EFFECT OF TOXIC HEAVY METALS AT DOWNSTREAM IRRIGATION OF WASTEWATER TREATMENT PLANT

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ABSTRACT

For several years, domestic wastewater from Addis Ababa's seven sub-cities has been treated at Kality domestic wastewater treatment plant. Despite being designed to treat domestic waste, certain industrial wastes were discharged into the treatment plant system via point and non-point sources, causing a number of problems. The effluent from the treatment plant was primarily used for irrigation by local farmers in the Akaki-Kality sub-city. To identify and quantify heavy and toxic heavy metals in treatment plant effluent, irrigated soil, and vegetable plants, as well as to determine how they affect human health downstream, a cross-sectional study design was used. Liquid samples were collected at the Up flow Anaerobic Sludge Blanket reactor (UASB) inlet and outlet, trickling filter and secondary clarifier outlets, a soil sample from a cultivated field, and plant samples such as habesha gommen and kosta grown using the effluent. The presence and concentration of heavy and toxic heavy metals were determined in the samples, and the ability of unit processes such as the UASB, trickling filter, and secondary clarifier to remove toxic heavy metals was assessed. The laboratory tests revealed that majority of the toxic heavy metals were present in the samples analyzed (chromium, cadmium, arsenic, copper, lead, and manganese) and the unit processes were inefficient to remove these metals.

Key words: Concentration, EPA, Toxic Heavy Metal, Trickling Filter, UASB

1. INTRODUCTION

There are two types of biological processes with a high content of organic materials in wastewater treatment plants: aerobic and anaerobic processes[1]. Anaerobic processes use less energy and produce methane which can be used as a source of energy. The *Kality* domestic wastewater treatment plant employs an anaerobic process (the UASB reactor). For *Kality* domestic wastewater treatment plant the overall design removal for COD and BOD is 55%. Since the plant's inception, the plant's effluent has been used for irrigation. The practice of using treated effluent for irrigation will boost food production, which will support Addis Ababa's formal food production. Because the Addis Ababa population is growing at an alarming rate, and sub cities are expanding the residents are practicing using domestic wastewater treatment plant effluents for irrigation to support the people's livelihood. An increase in population should result in an increase in sectors such as agricultural production and irrigated lands, which rely on water resources for irrigation. These conditions have compelled farmers to irrigate with alternative water resources (i.e., blackish water, wastewater, and effluent water), thereby closing the gap between freshwater availability and crop demand [2]. Irrigation with treated municipal wastewater is an important component of global environmental strategies, and the scientific community is focusing more on it [3-5]. In a number of countries, treated wastewater is already regarded as a suitable water source for irrigation, primarily in agriculture and landscaping [6-8]. Despite the potential economic, social and environmental benefits of irrigation with treated municipal wastewater, the effects of reuse must be continuously monitored to ensure resource protection, soil health and particularly human health. Irrigation with treated wastewater produces a significant amount of biodegradable organic material (carbon and nitrogen), mineral macro and micronutrients (such as phosphorous, potassium, and magnesium), and toxic heavy metals (such as Molybdenum, Selenium, Boron, Chromium, Manganese, Lead, Arsenic, Cadmium and Copper) required for crop growth but affects human health beyond the recommended concentration [9]. To maintain soil quality, however, the possibility of trace pollutants, heavy metals, and salts accumulating in the soil must be considered. Heavy metal content in effluents can vary depending on treatment method (less or more intensive) and wastewater source (industrial, municipal, etc.). So, concentrations in the receiving system (soil, plant) must be monitored [10-12]. In contrast, long-term application of fully or partially treated or untreated wastewater may result in toxic heavy metal deposition in the soil [13]. Home and business effluents, drainage water, atmospheric deposition, and traffic-related emissions carried by storm water into sewage and/or irrigation systems carry a variety of pollutants and enrich urban wastewater with toxic heavy metals [14-16].

This study was conducted to identify the types of toxic heavy metals that exist in *Kality* domestic wastewater treatment plant effluent, downstream irrigated soil, and cabbages, as well as their effect on human health, and to compare their magnitude with the Ethiopian Guideline Ambient Environmental Standards, FAO/WHO, in order to determine the treatment efficiency of UASB reactor, trickling filter, and secondary clarifier in removing toxic heavy metals.

