Reuse of Sludge from Wastewater Treatment Plants in Agriculture: Problem of Heavy Metals in Moshi Municipality Waste Water Treatment Plant

Nyangwe, P. B. [*1,2], **and Saria J.A.** [1]
[1]The Open University of Tanzania
[2]Moshi Urban Water Supply and Sanitation Authority (MUWSA),
*****Correspondence: pnyangwe@yahoo.com;

Abstract

Municipal wastewater treatment plants (WWTPs) have the potential to play a significant role in a circular economy by adopting the principles of reduce, reuse, and recycle (3R). While the primary goal of a WWTP is to decrease the pollution in sewage, this process also produces various potentially valuable byproducts such as treated effluent, biogas, and sludge. The challenge in recycling beneficial nutrients from sludge to agricultural soil primarily arises from the presence of heavy metals, partly due to their toxicity and environmental persistence. This study aimed to examine the concentrations of specific heavy metal contaminants (Cd, Zn, Fe, Cu, and Cr) in sludge from the Moshi municipal WWTP, which is slated for use as fertilizer. The samples underwent analysis using an Atomic Absorption Spectrophotometer (AAS). The examination of sewage sludge revealed a pH average indicating an acidic condition at 5.93 ± 1.05, while iron averaged at 53.32 ± 3.66 mg/kg and copper varied between 0.10 and 3.43 mg/kg, with an average of 1.63 ± 1.18 mg/kg. Environmental assessment involved the application of three pollution indices—Contamination Factor (CF), Index of Geo-accumulation (Igeo), and Pollution Load Index (PLI). These indices collectively confirmed the absence of contamination in the sludge regarding these elements. However, ensuring the elimination of environmental risks and evaluating potential impacts on human and animal health regarding the use of sludge from treatment plants necessitates comprehensive studies across various treatment facilities in the country, considering the chemical composition of these sludges.

Keywords: *Rural Water Supply, Sewage sludge, fertilizer, Moshi Municipal*

INTRODUCTION

Sewage sludge, a by-product from wastewater treatment plants, forms as a diverse blend of solid organic and inorganic elements, along with colloids, separated with varying chemical compositions, treatment durations, and physicochemical conditions (Goldan et al., 2022). during the treatment process (Gray, 2010). Managing sewage sludge disposal has emerged as a significant challenge in recent years. Adapting sewage sludge for soil enhancement involves a range of methods

The treatment of sewage sludge has become an immediate concern, primarily due to the significant population growth in urban areas and the evolving living standards, which have led to higher water consumption and the consequent release of used water into surface watercourses (Iticescu et al., 2018). Various countries have opted for different disposal methods for urban sewage sludge, such as using it in agriculture as fertilizer, incineration, composting, and landfill. When comparing the costs of these disposal methods, applying sludge to land and agriculture stands out as the most cost-effective compared to other approaches (Mehmood et al., 2022). However, the choice of sewage sludge management method is mainly influenced by the quantity and properties of the sludge itself (Urra et al., 2019).

Wastewater treatment plant sludge finds purpose through compost production, direct application to agricultural and forest land, creating growth substrates, and harnessing energy (Renaud et al., 2017). Due to practical and legal considerations, there's a growing trend to reuse sewage sludge rather than resorting to landfills. This strategy aims to reduce waste generation, foster bioeconomy growth through smart waste management, and aligns with a zero-waste approach (Ruiz-Gomez et al., 2017).

Sewage sludge exhibits fertilizer-like properties and offers potential for enhancing agricultural soils due to its rich content of nitrogen, phosphorus, and organic matter (Metcalf, 1991). Approximately, one ton of dried sludge typically comprises 200 kg of organic matter, 6 kg of nitrogen, 8 kg of phosphorus, and about 10 kg of assorted soluble salts on average (Zhang et al., 2016). This sludge, derived from wastewater treatment, has the capacity to retain moisture and can serve as a pH regulator within specific parameters. Alongside essential elements crucial for plant growth, it may also contain variable quantities of heavy metals and other pollutants (Deenik and Cooney, 2016).

