake (Nhapi, 2008). There is lack of information on the effects of irrigating Crowborough pastures with wastewater from CSTWs on water quality status of Marimba R and L. Chivero. In this study, the contribution of CSTWs to Marimba River and Lake Chivero pollution through sewage sludge disposal on Crowborough Farm was estimated.

2. MATERIALS AND METHODS

2.1 STUDY SITE

Crowborough Sewage Treatment Works (CSTWs) is located near the high-density suburb of Mufakose, right in the capital city of Zimbabwe, Harare. The CSTWs receives sewage from the surrounding high-density suburbs of Budiriro, Kuwadzana, Crowborough, Dzivarasekwa and Kambuzuma. Industrial effluent from the Workington and Willowvale industrial areas is also treated at CSTWs. The plant receives sewage whose origin is of both domestic and industrial and treatment is based on activated sludge system. The treated final pond effluent is used to irrigate pastures at the farm and discharged as seepage effluent into Marimba River.

2.2 SAMPLING

Sample collection was done twice per month from January to August between 0900 hrs and 1200 hrs. Grab samples (n=13) were collected using sterile 1-litre polythene bottles (rinsed with distilled water and own sample prior at the sampling site) from: raw sewage sludge, seven primary digesters and one secondary digester; pond effluent, the final effluent to the pastures at CSTWs; and seepage in pastures to the river at points denoted by Northeast 1, North, West and East 4 of Crowborough Farm. Samples were carried to the laboratory in an ice cooler box to maintain a temperature of less than 4 °C.

2.3 EXPERIMENTAL

Sewage sludge and seepage effluent samples were pre-digested in nitric acid and perchloric acid within 24 hrs. The concentrations of heavy metals were then determined using an atomic absorption spectrophotometer (LAAS-210) within 72 hrs. Physico-chemical parameters were analysed within 24 hrs from collection. Ammonia was determined calorimetrically by measuring the intensity of colour developed by the reaction of ammonia with Calgon solution in the presence of Nessler's reagent. Phosphates in sewage samples were determined calorimetrically as orthophosphate by comparing the intensity of the colour developed after ten minutes by standard phosphate. The pH of seepage effluent was determined using Mettler Toledo universal Pocket Meter following checking and calibration according to manufacturer's instructions. Chemical Oxygen Demand (COD) levels were determined by refluxing the samples in a condenser and titrating against ferrous ammonium sulphate using ferroin indicator. Biological Oxygen Demand (BOD) levels were measured by incubating the water samples for five days in tightly stoppered bottles in the dark and determining the oxygen consumed in five days. Sodium Absorption Ratio (SAR) in pond effluent was obtained by measuring the concentration of sodium, calcium and total hardness (TH). Sodium concentration was determined using flame spectrophotometer. TH was determined by adding TH buffer solution to the sample and titrating against EDTA using Eriochrome Black TH indicator. Calcium level was determined by adding sodium

hydroxide buffer to the sample and titrating against EDTA using calcein indicator. Since TH is the sum of calcium and magnesium concentrations, magnesium concentration was taken as the difference between TH and Ca. The final SAR was then calculated from the formula: $SAR = Na^+ / (Ca^{2+} + Mg^{2+})^{0.5}$.

2.3 DATA ANALYSIS

The mean variation concentrations of heavy metals in raw sludge, digested sludge and seepage effluent were computed using one way Analysis of Variance (ANOVA). Comparing with water and wastewater regulations of the Government of Zimbabwe and FAO using descriptive statistical analysis (95 % confidence limit) did the overall quality control.

3. RESULTS

3.1 HEAVY METALS

The concentrations of heavy metals in sewage sludge were higher than in seepage effluent except Zn which was higher in seepage effluent than sewage sludge. Copper had the highest concentration among the six metals of 2.33 mg l^{-1} with a range of 1.79 to 2.33 mg l^{-1} in raw sewage sludge. The lowest concentrations of heavy metals were recorded in seepage effluent. The concentrations of Cu, Cr, and Zn in seepage effluent were the lowest with non-detectable concentrations under experimental conditions. Results for the concentrations of heavy metals in raw sludge, digested sludge and seepage effluent are shown in figure 1.

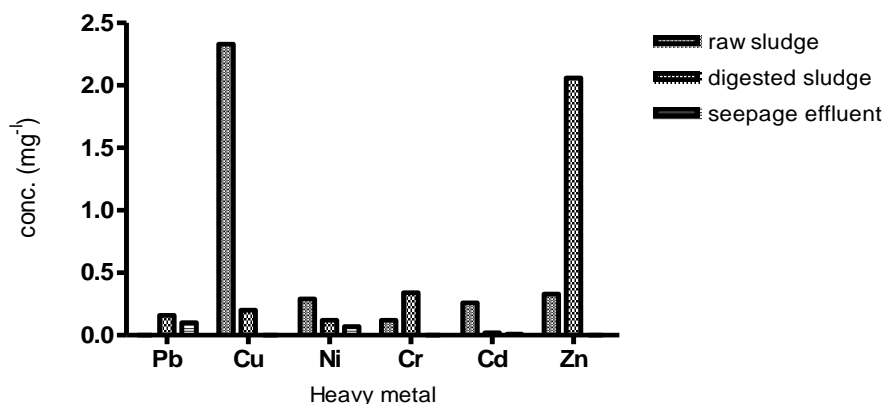


Fig.1. Mean concentrations of heavy metals in raw sewage sludge, digested sludge and seepage effluent.

