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Research Paper

Assessment of Heavy Metals in Treated Wastewater Used for the Irrigation of Vegetable Plants in Arusha City

***Furaha M. Chuma, Kelvin M. Mtei & Karoli N. Njau**

Department of Water and Environmental Sciences and Engineering, Nelson Mandela African Institution of Science and Technology, P.O Box 447, Arusha, TANZANIA

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Abstract: *The scarcity of fresh water has promoted a growing interest in the reuse of treated wastewater for irrigation activities. However, treated wastewater reuse has been associated with contamination of the soil and plants by heavy metals. This study investigates the levels of Chromium (Cr), Manganese (Mn), Iron (Fe), Zinc (Zn) and lead (Pb) in the treated wastewater from Arusha city waste stabilization ponds and its suitability for the irrigation of edible crops. The influent to the facultative pond and the effluent of the last maturation pond were sampled and analysed for Cr, Mn, Fe, Zn and Pb by using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). Similarly sludge from the facultative, first maturation and the last maturation ponds were collected and analysed for the same heavy metals using Energy Dispersive X-ray fluorescence spectrometer (EDXRF). The results indicated that the concentration of Cr, Zn and Pb in the sludge decreases from the facultative to the last maturation pond while that of Mn and Fe increases from facultative to last maturation pond. The heavy metal contents in the sludge were significantly higher than in the water column. Furthermore it was revealed that there was a significance difference of Cr, Fe and Zn concentration between the influent to facultative pond and the effluent of last maturation pond while the difference of Pb and Mn concentration between the influent to facultative pond and the effluent of last maturation pond was insignificant. The concentration of Cr, Mn, Fe, Zn and Pb in the treated wastewater was 0.19 mg/L, 0.16 mg/L, 0.17 mg/L, 0.03 mg/L and 0.1 mg/L for Cr, Mn, Fe, Zn and Pb respectively. The ability of Arusha waste stabilization ponds on the removal of heavy metals from the wastewater is relatively low leading into the discharge of partially treated wastewater with the Cr concentration above the prescribed limit (0.1 mg/L) of Food and Agriculture Organization of United Nations (FAO) for irrigation water. Thus the use of treated wastewater from Arusha waste stabilization ponds for irrigation may results into the contamination of soil and cultivated crop by heavy metals.*

Keywords: Heavy metals, Irrigation, Treated wastewater, Waste stabilization pond.

Introduction

Agricultural activity is a key of food security in the world as well as an economic activity supporting country development and livelihood of many families. Unreliable rainfalls resulted from climate change cause the agricultural activities to depend on irrigation instead of rain-fed [1]. However, fresh water scarcity arises from increasing demand of water resources, pollution of water sources, overexploitation of groundwater and periodic droughts due to climate change affects the irrigation practices and threatens the development and sustainability of agriculture [2]. Thus, treated wastewater has been identified as a practical solution for overcoming water scarcity and supporting the agricultural production [1].

Treated wastewater is a reliable and valuable water source in urban agriculture [1]. Apart from providing moisture content, it also contains essential nutrients and organic matter for plant growth leading into increased crop yield [3]. In spite of being important water sources for urban agriculture, treated wastewater is a marginal water source which may contain undesirable constituents such as pathogens, organic and inorganic constituents including heavy metals [4]. Heavy metals in the treated wastewater are of most concern as they are non-biodegradable, accumulated in the environment, biomagnified along the food chain and posing health risk to living organism [5].

Municipal wastewater treatment facilities receive effluents from residential dwellings, commercial premises, industries and urban runoff. The wastewater may contain heavy metals such as Zinc (Zn), Chromium (Cr), Manganese (Mn), Lead (Pb), Cadmium (Cd), Mercury (Hg) Nickel (Ni) and Iron (Fe) [6]. The removal of heavy metals from wastewater by wastewater treatment facilities depends on the concentration of heavy metals in the influents, speciation of the metals and efficiency of the treatment facility in removing heavy metals [7, 8]. Making treated wastewater reuse of a beneficial and preventing short term and long-term detrimental environmental impact and health risk associated with the heavy metals, the treatment facility has to effectively remove the heavy metals and produce the effluents that meet the desirable standards for irrigation purposes [4,5].