Eating food crops grown in wastewater-irrigated areas is one of the most important factors contributing to human pathogen exposure. Furthermore, growing crops for human consumption on wastewater-irrigated soil may result in trace metal uptake and buildup in edible plant parts, posing a risk to humans [17-19]. Heavy metals are extremely dangerous due to their non-biodegradability, long half-lives, and high bioaccumulation potential [20].According to several researchers, excessive accumulation of heavy metals and even important trace elements like Cu, Cd, Mn , As ,Pb, and Zn in the human body can cause serious health problems [20-23]. Some heavy metals are required for human biological processes, but their consumption can have unanticipated negative effects on health and the physiological system, depending on the dosage (concentration) [24]. Excessive heavy metal accumulation in agricultural soils as a result of wastewater irrigation may result in soil contamination as well as increased heavy metal uptake by crops, compromising food quality and safety [25].

According to Kim et al. [26], heavy metals, despite their beneficial health effects, act as carcinogenic agents. Dissolved forms of these metals enter the food chain via various means, including soil pollutants, water pollutants, and air pollutants, and eventually end up in humans, causing severe damage to the cellular system. Toxic metals pose health risks based on the concentrations of these metals in specific media and the length of exposure. Long-term and chronic exposure to hazardous metals, even at low levels, can cause health problems [27].

Heavy metal toxicity, according to Singh etal. [28], can be classified into the following categories: nephrotoxicity, neurotoxicity, hepatotoxicity, carcinogenicity, cardiovascular toxicity, immunological toxicity, skin toxicity, genotoxicity, and Reproductive and developmental toxicity.

Lead has toxic effects on various organ systems, but those in the kidney are the most difficult. Acute lead nephropathy causes proximal tubular dysfunction, resulting in Fanconi-like syndrome Cadmium can also cause glucosuria, Fanconi-like syndrome, Phosphaturia, and aminoaciduria [29- 31].

Manganese is a necessary element that is involved in a number of physiological functions in the body. Acute exposure may have a neuro-protective effect by lowering apoptotic cellular death, but chronic exposure can result in dangerous illnesses such as Alzheimer's and Parkinson's disease [32]. When arsenic is consumed, it causes central nervous system cognitive impairment. It has also been linked to a variety of neurological disorders, including neuro developmental changes, and is associated with an increase in neurodegenerative diseases [33]. Arsenic exposure also has an impact on synaptic transmission and neurotransmitter balance [34].

Cadmium affects two human tissues: the renal cortex and the liver [35]. It accumulates in the liver during acute exposure and has been linked to a variety of hepatic dysfunctions. Cadmium alters the redox balance of cells, causing oxidative stress and hepatocellular damage [36]. Cadmium-induced hepatotoxicity, both acute and chronic, causes liver failure and thus increases the risk of cancer [37]. Arsenic poisoning increases the risk of cancer by binding to DNA-binding proteins and slowing the repair process [38].

Lead is a carcinogenic chemical that causes the DNA repair mechanism, cellular tumor-regulating genes, and chromosomal structure and sequence to be damaged. It interferes with transcription by removing zinc from certain regulatory proteins [39].

Cadmium is a carcinogenic and toxic metal [40]. Exposure to low to moderate levels of cadmium causes hypertension [41], diabetes ('Urinary Cadmium, Impaired Fasting Glucose, and Diabetes in the [42], carotid atherosclerosis [43], peripheral arterial disease [44], myocardial infarction and [45]. Cadmium has been linked to an increased risk of cardiovascular death in the general population of the United States in prospective studies [46].

2. MATERIALS AND METHODS

2.1 Study Area

The *Kality* domestic wastewater treatment plant is owned by the Addis Ababa City Water and Sewerage Authority (AAWSA). It is located in Addis Ababa, Ethiopia, at 8°55' 11"N and 38°45'19"E.It is capable of handling a maximum flow rate of 100,000m^3/day. The process includes a UASB front end, trickling filters, secondary clarifiers, and chlorination/dechlorination for disinfection before dumping into the river. The plant's catchment area was modeled, and 18 kilometers of additional sewer trunk mains were constructed [47].The *Kality* wastewater treatment plant accounts for approximately 29% of the city's wastewater treatment coverage.

