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THE PERFORMANCE OF THE SELECTED WASTE STABILIZATION PONDS IN DAR ES SALAAM, TANZANIA IN REMOVING HEAVY METALS

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Abstract: This study investigated the performance of the selected Waste Stabilization Ponds (WSPs) in Dar es Salaam. The concentrations of heavy metals (Pb, Fe, Cu, Zn, Mn and Cr) in influents, effluents and sludge of University of Dar es Salaam-UDSM, Mabibo, Vingunguti industrial, and Mikocheni (WSPs) as well as the influence of pH on the concentrations of heavy metals in laboratory prepared effluents were determined. The samples of influents and effluents were respectively taken at inlets and outlets of the WSPs, while sludge samples were taken randomly as grab samples from the WSPs then mixed into composite samples.
The mean physical parameters; temperature, pH, TDS and EC of the WSPs were also determined and found to be within the working conditions of the WSPs. The mean concentrations of all heavy metals in effluents (0.0013 – 0.4293 mg/L) after treatment in the WSPs were lower compared to that of the influents (0.0037 – 7.11 mg/L) and were within permissible values according to TBS (2005) standards for effluent discharges to receiving environments. The mean concentrations of all heavy metals in the sludge from all WSPs except Pb (601.5 mg/kg) and Zn (14903 mg/kg) from UDSM WSPs were in compliance with the EPA permissible limits for sludge reuse on soil.
The concentration of heavy metals in laboratory prepared effluents decreased with increasing pH to the point at which no further decrease in the heavy metal concentration took place. In general the findings show that the studied WSPs perform well in removing heavy metals.
Keywords: Heavy Metals, Waste stabilization Ponds, Concentrations, Influents, Effluents, Sludge, Receiving environments.

INTRODUCTION

Urbanization and rapid industrialization in many cities throughout the world as a result of an increase in population density has led to an increase in domestic and industrial effluents that are discharged into receiving water bodies each day (Akpor, 2011). The use of water for domestic and industrial processes has also increased to higher magnitudes which result in considerable accumulation of wastes with diverse contaminations (Mansouri and

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Ebrahimpour, 2011). Wastewater may contain all sorts of chemical and biological pollutants which include nitrogen, phosphorus, heavy metals, detergents, pesticides, hydrocarbons, viruses, bacteria, and protozoa obtained before being discharged into the treatment plant. However, these chemicals such as heavy metals (As, Cd, Cr, Cu, Pb, Hg, Zn and Fe) and biological pollutants if not treated properlythey may cause deleterious effects to organisms and the environment (Mansouri and Ebrahimpour, 2011; Akpor, 2011; Nziku and Namkinga, 2013).

Increased volumes of wastewater sludge from treatment processes has also attracted attention on heavy metals and other toxic materials present in the sludge for the requirement of its safe reuse or disposal to the environment (Nelson et al., 1981). The detrimental effects from contaminants in discharges from wastewater treatment systems may include death of aquatic life, formation of algal blooms, and devastation of habitat by sedimentation, debris, and increased water flow (Nelson et al., 1981). Not only that but also, acute and chronic toxicity from chemical pollutants caused by bioaccumulation and biomagnification at superior trophic levels becomes eminent (Akpor, 2011; Karvelas et al., 2003).

Treatment of wastewater is a fundamental component in any community to safeguard the health and the environment of communities (Akpor, 2011).The processes for removing pollutants in wastewater can be chemical or biological. The biological treatment process has an advantage that it utilizes microorganisms, which has an ability to facilitate the removal of pathogens (WHO, 1987; Akpor, 2011).

Many developing countries such as Tanzania use WSPs to treat wastes in wastewater and sludge before being discharged into environments (Kayombo et al., 2005; WHO, 1987; Rose, 1999; Varón and Mara, 2004). Since some toxic materials are degraded by biological treatment, heavy metals are not, they remain in effluents which are gradually released into water bodies and in sludge which is disposed on land or used as fertilizers in agricultural soils or horticultural units (Stylianou et al., 2007; Travieso et al., 1999). At certain concentrations, heavy metals also affect treatment efficiencies in WSPs (Ramadhan and Ponce, 1999; Chipasa, 2003).