Because of its nutrient richness and substantial organic mass, sewage sludge in significant quantities can positively impact productivity, addressing a critical challenge: the removal of sewage sludge from wastewater treatment plants to prevent incineration, costly procedures, and further pollution. Application methods include liquid form, sludge cake (25% dry solids), or dried sludge granules (95% dry solids). Studies indicate nutrient loss during dehydration and drying processes, favoring the use of the first two forms. However, this recycling approach might pose challenges due to foul odors and potential health hazards from pathogens within the sludge (Tsadilas et al., 2014; Jamil et al., 2006).

Improper management of sewage sludge can lead to environmental contamination and groundwater pollution. The accumulation of heavy metals in the soil poses a significant risk as it profoundly impacts the natural circulation of elements in the environment (Urra et al., 2019). Heavy metals become a substantial threat to the quality of agricultural crops through the food web since consumed plants serve as a primary natural source of these metals for humans and animals. As wastewater treatment progresses, reducing the release of pollutants into receiving water bodies and improving water quality, more potentially harmful compounds are transferred to sewage sludge, rendering it unsuitable for agricultural purposes (Tsadilas et al., 2014).

Heavy metals are recognized as significant environmental pollutants due to their toxicity, extended atmospheric lifespan, and their ability to accumulate within the human body through bioaccumulation. Municipal wastewater, a complex amalgamation of various pollutants from domestic and industrial origins, has emerged as a crucial human-made source of pollution in aquatic environments (Han et al., 2017). Several studies elsewhere have indicated that the application of wastewater sludge to cropland can heighten the accumulation of heavy metals in specific crop plants (Singh and Agrawal, 2017; Singh and Agrawal, 2010; Muchuweti et al., 2006).

The motivation behind this study stems from acknowledging the role of municipal wastewater in contributing to heavy metal pollution in the environment. Its aim is to aid in nationwide estimation and policy formulation in Tanzania. This research specifically quantified the discharge of heavy metals from sewage sludge sourced from the wastewater treatment plant of Moshi Municipality, primarily utilized as manure.

MATERIALS AND METHODS

Description of the Study Area and Sample Collection

The wastewater treatment system of Moshi Municipality, situated in the northern part of Tanzania within the Kilimanjaro region, is overseen by the Moshi Urban Water and Sewerage Authority (MUWSA) (Fig. 1). This system handles domestic sewage from a sewered area covering 46% of the municipality, the highest coverage in Tanzania (Kihila et al., 2014). Additionally, it receives sewage from areas lacking a sewerage network via septic pump trucks. The treatment setup comprises a waste stabilization pond (WSP) interconnected with a constructed wetland (CW) system.

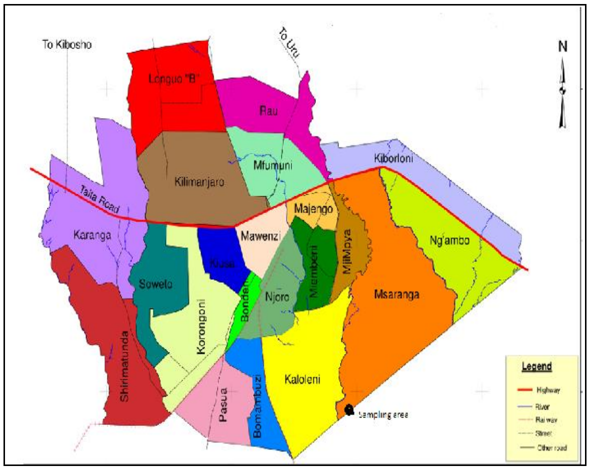

Figure 1: Moshi Municipality Wastewater Treatment System Coverage

The wastewater treatment system of Moshi Municipality is situated in Mabogini ward, approximately 4 km south of the center of Moshi town. The sewage treatment setup of the municipality includes a sequence of oxidation ponds that receive domestic sewage from both the town and its surrounding suburbs.

Volume of Solid Sludge Produced at Moshi Waste Water Treatment Plant

Determining the exact volume of municipal wastewater sludge generated by treatment facilities remains challenging due to fluctuations resulting from standard sludge treatment procedures. As per Metcalf and Eddy (1991), a typical primary and secondary wastewater treatment process yields approximately 0.94 kg of dry solids per 1,000 gallons (3.78 m^3) of treated wastewater. The wastewater treatment system in Moshi Municipality receives domestic sewage from a sewered area covering 46% of the municipality, the highest coverage in Tanzania. The Waste Stabilization Pond (WSP) within this system is designed with a capacity of 4500 m^3/d, comprising an anaerobic pond, two facultative ponds, and six maturation ponds (Kihila et al., 2014). This translates to an average production of 1,251 kg/day of dry solids in the treatment plant.