Waste stabilization pond is the preferable wastewater treatment in the developing countries especially in tropical and subtropical region as it is inexpensive system in terms of capital and maintenance costs. The pond is designed for the removal of organic matter, oxygen demand wastes, nutrients, pathogens and fecal coliform [9]. The removal of heavy metals by waste stabilization ponds is through sedimentation of wastewater solids, adsorption into algal or bacteria biomass, adsorption into bottom sludge, bioaccumulation into algal or bacteria biomass, and precipitation [10]. However, the adsorption of heavy metals into the biomass depends upon the metal speciation and concentration, reactivity of the biomass and the composition of other wastewater component [7]. Also precipitation of heavy metals depends on available pH [7]. Thus, efficiency of waste stabilization ponds in the removal of heavy metals depends upon the physical-chemical form of the metals and their response to the physical and biological treatment process [11]. Ling et al. 2010 [17] reported that efficiency of waste stabilization ponds in the removal of Zn, Cd, Pb, Ni and Cr from wastewater was quite low. Ustun et al. 2009[12] also reported that the removal of Cd, Mn and Pb by wastewater stabilization pond was relatively low. Partially treated wastewater may contain significant amount of heavy metals and its use for the irrigation may result into the accumulation of heavy metals in the soil and irrigated plants, it may also contaminate the groundwater or render the field useless [10]. On the other hand, with proper management of waste stabilization ponds, the effluents can be used for agriculture activities although continuous monitoring is needed to identify any changes in the effluent quality [13].

The concentrations of heavy metals in the treated wastewater used for irrigation have to be known and meet the required standards so as to avoid the short term and long term negative impact [4]. The treated wastewater from Arusha city waste stabilization ponds is being used for irrigating edible crops especially vegetable plants [14]. However, the concentrations of heavy metals in the treated wastewater from these ponds are so far unknown. Therefore, this study aims to investigate the heavy metal contents in the treated wastewater and its suitability for irrigating edible crops.

Material and Methods

Study area

This research was conducted in municipal wastewater treatment facility located in Northern East of Arusha city at latitude $3^0$23'S, $36^0$41'E in Lemara ward (Fig.1). The facility was put into operation since 1985, it is a series of waste stabilization ponds consisting of one anaerobic pond, two in parallel facultative ponds (FP) and two in series maturation ponds (Fig.2). The wastewater from domestic, industries including food processing industries, beverage industries, textile industries and iron steel processing industries and commercial premises such as garages and hospitals are discharged into the anaerobic ponds through direct municipal sewerage system as well as through cesspit emptier (Fig.1). The average flow rate is 4,350 m^3/day during dry season and 5,430 m^3/day during rainy season (AUWASA, 2012).

Water Sample Collection and analysis

Water samples from the inlet of facultative pond (Figure 2- P_1) and outlet of the last maturation pond (LM) (Figure 2-P_2) of Arusha city waste stabilization ponds were collected once per week between June and August 2014. Besides, fresh water from taps and wells were collected as a control samples. Samples were collected in a 1 liter pre-cleaned polyethylene sample container and after collection a drop of conc. HNO_3 was added into the sample to attain a pH of 2. Thereafter, the samples were then labelled, transported to NM-AIST laboratory and stored in a refrigerator at a temperature of 4^{o}C waiting for the analysis. Inductive Couple Plasma Optical Emission Spectrometer (ICP-OES) was used for the analysis of heavy metals. The physicochemical parameter of the water sample that is Temperature, pH, and Total Dissolved Solid (TDS) were determined on-site by using a thermometer, Hanna pocket pH meter (HI96107) and TDS meter (HI98129).

Sludge sample collection, preparation and analysis

The sludge samples were collected from the facultative, first maturation and last maturation ponds (Figure 2 - P_3, P_4 & P_5). The samples were sun dried for 9 hrs and then oven dried for 24hrs at 80^{0}C in a Heraeus Thermo Scientific oven. The samples were then ground using Pulverisette 6 Planetary mono-mill to achieve a fine powder of less than 150µ diameter and pressed into a pellet of 32 mm diameter using Retsch Hydraulic Press and analyzed for heavy metal content by using Spectro Xepos Energy Dispersive X-ray Fluorescence spectrometer (EDXRF).

Statistical analysis

The Statistical Package for Social Sciences (SPSS Version 20) was used to analyse data. The paired T-test ($P<0.05$) was used to test the difference of heavy metals content between the influent to the facultative pond, treated wastewater and the control. Also the paired T-test was used to test ($P< 0.05$) the difference between the heavy metals in the water and the sludge.