In Tanzania, Dar es Salaam in particular, many studies on heavy metals have indicated the presence of heavy metals in various sites at significant levels (Bahemuka and Mubofu, 1999; Mwegoha and Kihampa, 2010; Othman, 2001; Ngassapa et al., 2010). Despite some efforts to establish the levels of heavy metals in various sites, little work has been done on the levels of heavy metals in WSPs (Kihampa, 2013; Nziku and Namkinga, 2013; and Kamagenge, 1996)

but none on their performance. This study therefore, aimed at ascertaining the performance of WSPs in removing heavy metals (Pb, Cr, Fe, Mn, Cu, and Zn) by determining the levels of heavy metals in influents, effluents and sludge. The influence of pH on decreasing the concentration of heavy metals in effluents was also investigated.

MATERIALS AND METHODS

Study Area and Sampling

The wastewaters were taken at an inlet and outlet of each of the four anaerobic and/or primary facultative pond (PFP) WSPs (University of Dar es Salaam-UDSM – S1, Mabibo – S2, Vingunguti industrial –S3, and Mikocheni – S4) all located in Dar es Salaam City, Tanzania (Figure 1). These WSPs receive influents as described in Table 1 and some of their physical characteristics are given in Table 2.

A total of 60 samples including 20 influent samples, 20 effluent samples and 20 sludge samples were collected between July and August 2012 at 13.30 hours. Wastewater samples were collected into 1000 mL plastic bottles that were soaked overnight with 10 % HNO_3, thoroughly washed with distilled water and then rinsed with the wastewaters to be sampled.

Soon after sampling, the pH, temperature, Total Dissolved Solids (TDS) and Electrical Conductivity (EC) were measured using the digital pH meter water proof. The wastewater samples were preserved by adding 2 drops of concentrated HNO_3 in every sample to the pH $\leq$ 2 and placed in an ice cool box.

Sludge samples (500 g) were taken randomly as grab samples from the ponds then mixed into composite samples in polyethylene bags and placed in an ice cool box. The samples were then transported to chemistry department laboratory and stored in a refrigerator ($\leq$ 4 ºC) until analysis.

Sample Preparation and Analysis

Samples of wastewater were digested by taking 100 mL into 250 mL conical flask into which 5 mL concentrated HNO_3 were added. The flask with the contents were placed on the hot plate and evaporated under open reflux condition while adding small portions of the acid until complete digestion was marked by reduction of volume to 20 mL. The flask contents were then cooled, filtered, and filled to the mark with distilled water. The samples were taken for metal determinations.