Sampling Procedure

Sewage sludge samples were gathered from five separate WWTPs located in Moshi Municipal. In each site, four samples were collected monthly between August and November 2018 from the sludge drying beds, amounting to a total of twenty samples. The collection method involved manual sampling through composite sampling taken from the middle depths of identified sludge beds.

Plastic sampling containers with screw caps were employed (Gomez et al., 1986). The sample volumes and necessary sampling conditions followed the guidelines outlined in the Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, WEF 1998). Each sample was gathered in a labeled plastic bag, then stored in a cooler box with ice during transportation and subsequently placed in a refrigerator at 4°C until further analysis.

Preparation of Samples

The collected samples underwent air-drying at room temperature (27°C) in the laboratory for a duration of five days. Following this, the samples were subjected to nitric acid digestion as per the EPA guidelines (Hseu, 2004). Approximately 2 grams of the milled sewage sludge sample was weighed and placed in a conical flask. Subsequently, 20 mL of HNO_3 (55% concentration) was added, and the mixture was heated at 90°C for 45 minutes, followed by an increase in temperature to 150°C for 10 minutes. Throughout the heating and boiling process, 10 mL of HNO_3 (55% concentration) was intermittently added three times to ensure the maintenance of the liquid content.

The blend was permitted to cool at ambient conditions. Subsequently, the samples were filtered into 100 mL volumetric flasks and filled to capacity using distilled water. The mixture was filtered through acid washed Whatman No. 44 filter paper into a 50 mL volumetric flask and diluted to its full volume. The resulting sample solution was then drawn into the Varian AA240 Atomic Absorption Spectroscopy apparatus.

The determination of total nitrogen (N), phosphorus (P), and potassium (K) followed methodologies outlined in existing literature (Arvas et al., 2011; Kihila et al., 2014). A sample underwent digestion in concentrated sulfuric acid (VI) with hydrogen peroxide acting as an oxidant. Subsequently, the sample underwent specific analyses:

nitrogen measured calorimetrically via the hypochlorite method, phosphorus assessed calorimetrically using the vanadium-molybdenum method, potassium, calcium, and sodium determined through atomic emission spectroscopy, and magnesium analyzed using the atomic absorption spectrophotometric method.

Determination of pH

To conduct pH testing, 10 grams of air-dried sample was deposited into a 100 mL beaker. Following this, precisely 40 mL of distilled water was added, thoroughly mixed, and left undisturbed for 30 minutes. Subsequently, the pH electrodes were immersed into the partially settled suspension, and the readings were recorded.

Evaluation of Heavy Metal Pollution

The level of contamination in the sewage sludge from the wastewater treatment plant of Moshi Municipality, primarily utilized as manure, was evaluated using three environmental assessment indices. These indices include the Geoaccumulation index (I_{geo}), the Contamination Factor (CF), and the Pollution Load Index (PLI).

Geoaccumulation Index (I_{geo})

The I_{geo} is a pollution degree evaluation index proposed by Müller and is widely used to evaluate the metal pollution degree in water, ocean, and soil environments (Olumuyiwa, et al., 2014). The calculation formula can be expressed as follows:

$$I_{geo} = Log_2\left(\frac{C_i}{1.5B_i}\right) \qquad (1)$$

Where Bi and Ci are the background and measured concentrations of the sludge samples respectively.

In the process of interpreting geochemical data, background values and its choice plays a significant contribution. The most common way is the use of average shale values as suggested by Turekian & Wedepohl, (1961) and average crustal abundance data as reference baselines (Ali, *et al*., 2016). The background values adopted from Edori and Kpee (2017) where: Fe = 47,200; Cr = 90; Cu = 45; Zn = 95 and Cr = 0.3.

Single Pollution Index Models

Contamination factor (C_f) was determined using Single Pollution Index Model. This is a basic and useful tool for detecting toxic metal contamination. The C_f is used to evaluate the individual toxic metal contamination insoil. The standard employed for the interpretation of the contamination factor values was adopted from Edori and Kpee (2017). The contamination factor is given in Eq. (i):

$$C_f = \frac{C_m}{C_b} \qquad (2)$$

Where: C_f = Contamination factor; C_m = Is the concentration of the metal and C_b = The background value.