2.2 Study Layout

A cross-sectional study was used to investigate heavy metal and toxic heavy metal concentrations in the *Kality* wastewater treatment plant, downstream irrigated soil, and vegetables during dry seasons.

2.3 Reconnaissance Survey

Before the official survey began, a reconnaissance survey was conducted. The preliminary data needed for sampling and sample transportation was assessed. The site description, vegetable varieties grown downstream of the treatment plant, and irrigated areas using the treatment plant's effluent were all documented.

2.4 Sample Collection and Preparation

Six specific sampling areas were selected based on vegetable availability, irrigation soil, and wastewater. For all samples, we used grab sampling techniques. Four water samples were collected from different treatment plant unit processing regions (sample-1: UASB reactor inlet, sample-2: UASB reactor outlet, sample-3: trickling filter outlet, sample -4: secondary clarifier outlet). A representative soil sample was collected from the irrigation area. Two types of plants were collected from the area where treatment plant effluent was used for irrigation. These points were chosen because we believed they would produce a better result. Triplication was done for each sample to get best representatives result.

2.4.1 Water Samples

At various unit process locations, four water samples were collected from the treatment plant.

To avoid cross-contamination,1000 ml of water was collected from each sampling station using pre-cleaned bottles. The locations of the samples were labeled. The water samples were kept cool in an icebox, and the time between sampling and analysis was kept to a bare minimum of 2hrs.

The optimum procedure for digestion of water and sediment samples was carried out for three hours at 250°C using 50 mL of water, 4 mL of HNO_3, and 1 mL of HCl. The digested volume remained at 25 ml after digestion, and was filtered in a 50 ml Erlenmeyer flask and refilled to volume.

2.4.2 Soil Samples

One kilogram of soil was taken from the irrigation area. The sample was taken during the dry season to allow for easier soil-water mixing and to avoid inaccurate results caused by urea fertilizer and lime. To obtain an accurate result, the sample was made leaf-free. To avoid mixing with metal containers, the sample was stored in non-reactive containers in plastic bags. To avoid mixing of plant leaves and other materials; the sampling depth was set between 10 and 15 cm.

The soil sample was dried in an oven set to 30-40°C until it reached a constant weight. The dried sample was sieved with 2mm sieve size. The sample was ground to 9µm.The Coupled Plasma Optical Emission Spectrometry (ICP-OES) instrument was used for heavy metal analysis.

The sample (1g) was placed in a 50 mL crucible and treated with 10mL of concentrated HNO_3. To allow oxidation, the solution was placed on a hot plate for 30-45 minutes. Following cooling, 4 ml of 20% H_2O_2 was added, and the solution was reheated on a hot plate until the digest became clear and semi-dried. Before GF-AAS analysis, the suspension was filtered into a 50ml volumetric flask and diluted with deionized distilled water to the mark.

2.4.3 Plant Samples

During the dry season, farmers irrigate two types of widely consumed fresh vegetables cultivated with the *Kality* wastewater treatment effluent: Ethiopian Kale (*habesha gommen*) and Swiss chard (*kosta*). Two plant samples were collected (each 500gram).Plants were collected from every corner of the plots to ensure that the samples were representative. The samples were carefully collected to avoid damaging, dead, or dying plant tissue. Before placing the samples in the bag, soil from the plant material was brushed off. To avoid cross-contamination, samples were collected in clean plastic bags separately. The plant samples were kept cool in an icebox.

In a "high form" porcelain crucible, 1.25g of sample was weighed. The sample was placed in the furnace, whose temperature was raised to 540 . The sample was ashed for 6 hours and then wetted with distilled water before being dried on a hot plate with 5-10 ml of 6NHCl. To dissolve the ash, 10 mL of 1NHCl was added to the sample before the ash was dissolved. The sample was transferred to the ICP test tube.