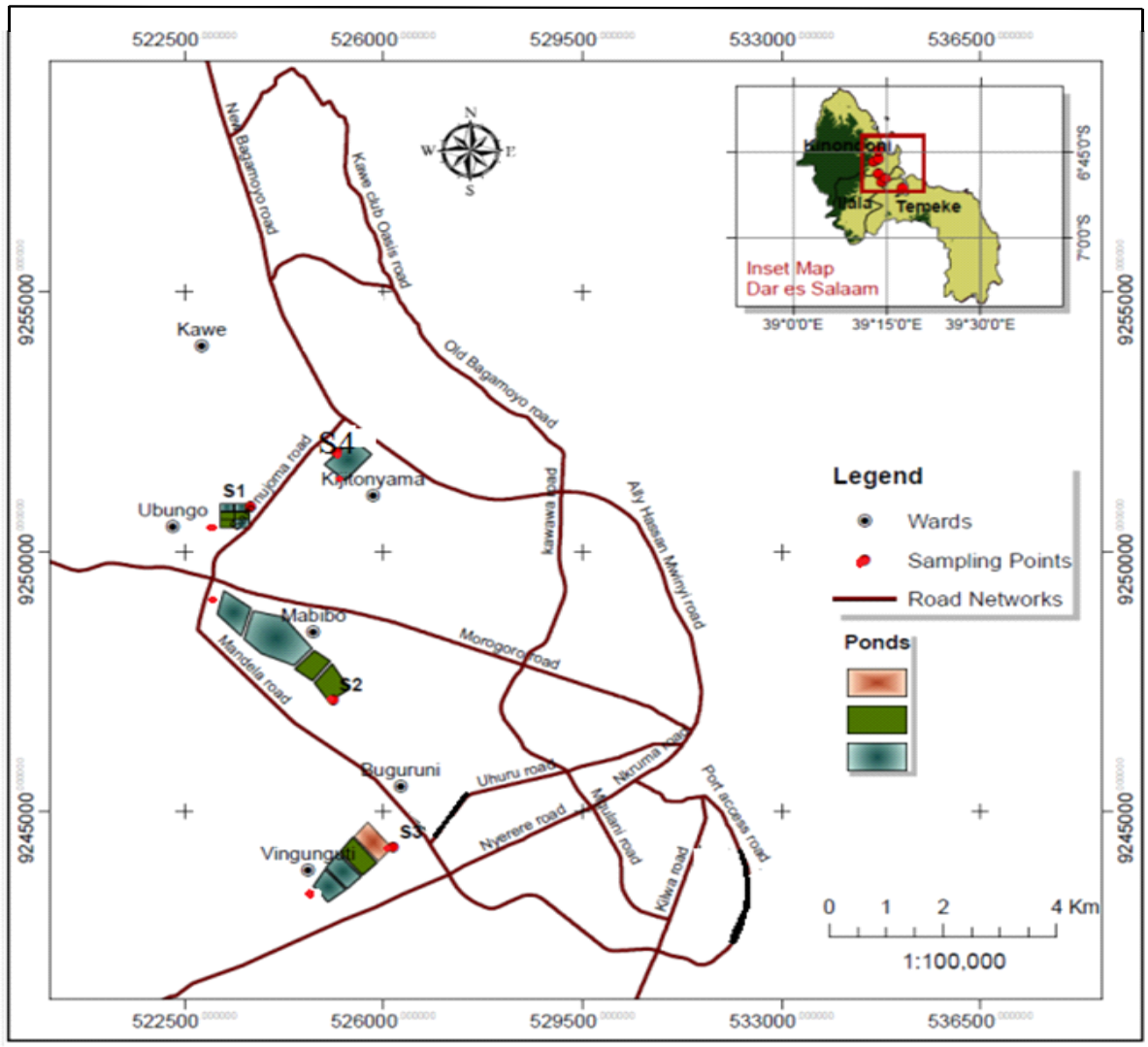
The sludge samples were prepared as per APHA, 1999 and Fuentes et al., (2004) standard methods.

Preparation of Laboratory Effluents

To study the influence of pH on the concentration of heavy metals in effluents, 1 M NaOH was used to carry out precipitation reactions. Standard solutions of heavy metals (laboratory effluents) were prepared as per standard procedure (Technologies A, 2012).Then 1M NaOH was added dropwise while stirring to obtain the solutions with the pH 0.25 (control), 1.93, 4.32, 6.21, 7.02, 8.08, 9.06, 10.01, and 11.22. The mixture were left for 1 hour, filtered and then taken for metal determinations.

Analysis

The concentrations of heavy metals in the prepared samples (influents, effluents, sludge and laboratory effluents) were determined by AAS (iCE 3000 v1.30).



Source: Kihampa (2013) with modification to include only studied ponds

Fig. 1: Site description and sampling points' allocation

Table 1: Description of the waste stabilization ponds (WSPs) investigated.

Sampling site (WSPs)	**Geographical position**	**Wastewater sources**	**Significant industrial discharges**	**River/ or stream**
University of Dar es Salaam (UDSM) (S_1)	S 06.77768 E039.21402	Residential, laboratories, workshops, health centre	70% Institution 30% Residential	Mlalakuwa
Mabibo (S_2)	S06.81151 E039.22733	Industries, institutions, Residential	50% Industrial 50% Residential	Msimbazi
Vingunguti industrial (S_3)	S06.83721 E039.23685	Industries Residential	85% Industrial 15% Residential	Msimbazi
Mikocheni (S_4)	S06.76829 E039.22780	Industrial, Residential	85% Industrial 15% Residential	Mikocheni