The Pollution Load Index (PLI)

The Pollution Load Index (PLI) is obtainedas concentration Factors (CF). This CF is the quotient obtained by dividing the concentration of each metal. The PLI of the place are calculated by obtaining the n-root from the n-CFs that were obtained for all the metals. With the PLI obtained from sampling site. Generally pollution load index (PLI) as developed by Lacatusu (2000) which is as follows (Eq iii): $PLI = (C_{f1} \times C_{f2} \times C_{f3} \times C_{f4} \times \ldots C_{fn})^{1/n}$ (3)

Where: PLI is Pollution Load Index, C_f contamination factor of respective metal, n = number of metals.

Table 1 shows different classifications into which the contamination factor (C_f), Geoaccumulation Index (I_{geo}) and Pollution load index (PLI) are categorized

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Table 1: Classification of Different Pollution Indices

I_{geo} value[a]	**Description**	C_f value[b]	**Description**	PLI value[c]	**Decription**
$I_{geo} < 0$	Practically Uncontaminated	$C_f < 1$	Low contamination	$PLI = 0$	Excellent
$0 < I_{geo} < 1$	Uncontaminated to moderate contaminated	$1 \le C_f < 2$	Low to moderate contamination	$PLI = 1$	Baseline level of pollutants
$1 < I_{geo} < 2$	Moderate Contaminated	$2 \le C_f < 3$	Moderate contamination	$PLI > 1$	Polluted
$2 < I_{geo} < 3$	Moderate to heavily contaminated	$3 \le C_f < 4$	Moderate to high contamination		
$3 < I_{geo} < 4$	Heavily contaminated	$4 \le C_f < 5$	High contamination		
$4 < I_{geo} < 5$	Heavily to extremely contaminated	$5 \le C_f < 6$	High to very high contamination		
$5 < I_{geo}$	Extremely contaminated	$C_f \ge 6$	Extreme contamination		

[a] Muller (1969), [b] Ma et al., (2022), [c]Mkude et al., (2021)

Quality Assurance

To guarantee the accuracy of the test outcomes, suitable safety precautions and quality assurance protocols were adhered to. All chemicals and reagents employed were of analytical and trace-metal grades. The glassware and utensils were thoroughly cleaned, and distilled water was utilized throughout the study. Samples were handled carefully to reduce cross-contamination risks, and reagent blank determinations were conducted to adjust the instrument readings.

The validation of the sample preparation procedure was accomplished through a recovery study. The mean recoveries (± relative standard deviation) acquired were as follows: Cr: 101 ± 3.4%; Cd: 89 ± 3.1%; Zn: 98 ± 3.3%; Cu: 96 ± 2.7%; and Fe: 94 ± 3.5%. Post-calibration, the sample solutions were promptly drawn into the AAS instrument for direct measurement of the metal concentrations (Table 2).

Table 2: Calibration Curve A vis Conc. of Heavy Metals (mg/L)

Metal	Model for Absorbance vis Conc.	R^2
Fe	y = 0.0362×	0.9946
Cr	y = 0.0791×	0.9951
Cu	y = 0.0834×	0.9938
Zn	y = 0.0214×	0.9973
Cd	y = 0.0168×	0.9972

The AAS sequence included a QC sample and a blank after 10 soil samples. A second identical sequence was run with the duplicate samples.

RESULTS AND DISCUSSION

The pH of the Sludge Used as Manure

The interplay between pH, acidity, and alkalinity holds a crucial role in biological wastewater treatment, emphasizing the importance of monitoring and regulating pH for optimal outcomes (Ekama and Wentzel, 2008). pH variability significantly impacts agricultural productivity as it affects micronutrient availability in the soil. It's widely understood that as soil pH decreases, its capacity to adsorb and retain metals diminishes (Brady and Weil, 2002). The examined sewage sludge revealed an average acidic pH value of 5.93 ± 1.05, with a minimum of 4.59 and a maximum of 7.90 (Table 1).