2.5 Sample Characterization

Total Cu, Pb, Cr, Cd, As, and Mn levels in digested water, soil, and vegetable samples were determined using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).

3. RESULTS AND DISCUSSION

3.1 Water Samples

The major heavy metals found in the analysis of *Kality* domestic wastewater treatment plant effluent, irrigated soil, and plants were Iron, Manganese, Nickel, Cobalt, Copper, Zinc, Cadmium, Mercury, Lead, Arsenic, Boron, and Chromium.

Toxic heavy metals like Arsenic, Cadmium, Chromium, Copper, Manganese, and Lead were also discovered in the effluent, as shown in Table 1.

The samples were analyzed for heavy metals and toxic heavy metals. Heavy metals such as Iron, Manganese, Nickel, Cobalt, Copper, Zinc, Cadmium, Mercury, Lead, Arsenic, Boron, and Chromium were found in all of the samples. Again, the samples were analyzed for the presence of toxic heavy metals. In all of the samples Arsenic, Cadmium, Chromium, Copper, Manganese, and Lead were found in the effluent as shown in Table 4. Point and non-point sources were assumed as the possible sources of toxic heavy metals.

As shown in Table 4, the UASB reactor has a removal efficiency of 33.3 percent for As, 0 percent for Cd, 28.9 percent for Cr, 75.7 percent for Cu, 34.2 percent for Mn, and 11.0 percent for Pb. The UASB reactor removal efficiency for toxic heavy metals such as As is higher than the surface water quality standard set by Ethiopia's Guideline Ambient Environment Standard (EPA), but it is lower for Cd, Cr, Cu, Mn, and Pb. Since the UASB reactor's primary use is for biological processes, it is inefficient at removing toxic heavy metals. According to FAO/WHO standards, the UASB reactor is effective at removing toxic heavy metals such as As, Cr, and Cu, but it is ineffective at removing toxic heavy metals such as Cd, Mn, and Pb. The removal efficiency of toxic heavy metals (As, Cr, Cd, Mn, Cu, Pb) by trickling filters and secondary clarifiers is below the standard for both surface water quality guidelines and FAO/WHO. Despite the fact that the treatment plant's primary purpose is for biological processes, the removal of toxic heavy metals from domestic wastewater must be taken into account.

Table1 Toxic heavy metals and their mean concentration in the water samples

Toxic Heavy metals	(Sample-1) Concentration at the UASB inlet (mg/L)	(Sample-2) Concentration at the UASB outlet (mg/L)	(Sample-3) Concentration at the Trickling filter outlet (mg/L)	(Sample-4) Concentration at the secondary clarifier outlet (mg/L)	Surface water quality standard by Guideline Ambient Environment Standard for Ethiopia	FAO/ WHO standard for irrigation water (mg/L)
Arsenic (As)	0.070±0.010	0.048±0.009	0.034±0.034	0.059±0.059	0.05mg/L	0.100
Cadmium (Cd)	0.050±0.001	0.053±0.005	0.036±0.002	0.056±0.004	5µg/l	0.010
Chromium (Cr)	0.150±.002	0.103±0.011	0.075±0.012	0.073±0.055	50µg/l	0.550
Copper (Cu)	0.058±.0100	0.014±0.010	0.006±0.002	0.080±0.003	5mg/L	0.017
Manganese (Mn)	1.215±.0100	0.800±0.003	0.578±0.005	0.441±0.003	0.3mg/L	0.200
Lead (Pb)	0.490±.080	0.436±0.041	0.219±0.005	0.334±0.001	0.05mg/L	0.065

3.2 Soil Sample

The soil sample contained toxic heavy metals such as Arsenic, Cadmium, Chromium, Copper, Manganese, and Lead. Table 2 shows the mean concentrations of toxic heavy metals in the soil sample. Toxic heavy metal such as Arsenic, Cadmium, Chromium, Copper, Manganese, and Lead were found in the irrigated soil sample at downstream of *Kality* Wastewater Treatment Plant. Table 2 summarizes the results