Table 2: Physical Characteristics of the Ponds

	(UDSM) (S1)	Mabibo (S2)	Vingunguti (S3)	Mikocheni (S4)
Capacity (m^3)	-	47750	71200	-
Flow capacity (L/s)	53	92.9	21.4	105
Retention Time (days)	5	5	6	5
BOD removal (mg/L)	13	20	10	7
FC removal (No/100mL)	173	266	100	82

Source: Ahmed A., 2002

RESULTS AND DISCUSSION

Physical Parameters

The mean and standard deviation (STDEV) of physicochemical parameters are given in Table 3. The temperatures of the WSPs generally decreased from influents to effluents except that of UDSM WSPs, where it increased. The mean temperatures of both influents and effluents were in the range of 26.56-30.00 ºC which is within the permissible limit for effluents discharge to the receiving environments (TBS, 2005).

For pH values, the general trend was an increase from influents to effluents. The values of pH in influents and effluents of the studied sites ranged from 6.74 to 10.16. The pH of influents (6.74 to 7.25) was neutral while that of effluents (7.76 to 10.16) was slightly alkaline to moderately alkaline. Except for effluents from UDSM WSPs, all other pH values were within the TBS and WHO permissible limits (TBS, 2005; Mustafa, 2006). The increment in pH might be due to increased photosynthetic activities which are maximum at noon, the time when sampling was done (Kayombo et al., 2005; Sewhunegn, 2011). The algal photosynthesis consumes CO_2, which in turn elevates the concentration of hydroxide ions hence an increase in pH (Curtis et al., 1992).

The TDS in influents and effluents ranged from 336 to 1759 mg/L. The TDS decreased generally from influents to effluents except for Mabibo WSPs. The TDS of effluents from Mabibo WSPs and influents and effluents from vingunguti WSPs were higher than the WHO permissible limits. This could have been attributed by the high contents of salts in domestic effluents from residential areas.

The EC values ranged between 606.67 µS/cm in effluents of UDSM WSPs and 3354.00 µS/cm from vingunguti WSPs influents. The EC values from Mabibo effluents, Mikocheni influents and Vingunguti WSPs were higher than the WHO permissible values. The higher TDS and EC values could probably be due to ionization of the constituents from the accumulated sludge caused by absence of desludging or because of decreased water level caused by evaporation from high temperatures of the dry period since sampling was done during this period (Taru et al., 2012). The EC values in effluents from all the studied sites were higher than those reported earlier (Kihampa, 2013). Such a difference could have been caused by difference in the sampling seasons; Kihampa (2013) study was done during rainy season while the present study in dry season.

Table 3: The mean physical parameters of the selected WSPs

Ponds		**T (°C)**	**pH**	**TDS (mg/L)**	**EC (µS/cm. at 25 °C)**
UDSM	Influents	27.3±0.2645	6.74± 0.055	402±3.0	764±3.64
	Effluents	30.0±0.1	10.16±0.00577	336±1.0	606.67±0.5777
Mabibo	Influents	28.3±0.1	7.13 ±0.01	1122±1.0	2094 ±1.527
	Effluents	26.566 ±0.115	8.866 ±0.0577	1571±0.577	3050.6±0.577
Vingunguti	influents	27.8±0.1	7.25±0.01	1719±0.577	3234±1.0

industrial	Effluents	27.5±0.1	7.98±0.1527	1759±0.577	3354±0.577
Mikocheni	Influents	28.3±0.0577	7.22±0.00577	1238±1.0	2306±1.5275
	Effluents	27.8±0.1	7.76±0.01	954.66±0.577	1798.66 ±1.1547

Concentration of Heavy Metals in Influents, Effluents

The mean concentrations of influents and effluents and the percentage removal efficiencies for heavy metals as well as the TBS permissible limits of the WSPs for the concentration of heavy metals in effluents to be discharged to receiving environments are shown in Table 4 and Fig. 2, respectively. The general trend observed was the decrease in the concentration of heavy metals from influents to effluents. The mean percentage removal efficiencies for heavy metals ranged between -0.8%-Pb (none was removed) and 100%-Cu from UDSM WSPs, which means all Cu was removed. It is noteworthy that the percentage removal efficiencies for almost all metals in the WSPs were above 50%, suggesting that the performance was promising.