These recorded values fall notably below recent findings (You et al., 2021), where pH levels ranged between 6.54 and 7.16, indicating weak alkalinity. Shrivastava and Banerjee (1998) highlight the necessity of adjusting the soil pH for this type of sludge within a range of 6.5–7.0 to regulate heavy metal availability in sludged soils. Modifying soil pH to a specific value through liming can diminish the mobile fraction of numerous heavy metals in the soil. To counter potential soil acidification stemming from these alterations, Alvarenga et al. (2016) suggest simultaneous application of sludge treatment and chemicals in agricultural land to create an acid-base buffer system's effect. Such systems maintain soil pH within the boundaries of the acidic component's pKa (Hamdi et al., 2019). Given the pH of agricultural soils in Moshi Municipality at 5.93 ± 1.05, the pKa of the acidic component within the buffer system must align within this range. In the scenario of sludge application on arable lands, the buffer system of $CaCO_3$-$Ca(HCO_3)_2$ was considered, possessing an acid component with a pKa value of 7.48.

The Concentration of Chemical Elements in the Sludge

Concentration of Total Nitrogen (N_t), Phosphorus (P) and Pottasium (K) in the Sludge

The concentration of N_t, P and K observed in Moshi municipality wastewater treatment sludge is shown in Table 3.

Table 3: The **Concentration of Heavy Metals (mg/kg)**

Variable	**Minimum**	**Maximum**	**Mean**	**Std Deviation**
pH	4.59	7.90	5.93	1.05
K	1.00	2.20	1.67	0.41
P	13.80	39.60	26.81	11.64
N_t	0.21	1.51	0.76	0.60
Cu	0. 10	3.42	1.63	1.18
Fe	b.d.	86.96	53.32	3.66
Zn	b.d	7.91	3.74	2.15
Cr	6.06	8.40	7.49	0.70
Cd	BDL	0.16	0.02	0.05

Source: Researcher (2018); BDL = below detection limit

The obtained sewage sludge sample exhibited substantial concentrations of nitrogen, phosphorus, and potassium. The average quantities of N_t, P, and K in the sewage sludge were 0.76 ± 0.60, 26.81 ± 11.64, and 1.67 ± 0.41 mg/kg, respectively. These figures surpass the recently detected values reported by Głodniok et al. (2021), which recorded Nitrogen at 0.44 mg/kg, phosphorus at 0.30 mg/kg, and potassium at 0.81 mg/kg. Gorlach and Mazur (2002) explain that this discrepancy is expected due to the low pH of the sewage sludge (5.93 ± 1.05), wherein these micronutrients contend more with soluble aluminum (Al) and H^+. The presence of H^+ and Al^{3+} displaces other exchangeable cations such as (N^{3+}, P^{3+}, and K^+), mobilizing them into the soil solution and consequently heightening the potential for leaching.

Concentration of Heavy Metals in the Sludge

The introduction of this sludge, with its acidic pH level (5.93 ± 1.05), contributes to the soil's acidic condition, potentially leading to the liberation of heavy metals bound to metal oxides (Table 3). The concentration of Cd in the sludge samples varies from Below Detection Limit (BDL) to 0.02 ± 0.05. These figures were notably 58 times lower than the values previously identified in Poland (Milik et al., 2017).

Cadmium concentrations were notably lower compared to the recommended soil concentration of 100 mg/kg in Tanzania (TZS, 2003), yet they may still pose risks to human and environmental health. The presence of Cd primarily stems from the mixing of industrial effluents with wastewater channels (Nassef et al., 2007). The frequent utilization of cadmium-based phosphatic fertilizers in various agricultural practices contributes significantly to Cd presence in wastewater bodies. Moreover, Cd is prevalent in rechargeable batteries for household use (Ni-Cd batteries), paints, photography, and urban wastewater originating from diverse sources such as food items, detergents, body care products, and stormwater. Elevated Cd levels can lead to kidney dysfunction, high blood pressure, and organ damage (Nassef, 2007; Rajappa et al., 2010).

Copper, iron, and zinc are essential elements, yet they pose potential toxicity risks at elevated concentrations and can induce deficiency symptoms even at low environmental levels. Iron (Fe) plays a pivotal role in diverse physiological and biochemical processes within plants, serving as an electron carrier, contributing to chlorophyll synthesis, and upholding chloroplast structure and function—making it a crucial trace element for plants (Roy et al., 2013). The average concentration of iron in the sludge samples was 53.32 ± 3.66 mg/kg. This value surpasses the previously recorded values in India, which were 10.5 ± 0.42 mg/kg (Roy et al., 2013), yet remains lower than the values detected in Turkey, averaging at 367.0 mg/kg (Dolgen et al., 2007).