3.2 PHYSICO- CHEMICAL PARAMETERS

The pH of seepage effluent was 7.37 and slightly above the neutral point. Phosphates were high with mean concentration of 2.74 mg l^{-1} and a range of 1.66 to 3.82 mg l^{-1} . The concentration of ammonia with a mean of 9.36 mg l^{-1} was very high and ranged from 3.17 to 15.55 mg l^{-1} . The Biological Oxygen Demand of 15.36 mg l^{-1} was very low in seepage effluent. The mean concentration of Chemical Oxygen Demand ranged from 53.30 to 122.08 mg l^{-1} with a mean of 87.69 mg l^{-1} in seepage effluent. The SAR of pond effluent had a mean concentration of 9.00 and ranged from 8.71 to $9.21 (\text{me l}^{-1})^{0.5}$. Table 1 shows a summary of the mean concentrations of physico-chemical parameters of sewage effluents.

Table 1. Mean concentrations of physical and chemical parameters of seepage and pond effluent (\pm standard error).

Parameter	Mean concentration(\pm standard error)
pH (pH units)	7.37 \pm 0.00
Phosphates (mg l ⁻¹)	2.74 \pm 1.08
Ammonia (mg l ⁻¹)	9.36 \pm 3.16
BOD (mg l ⁻¹)	15.20 \pm 7.84
COD (mg l ⁻¹)	87.69 \pm 39.98
SAR (me l ⁻¹) ^{0.5}	9.00 \pm 0.41

4. DISCUSSION

4.1 HEAVY METALS

Generally, the concentrations of heavy metals reported in raw sewage sludge were significantly higher than in digested sewage sludge which was in turn higher than in seepage effluent. This might be probably due to effective bio-sorption, a metabolism-independent binding of heavy metals to living cells, non-living biomass, or microbial extracellular during biological treatment at CSTWs (Chipasa, 2003). According to Kulbat *et al.* (2003) heavy metals can be actively bound to living organisms by means of intracellular accumulation, extracellular precipitation and chemical transformations catalysed by these microorganisms such as oxidation, reduction, dimethylation and methylation. The above mechanisms might explain the difference in heavy metal concentrations between raw sewage and sludge effluents.

The metals, Zn and Cu showed no significant difference in concentrations in seepage effluent and sewage sludge may be because of failure to precipitate to complexes that are able to settle down during biological treatment. The concentrations of Cr and Pb in digested sludge and Cr, Pb and Cu in raw sludge were higher than the acceptable levels of water and wastewater regulations of the Government of Zimbabwe (Cr \leq 1.0; Pb \leq 0.05; and Cu \leq 1.0 mg l⁻¹). The elevated levels of these heavy metals reported signals high hazards of pollution on receiving Marimba R. and L. Chivero waters. Heavy metals are toxic to higher organisms, plants and microorganisms at specific concentrations. They strongly affect microbial activity by inhibiting nitrification, denitrification and microbial oxidation processes in biological wastewater treatment (Chipasa, 2003). Metals such as Pb are toxic to microorganisms even at low levels therefore have negative effects on growth of water microorganisms thus depressing their numbers (Sa'idi, 2010). The toxicity of heavy metals in biological treatment mainly depends upon metal species and its concentration though to a lesser extent, factors such as pH, sludge concentration and influent strength also have an effect (Sa'idi, 2010). The possible sources of these metals are industrial activities like electroplating in western industrial sites of Harare and some traces from household activities like washing, cooking, bathing and so on. (Mathuthu *et al.*, 1995). Corrosion of aging pipes might also have contributed some traces of metals to the sewage and its effluent.

However, the use of CTSWs wastewater for pastures irrigation is justified despite its potential to increase soil metal content and health hazard impacts on receiving water bodies. Wastewater is useful for irrigation to replace the scarce water resource and utilize the high nutrient content thus reducing the cost of fertilizers. Irrigation using wastewater is also one of the cheapest ways of sanitary disposal of municipal waste (Madyiwa, 2006).