Chromium was the only heavy metal below detection limit in all the WSPs except at Mikocheni (0.0037 mg/L) WSPs. The mean concentration of Pb for UDSM WSPs in both effluents and influents (0.0517 mg/L) was almost the same contrary to what was anticipated, this warrants further investigation. The concentrations of Pb, Cu and Cr in effluents of the studied sites were in line with those reported by Kihampa (2013), and were within safe limits according to TBS (2005) standards.

The decreased concentration of heavy metals in effluents signifies reduction along the treatment path in the WSPs which was probably caused by precipitation as the pH of wastewater was between 6.74 and 10.16 (Table 3), the pH media (alkaline) at which heavy metals form hydroxide precipitate (Gray, 2005; Pavlovic et al., 2006). The removal of heavy metals may also be caused by complexation of biopolymers, adsorption to bacterial cells and solids, biosorption and most probably ending in the sediments as colloidal precipitates during floc formation (Manasreh et al., 2009).

Table 4: The mean concentrations of heavy metals (mg/L) in influents and effluents and % removal efficiency

Ponds	**Metal**	**Influent (n = 3)**	**Effluent (n = 3)**
UDSM	Pb	0.0517±0.0029	0.0517=+0.00153
	Fe	1.51±0.0173	0.1387±0.0006
	Cu	0.0067±0.0012	BDL
	Zn	0.072±0.001	0.0013±0.00057
	Mn	0.314±0.0017	0.0923±0.00153
	Cr	BDL	BDL
Mabibo	Pb	0.0483±0.00153	0.032±0.00265
	Fe	2.21±0.01	0.333±0.000577
	Cu	0.03067±0.000577	0.021667±0.001528
	Zn	0.3233±0.00577	0.081±0.001
	Mn	0.252±0.02	0.0558±0.00115
	Cr	BDL	BDL
Vingunguti	Pb	0.9667±0.0012	0.0773±0.00152
industrial	Fe	3.7603±0.0015	0.4293±0.0006
	Cu	0.0607±0.0012	0.0233±0.0015
	Zn	0.843±0.0015	0.0877±0.0006
	Mn	0.3317±0.0015	0.2637±0.0012
	Cr	BDL	BDL
Mikocheni	Pb	0.0713±0.0005	0.044±0.002
	Fe	7.11±0.01	0.1903±0.000577
	Cu	0.08033±0.000577	0.0057±0.001155
	Zn	0.746±0.0025	0.027±0.001
	Mn	0.4737±0.0021	0.276±0.0017
	Cr	0.0037±0.0015	BDL