The copper concentration in the sludge derived from the examined sewage treatment plant ranged between 0.10 and 3.43 mg/kg, averaging at 1.63 ± 1.18 mg/kg. These values align closely with previously detected values in Poland (Bowszys et al., 2015), ranging from 1.51 to 1.98 mg/kg. However, they were notably lower than those detected earlier in Poland (Milik et al., 2017), which ranged from 107.69 to 160.36 mg/kg. While copper is an essential trace element for life, its toxicity escalates at higher concentrations. Copper originates from diverse sources like cleaning products, cosmetics, shampoos, fuels, and ointments (Tiruneh et al., 2014). Furthermore, it's present in various food items, oils, lubricants, paints, pigments, and other alloy-related industries. Additionally, copper emissions can arise from small-scale commercial activities, warehouses, and buildings equipped with commercial heating systems (Sternbeck, 2000).

Copper, while essential for numerous organisms, also holds significant toxicity. It's known to elicit several adverse effects on both crops (Baryla et al., 2000) and soil microorganisms, potentially impacting soil fertility negatively.

The sludge samples revealed an average zinc content of 3.74 ± 2.15 mg/kg. These values were lower than previously detected values (Bowszys et al., 2015), ranging from 6.41 to 15.14 mg/kg. Zinc stands as an essential trace element for humans, animals, and plants. However, elevated zinc concentrations pose potential toxicity to plants, humans, and animals (Ohnessorge and Wilhelm, 1991).

Although zinc (Zn) poses relatively low toxicity to humans and animals, studies indicate potential allergies associated with high levels of zinc, and zinc poisoning along the food chain may disrupt copper metabolism (Ohnessorge and Wilhelm, 1991). Zinc originates from natural, domestic, and industrial sources (Solomons, 2001).

Household zinc compounds are commonly present in a variety of products like cosmetics, shampoos, lubricants, medications, and detergents. These sources encompass various industrial processes such as galvanization, brass and bronze alloy production, tire and battery manufacturing, as well as plastics, rubber, fungicides, and textiles. Zinc chloride is utilized in taxidermy, embalming solutions, construction materials, specialized cements like zinc oxide and zinc fluorosilicate, dental applications utilizing zinc oxide, cosmetics, and pharmaceuticals (Solomons, 2001). Industrial zinc sources include wastewater streams from steelworks, fiber manufacturing, wood-pulp production, and wastewater generated from plating and metal processing industries (Obladen et al., 1998).

Chromium (Cr) stands as the seventh most abundant element globally and ranks 21st in the Earth’s crust, typically with an average concentration of 100 mg/kg (Puzon et al., 2008). The maximum permissible concentration of chromium in drinking water is 0.10 mg/L due to the toxic effects of Cr(VI) and the potential conversion of Cr(III) to Cr(VI) (WHO, 1996). The sludge samples exhibited an average chromium level of 7.49 ± 0.70 mg/kg. These values are lower than those previously detected (Momeni et al., 2019) with an average of 16.62 ± 2.18 mg/kg and also fall below Tanzania's acceptable soil standard of 200 mg/kg (TZS, 2003).

According to Álvarez et al. (2002), the reduced heavy metal concentrations in sludge may be linked to the weight loss of fresh sludge during anaerobic digestion and, subsequently, an increase in dry matter content during sludge dehydration. The impact of increased dry matter (DM) content on total heavy metal concentrations in sludge was observed in dewatered sludge, characterized by higher DM and metal contents compared to primary or secondary sludge.

Heavy Metals Pollution Levels

Geo-accumulation Indices

Figure 2a showcases the geo-accumulation index employed to gauge heavy metal accumulation in the study area, resulting in values of -0.4091, -4.01714, -5.3748, -5.2543, and -4.4933 for Fe, Cr, Cu, Zn, and Cd respectively. As per Muller (1969), the site is categorized as practically uncontaminated due to all values falling below 0 (refer to Table 1). These values are notably lower than those determined in prior assessments (Jena et al., 2019), where the Igeo values for Cr, Cu, Cd, and Zn were 0.16, 0.37, 0.65, and 0.67 respectively.