Except for Cu and Pb metals, the mean concentrations determined by soil sample test analysis were found to be higher than the soil standard established by the Ethiopian Guideline Ambient Environment Standard (EPA) and FAO/WHO standards, as shown in the Table 5. Since *Kality* WWTP's primary use is for biological processes, the existence of higher concentration of toxic heavy metals at downstream irrigated soils were expectable. Thus, other treatment facilities were required to reduce their concentrations to an acceptable level based on the standard

3.3 Plant Samples

Toxic heavy metals such as As, Cd, Cr, Cu, Mn, and Pb were found in plant samples. Plant samples like local cabbage (*habesha gommen*) and Swiss chard (*Kosta*) were found contained toxic heavy metals. The mean concentration of the toxic heavy metals' are shown in the Table 3.

Local Cabbage (Habesha Gommen) and Swiss chard (kosta) plant samples were analyzed for toxic heavy metals such as As, Cd, Cr, Cu, Mn, and Pb. Table 6 summarizes the findings.

The mean concentrations of As, Cd, and Pb certain toxic heavy metals in local cabbage and Swiss chard plants were higher than the FAO/WHO. Owing to the fact that the WWTP did not have unit processes for the removal of toxic heavy metals

Table 2 Mean toxic heavy metal concentration in soil sample

Toxic Heavy metals	Concentration of toxic metal in Soil sample (mg/L)	Soil standard by Guideline Ambient Environment Standard for Ethiopia (mg/kg of dry wt.)	FAO/WHO standard for soil (mg/L)
Arsenic (As)	8.758±0.139	20.000	-
Cadmium (Cd)	7.627±0..096	0.500	3.000
Chromium (Cr)	41.287±0.866	20.000	-
Copper (Cu)	21.209±0.410	500.000	140.000
Manganese (Mn)	929.665±12.210	20.000	80.000
Lead (Pb)	119.610±3.301	40.000	84.000

Table 3 Mean heavy metal concentrations in plant sample

Heavy metals	Ethiopian Local Cabbage concentration (mg/L)	Swiss Chard concentration(mg/L)	FAO/WHO standard for plant (mg/L)
Arsenic (As)	0.766±0.038	0.272±0.027	-
Cadmium (Cd)	0.189±0.014	0.008±0.046	0.020
Chromium (Cr)	1.193±0.092	0.327±0.042	5.000
Copper (Cu)	4.724±0.420	4.349±0.040	40.000
Manganese (Mn)	23.618±1.288	54.320±0.286	500.000
Lead (Pb)	2.784±0.373	0.559±0.045	0.300

4. CONCLUSIONS

The presence of (toxic) heavy metals in treatment plant effluent, irrigated soil, and vegetable plants were investigated in this research. The ability of unit processes such as the UASB reactor, trickling filter, and secondary clarifier to remove toxic heavy metals was determined. Heavy metals such as Iron, Nickel, Cobalt, Zinc, Mercury, and Boron were found in all of the samples tested. Majority of toxic heavy metals such as Chromium, Cadmium, Arsenic, Copper, Lead, and Manganese were also found in the samples. Furthermore, the mean concentrations of these chemicals in effluent, soil, and cabbage plants were compared to Ethiopian Ambient Environmental Standards and FAO/WHO Standards. Majority of the mean concentrations of toxic heavy metals in the effluent, irrigated soil samples, and vegetables were found to be above values set in these standards. Though the UASB reactor removes some toxic heavy metals, its removal efficiency is determined to be less than the standards. Likewise, laboratory results showed that trickling filters and secondary clarifiers were ineffective in removing toxic heavy metals. Thus, individuals exposed to the consumption of vegetables irrigated by the plant's effluent have a significantly higher risk of developing illnesses such as nephrotoxicity, neurotoxicity, hepatotoxicity, carcinogenicity, cardiovascular toxicity, immunological toxicity, skin toxicity, genotoxicity, etc. It is recommended to include chemical processes like hydration, chemical precipitation, adsorption and heavy metal settlement processes in the *Kality* Wastewater Treatment Plant in order to minimize the effect of toxic heavy metals on those who use the effluent for irrigation.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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