TBS Metal Stds	**Fe**	**Pb**	**Cu**	**Zn**
mg/L	5.0	0.1	2.0	5.0

BDL = Below Detection Limit

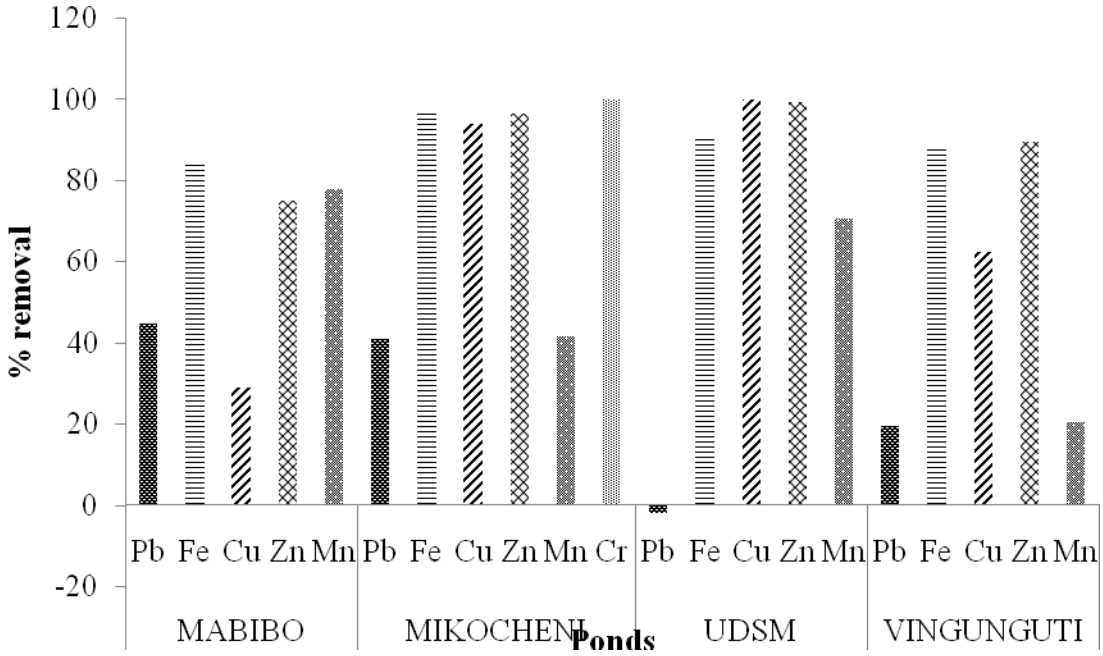


Fig. 2: The removal efficiencies of heavy metals from studied WSPs

The Concentration of Heavy Metals (mg/kg-dw) in the Sludge

The mean concentrations of heavy metals in the sludge from WSPs are shown in Table 5. It was observed that the concentrations of all heavy metals in the sludge from UDSM WSPs were the highest. Nevertheless, the mean concentrations of all heavy metals in the sludge except Pb (601.5 mg/kg) and Zn (14903 mg/kg) from UDSM were within the EPA permissible limits (Table 5). This suggests that they are suitable and therefore safe to be used in agriculture as fertilizer or for soil improvement. The concentrations of heavy metals in the sludge from UDSM WSPs were comparable to results obtained by other researchers from the Republic of Korea (Chanpiwat et al., 2010), Romania (Balbae et al., 2009) and Spain (Fuentes et al., 2004). The highest values of metals in the sludge from UDSM WSPs could be due to massive production of metals in waste waters from the University laboratories, engineering workshops, health center and residential houses and hostels. On the other hand, industrial activities such as textiles, brewery, battery, aluminium, steel and paint industries as well as residence could be exclusively the source of metals in other WSPs. The observed low concentrations of Cr in the sludge in all WSPs in this study might be due to its low concentrations in influents of wastewater (Karvelas et al., 2003). This could probably be due to the nature of activities that do not incorporate Cr compounds.

Table 5: The mean concentration of heavy metals (mg/kg-dw) in the sludge from WSPs

Sampling sites (n = 3)	Pb	Fe	Cu	Zn	Mn	Cr
UDSM	601.5±0.351	233002±2.646	2760±2.00	14903±6.658	7774±4.00	740±0.586
Mabibo	107.2±0.25	14250±2.081	107.26 ±0.208	292.3±0.231	393.2 ±0.208	24.1 ±0.208
Vingunguti industrial	453.1±0.265	4572±2.52	191.1±0.252	927±5.0	467±3.786	59.9±0.451
Mikocheni	56.22±0.0208	2892±1.732	119.6±0.577	646.2±0.25	375.3±1.5275	25.25±0.05
EPA	300-420	Nr	1500-4300	2800-7500	nr	150-3000

Note: dw = dry weight, nr = not regulated

Concentration of heavy metals in laboratory prepared effluents as a function of pH.

The concentration of heavy metals in effluents prepared in the laboratory as a function of pH is given in Figure 3. There is a decrease in the concentration of heavy metals with increasing pH up to the point where there is no further decrease in the concentration of metals with an increase in pH. Different metals have different pH values at which they form hydroxide precipitates. For instance, Fe precipitated at the pH 4.32, Pb at 6.21, Cu start to precipitate at 6.21 and Mn at 9.06 and both continues up to 11.22, while Zn starts at 8-10 above which it starts to dissociate with the resulting metal ions going back into solutions. These results are in agreement with Pavlovic et al., 2006 and Brbootl et al., 2011.