4.2 PHYSICO- CHEMICAL PARAMETERS

The noted seepage effluent pH range of 6-9 was within the acceptable limits in Zimbabwe. The pH had no significant negative effects to public health and biota on receiving water bodies as most of microorganisms and other higher order organisms thrive in alkaline pH. The mean concentration of ammonia was notably higher than the acceptable limits of the Government of Zimbabwe (\leq 0.5 mg l⁻¹). This signals high hazards on receiving water bodies. The high level of ammonia might be due to the following activities in Workington industrial area: fertilizer residues from fertilizer manufacturing companies, animal feed production and in manufacture of fibres, plastic, paper, rubber, batteries, metal processing and food production (WHO, 1996). Ammonia either in the free un-ionized form or as ionized ammonia is a common pollutant. The toxic effects of ammonia are directly related to the concentration of un-ionized form and the ammonium ion has little or no toxicity (Williams, 1987). Ammonia is not stable under aerobic conditions as it is quickly oxidized to nitrate. Thus ammonia can increase the level of nitrates on receiving water bodies resulting in overgrowth of aquatic weeds which when die off, decaying results in deoxygenation (increased biological activity) leading to eutrophication. According to Burke and Thornton (1995), deoxygenation and the accumulation of ammonia in the hypolimnion was a result of the L. Chivero's eutrophic status and was the cause for massive fish kills at the time of turnover.

Phosphates were very high exceeding the recommended limits of $\leq 0.5 \text{ mg l}^{-1}$. This again signals high hazards on receiving water bodies. High levels of phosphates might be due to the use of phosphate additives in detergent formulations, which can be disposed in domestically or industrially generated wastewater (Olajire and Imeokparia, 2001). Nitrogen in form of ammonia (NH_3) and nitrates (NO_3^-) and phosphorous are essential nutrients for plant growth (Igbinosa and Okoh, 2009). The excess of these plant nutrients stimulate overgrowth of aquatic weeds such as algal blooms which when decaying results in deoxygenation (excessive production of COD and loss of oxygen resources) and eutrophication, changes in aquatic population and subsequent deterioration of water quality (Igbinosa and Okoh, 2009). Eutrophication could adversely reduce the utility of L. Chivero water for recreation purposes as macrophytes will cover large areas blocking access to water ways. In addition, it can cause scum which could lead to growth of blue-green algae that release cyanotoxins poisonous to livestock in water systems (Igbinosa and Okoh, 2009).

The BOD of seepage effluent was within the acceptable limits of $\leq 30 \text{ mg l}^{-1}$. This low BOD is usually associated with low activities of organic matter decomposition by bacteria and fungi therefore can support the growth of aerobes. The lower BOD concentration means high dissolved oxygen concentration therefore support fish and other forms of aquatic life on disposal in water bodies. The COD of seepage effluent was higher than the Government of Zimbabwe recommended limits of $\leq 60 \text{ mg l}^{-1}$. This is associated with high oxygen demand by microbes to oxidize non-abiotic (e.g heavy metals) components of the sediments. High COD reduces the dissolved oxygen on receiving Marimba R and L Chivero waters to levels that can harm aquatic life especially fish.

Sodium Absorption Ratio (SAR) is used to determine the sodium hazard to irrigation waters. The SAR of 9.00 (me l^{-1})^{0.5} reported for pond effluent (the final effluent to the pastures) was three times higher than FAO acceptable limit of 3 (me l^{-1})^{0.5} for long term irrigation. There is the predisposition for soils to become saline by the re-use of salt rich wastewater for irrigation on the farm (Samaila *et al.*, 2011). Continued use of pond effluent with high SAR may lead to breakdown in physical structure of soil. Saline soils in advanced stage inhibit plant growth rate by reducing the ability of plants to take up water and damage cells in transpiring leaves as a result all vegetation including pastures is killed and leads to barren land (Ghassemi *et al.*, 1995). On receiving water bodies, highly saline wastewaters can affect biota in freshwater resulting in loss (or gain) of species (Nielsen *et al.*, 2003).

5. CONCLUSION

Since the concentrations of ammonia, phosphates and COD in seepage effluent and Cr, Cd and Pb in sewage sludge were higher than the recommended limits, the treatment process and pastures were not effective in reducing their levels. Therefore, modern technologies and treatment to tertiary level should be a pre-requisite prior to disposal. On the other hand, levels of Ni, Zn, Cu, pH and BOD studied were within the recommended limits, suggesting that the sewage treatment process and phytoremediation were effective in controlling their levels. Continuing to irrigate with pond effluent might result in salinisation of the soil at the farm as indicated by pond effluent with high SAR. Addition of Ca^{2+} salt such as gypsum to the effluent before irrigation is recommended to lower the sodium hazard which the farm is more likely to face. There must be strict enforcement of Trade and Waste effluent regulations so that the industrial wastes directed into city's sewers are of acceptable quality. Imposition of stiff penalties to those who do not comply with standard limits and development of industrial policies will ensure that there is no illegal discharge of toxic wastes into streams. This would remove the contribution of sewage effluents to the pollution of Crowborough farm soils, Marimba River and Lake Chivero.

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