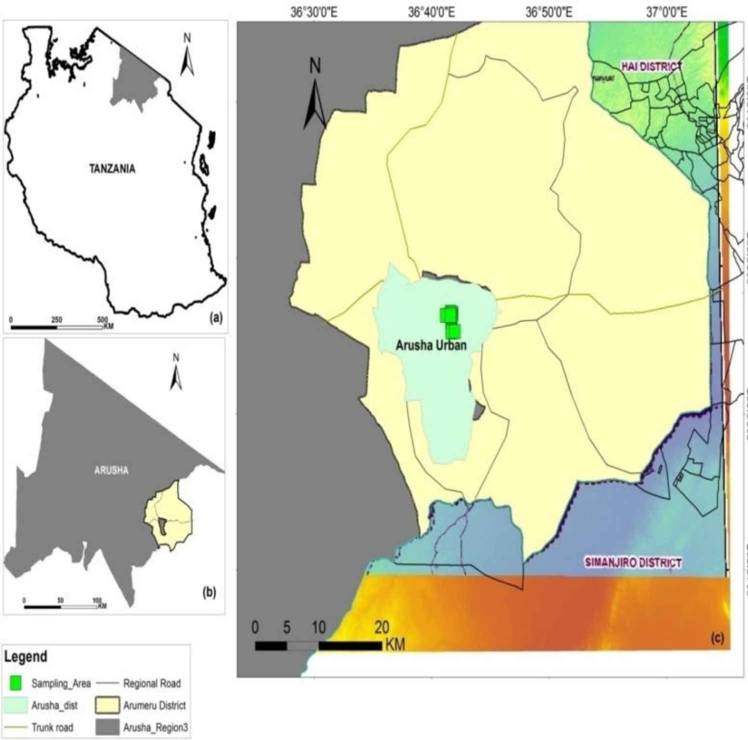

Figure 1: Location of Arusha city waste stabilization pond as a sampling area

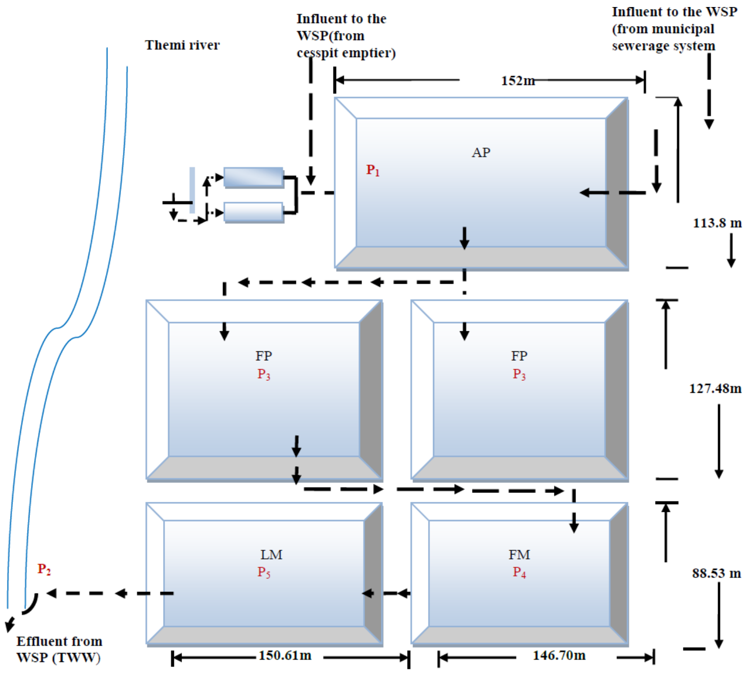

Figure 2: Layout of Arusha city waste stabilization ponds

P_1, P_2, P_3, P_4, and P_5 are - sampling points, AP-Anaerobic pond: FP-Facultative pond: FM-first maturation pond: LM-Last maturation pond: TWW-Treated wastewater: WSP-Waste stabilization pond

Results and Discussion

Physicochemical parameters of the influent to the facultative pond, treated wastewater and Control