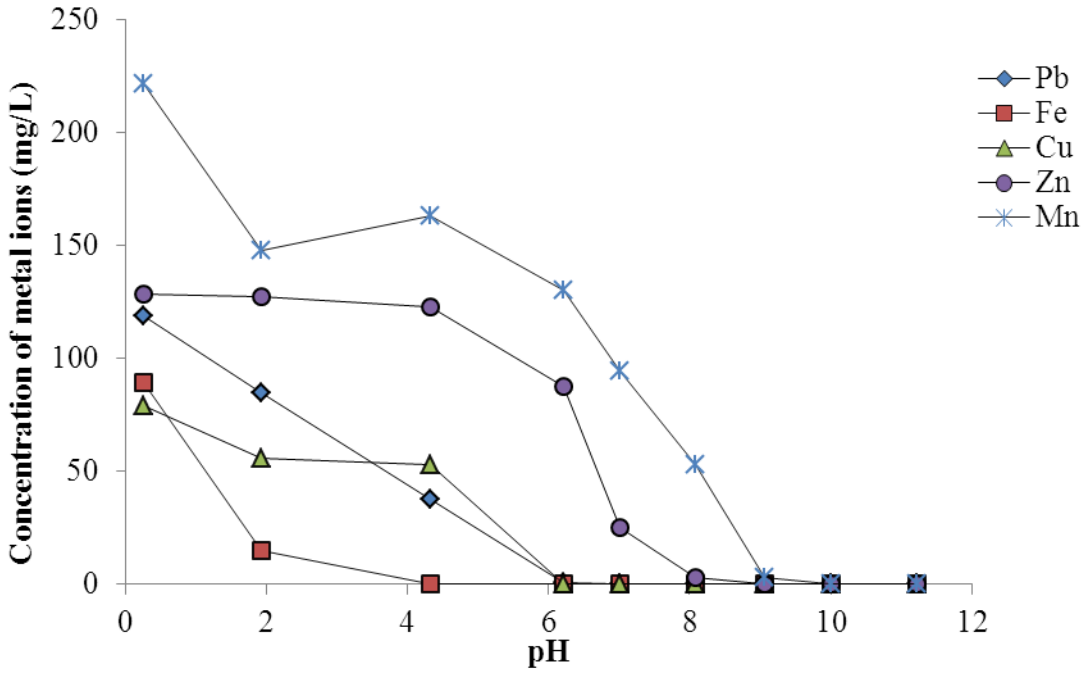


Fig. 3: Effect of pH on concentrations of heavy metals in laboratory prepared effluents

The removal of heavy metals in laboratory prepared and WSPs effluents in regard to pH (Figure 3 and Table 3) were not comparable. The differences were probably due to differences in the matrices where in the WSPs there are both biological and chemical reactions caused by microorganisms and presence of other chemicals which are absent in the laboratory prepared effluents. It has been observed that the pH of solution exerts strong influence as regards to the concentration of heavy metals in solutions (Ayres et al., 1994). Generally, metals are soluble in acidic solutions and can be precipitated in basic media (Pavlovic et al., 2006; Ayres et al., 1994).

Conclusion

This study revealed the presence of heavy metals (Pb, Fe, Cu, Zn, Cr and Mn) in influents, effluents and in the sludge from WSPs. The concentrations of the heavy metals in effluents did not exceed the TBS (2005) permissible limits for discharges to receiving environments. This shows that the WSPs perform well in heavy metal removal. However, heavy metals detected in treated effluents can pose health risk to people through long term use of such waters for irrigation, washing, livestock keeping and fishing; and to aquatic life in rivers and Indian ocean where the effluents are discharged. The concentrations of the metals in the sludge from UDSM WSPs were higher than permissible limits and thus the sludge from such pond is not suitable for disposal on soil or reuse in gardens and other activities.

Most of the heavy metals were removed within pH range 7−10 which did not comply with the laboratory prepared effluents pH removal due to the reasons stated above. However, it is important to ensure that the pH value of the wastewater entering the ponds is within neutral to moderate alkaline for effective removal of heavy metals in WSPs.

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