The mean value of Temperature, TDS (Total dissolved solid) and pH for the influent to the facultative pond, treated wastewater and the control sample are shown in Table 1. Results in Table 1 show that there was no significance difference of temperature between the influent to the facultative pond, treated wastewater and control. The mean value of temperature for the influent to the facultative pond, treated wastewater and control was 21^{o}C, 22^{o}C and 20^{o}C respectively. The difference of TDS value (Table 1) for the influent to the facultative pond and the treated wastewater was not significant ($P<0.05$) while the TDS value for the control was significantly lower ($P<0.05$) than that of the influent to the facultative pond and the treated wastewater. The mean value of TDS for the influent to the facultative pond, treated wastewater and control was 1235.66 mg/l of 1210.67 mg/l and 370.33 mg/l respectively. Similarly, results in Table 1 indicate that there was no significance difference (P< 0.05) of pH between the treated wastewater and the control whereas the difference of pH between the treated wastewater and the influent to the facultative pond was significant (P<0.05). The mean value of pH for the treated wastewater, influent to the facultative pond and control was 8.01, 7.25, and 7.75 respectively. The pH and TDS value for treated wastewater and control were within the acceptable range of 6.5-8.4 for pH and below 2000 mg/l for TDS as per FAO standards for the irrigation water.

Table 1: Physicochemical parameters of the influent to the facultative pond, treated wastewater and control

	Temperature (^oC)	TDS (mg/l)	pH
Influent to Facultative pond	21 ± 1.62 ^{a}	1235.66 ± 114^a	7.25 ± 0.16 ^{b}
Treated wastewater	22 ± 1.49 ^{a}	1210.67 ± 69^a	8.01 ± 0.25 ^{a}
Control	20 ± 0.35 ^{a}	370.33 ± 110.87^b	7.75 ± 0.14 ^{a}
FAO standards	-	<2000	6.5-8.4

The values are the mean of 8 samples, Values of the same letter in a column are not significantly different (P<0.05), TDS- Total Dissolved Solid, FAO-Food and Agriculture Organization of United Nations

Concentration of heavy metals in the influent to the facultative pond, treated wastewater and control

The mean value of heavy metals concentration in the influent to the facultative pond, treated wastewater and the control are presented in Table 2. Data in Table 2 illustrate that the concentration of Cr (1.01 mg/l), Fe (0.77 mg/l) and Zn (0.05 mg/l) in the influent to the facultative pond were significantly higher (P<0.05) than in the treated wastewater with the corresponding value of 0.19 mg/l, 0.17 mg/l and 0.03 mg/l for Cr, Fe and Zn respectively. The concentration of Mn (0.17 mg/l) and Pb (0.1 mg/l) in the influent to the facultative pond were not significantly different (P<0.05) compared to that in the treated wastewater with the mean value of 0.16 mg/l and 0.1 mg/l for Mn and Pb respectively. The concentration of Cr, Mn, Zn and Pb in the control (Table 2) was below the detection limit of 0.01 mg/l while that of Fe was 2.04 mg/l which was significantly higher than that of the influent to the facultative pond and the treated wastewater. The concentrations of heavy metals in the influent to the facultative pond and in treated wastewater were in the order of Cr>Fe>Mn>Pb>Zn.

Findings revealed that both facultative and maturation ponds were unable to remove Mn and Pb metal from the wastewater. The obtained value of Mn, Fe, Zn and Pb in the treated wastewater were within the permissible level of 0.2 mg/l, 5 mg/l, 2 mg/l and 5 mg/l for Mn, Fe, Zn and Pb respectively as per FAO standards for heavy metals in the irrigation water (FAO, 1992). However, there is high possibility for Mn in the treated wastewater to exceed the maximum acceptable level for irrigation water with the fact that, Mn level in the treated wastewater was closely to the maximum acceptable level for irrigation water and also the ponds was unable to remove the Mn content in the wastewater . The discharge of untreated effluents from iron steel company was probably the reason for the Mn metal in the waste stabilization ponds and treated wastewater [15]. Similarly, the concentration of Cr in the treated wastewater was above the permissible level of 0.1 mg/l for the irrigation water [4]. The higher value of Cr in the treated wastewater was probably caused by the discharge of untreated textile industrial effluent into waste stabilization ponds. This was also reported by [16] who found that both treated and untreated effluent from textile industries was the main source of Cr contamination in the water bodies. In addition, the availability of Cr in the treated wastewater was probably caused by its mobility characteristic as it was reported by [17], who found that the removal of Cr from pig farm wastewater was only 9%. The obtained value of Cr in this study was higher than those of Dar es Salaam waste stabilization ponds [18]. Furthermore, the concentration of Cr, Pb and Zn in the treated wastewater was higher than those reported by [13] on heavy metal characteristics of waste stabilization pond.

Table 2: Concentration of heavy metals in the influent to facultative pond, treated wastewater and control

	Cr (mg/l)	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Pb (mg/l)
Influent to FP	1.01 ± 0.44^b	0.17± 0.01^a	0.77 ± 0.09^b	0.05 ± 0.009 ^{b}	0.1 ± 0.01^a
TWW	0.19 ± 0.02^a	0.16 ± 0.01^a	0.17 ± 0.03^a	0.03 ± 0.008 ^{a}	0.1 ± 0.02^a
Control	<0.01	<0.01	2.04 ± 0.78	<0.01	<0.01
FAO standards	0.1	0.2	5	2	5

The values are the mean of 8 samples. Values of the same letter in the column are not significantly different (P<0.05), FP-Facultative pond, TWW-Treated wastewater, FAO- Food and Agriculture Organization of United Nations, Cr-Chromium, Mn-Manganese, Fe-Iron, Zn-Zinc, Pb-lead

Heavy metals concentration in the sludge

- **Chromium, Zinc and Lead**

The concentration of Cr, Zn and Pb in the sludge from facultative, first maturation and last maturation ponds is presented in Figure 3, Figure 4 and Figure 5. The concentration of Cr, Zn and Pb in the sludge shows a decrease trend from the facultative pond to the last maturation pond with the highest value of 620.02 mg/kg, 1191.96 mg/kg and 53.78 mg/kg for Cr, Zn and Pb in facultative pond and lowest value of 159.64 mg/kg, 335.77 mg/kg and 30.78 mg/kg for Cr, Zn and Pb in the last maturation pond.

- **Manganese and Iron**

The concentration of Mn and Fe in the sludge from facultative, first maturation and last maturation ponds is presented in Fig. 6 and Fig. 7. Mn and Fe concentration in the sludge shows an increase trend from facultative pond to the last maturation pond with the highest value of 1683.92 mg/kg and 61014.70 mg/kg for Mn and Fe in the last maturation pond and lowest value of 1122.71 mg/kg and 48909.18 mg/kg for Mn and Fe in the facultative pond. In wastewater treatment system, heavy metals usually do not disappear, they are either settled down in the sludge or remain in the water column [10]. This study found that the heavy metal content in the sludge pond was significantly higher than in the water column. The sludge decomposition may occur and result into the release of heavy metals in the water column [10], this bring the possibility of increasing heavy metal content especially Mn and Fe in the treated wastewater.

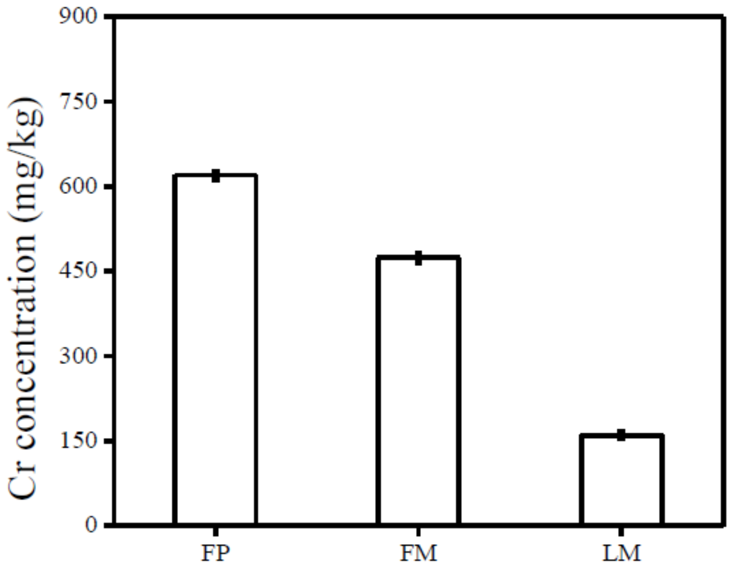

Figure 3: Chromium (Cr) concentration in the sludge from facultative, first maturation and last maturation ponds
Bar line indicating standard error, FP-Facultative pond, FM-First maturation pond, LM-Last maturation pond

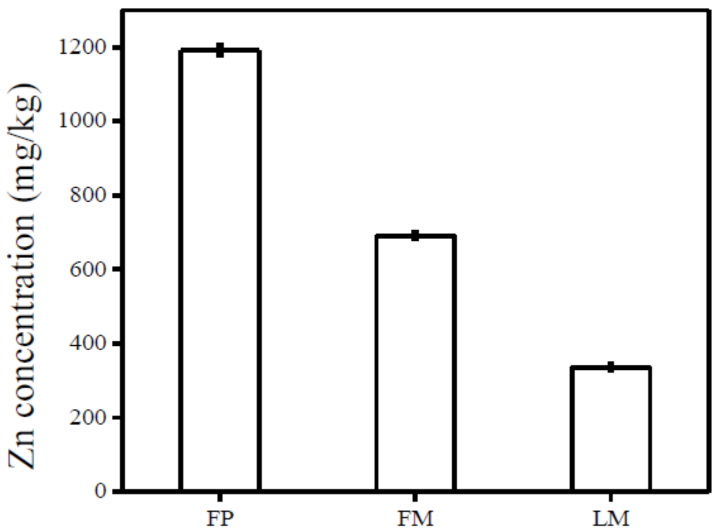

Figure 4: Zinc (Zn) concentration in the sludge from facultative, first maturation and last maturation ponds
Bar line indicating standard error, FP-Facultative pond, FM-First maturation pond, LM-Last maturation pond

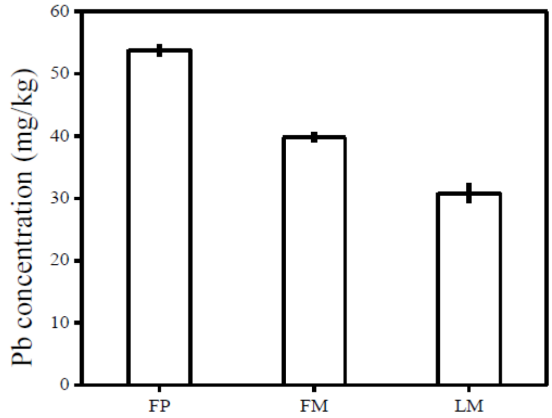

Figure 5: Lead (Pb) concentration in the sludge from facultative, first maturation and last maturation ponds
Bar line indicating standard error, FP-Facultative pond, FM-First maturation pond, LM-Last maturation pond

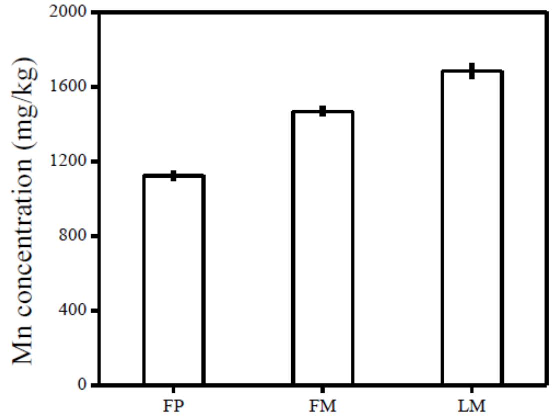

Figure 6: Manganese (Mn) concentration in the sludge from facultative, first maturation and last maturation ponds
Bar line indicating standard error, FP-Facultative pond, FM-First maturation pond, LM-Last maturation pond

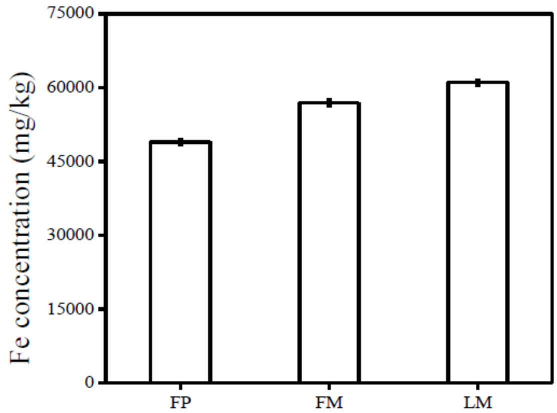

Figure 7: Iron (Fe) concentration in the sludge from facultative, first maturation and last maturation ponds
Bar line indicating standard error, FP-Facultative pond, FM-First maturation pond, LM-Last maturation pond

Conclusion

Arusha waste stabilization ponds are unable to polish the wastewater into the desirable level for irrigation, thus the long-term use of treated wastewater from Arusha waste stabilization ponds in the agricultural soil may result into the accumulation of heavy metals in the soil and grown plants. In regard to this, monitoring of the treated wastewater has to include heavy metal parameters so as to avoid any environmental impact which might arise by

discharging partially treated wastewater to the environment. Also the industrial wastewater should be pre-treated at the site of the industry rather than mixed with the municipal wastewater. Lastly the management of Arusha waste stabilization ponds has to be improved to avoid further environmental pollution.

Acknowledgment
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