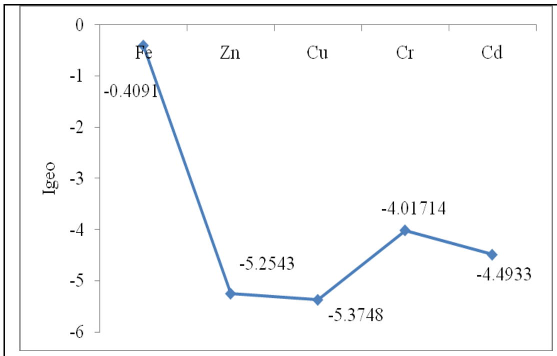

Fig 2a: Geoaccumulation Index Determined

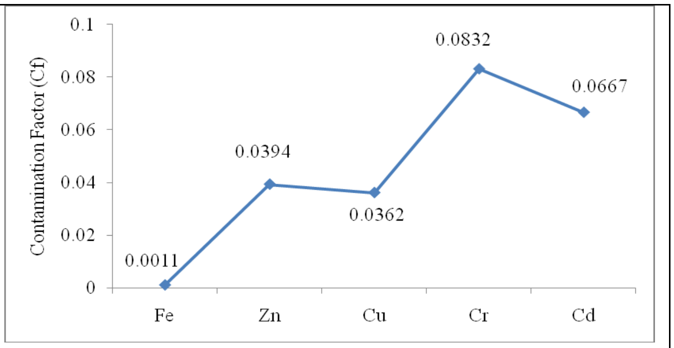

Fig 2b: Contamination Factor (Cf) Determined

Single pollution index analysis of heavy metals

The Contamination factor (CF) pollution index for the five heavy metal elements was computed using the single-factor pollution index method, and the outcomes are displayed in figure 2b. The CF values for Fe, Cr, Cu, Zn, and Cd were 0.0011, 0.0832, 0.0362, 0.0394, and 0.0667 respectively, all falling within the low contamination category (Table 1).

Pollution Load Index (PLI)

The Pollution Load Index (PLI) for the sludge obtained from the Moshi Municipal water treatment plant, used as manure, was determined to be 0.0244. This figure corresponds to values previously detected (Mkude et al., 2021) in the Wami River, ranging from 0.007 to 0.014 across different river sections. Following pollution categorizations (Table 1), the calculated PLI remains below 1, indicating that the manure exhibits an 'excellent' quality regarding the pollution extent from the analyzed heavy metals.

CONCLUSION AND RECOMMENDATIONS

The composition of sewage sludge greatly depends on the quality of the processed wastewater. Analyzing the total concentrations of heavy metals (Zn, Fe, Cd, Cu, and Cr) in sewage sludge remains a critical aspect for evaluating the potential risks these elements pose to the environment and living organisms. It's been observed that the concentrations of heavy metals in sewage sludge fall within the permissible norms outlined by the Tanzania Bureau of Standards (TZS, 2003) for soil, indicating suitability for agricultural use.

The wastewater treatment plants in Moshi Municipality primarily handle domestic wastewater and discharge from consumers engaged in economic activities that don't involve substantial industrial pollution. Typically, any industrial wastewater in the area is initially treated within the sewage treatment plants of major industrial facilities before being introduced into the municipal wastewater system.

This accounts for the notably low levels of heavy metals detected in the analyzed sludge, well below the limits stipulated by current legislation. Another contributing factor to the reduced heavy metal load is the limited industrial activity and relatively modest economic development in the Moshi Municipal area, resulting in very few industries discharging wastewater into the river.

The significance of these detected low heavy metal concentrations shouldn't be underestimated, given their potential to profoundly affect both environmental quality and human health. This is attributed to their persistent nature in the environment and their tendency to accumulate in plants and vegetables. Consequently, it's advisable to ensure proper treatment of sludge from wastewater treatment plants to diminish the levels of contaminants to safe thresholds for the environment and human health before considering its use as fertilizer or manure. This treatment plays a pivotal role in mitigating the risks associated with potentially hazardous substances present in the sludge. Without adequate treatment, these contaminants could pose significant threats to soil quality, water systems, and ultimately human health when applied in agricultural contexts. Thus, ensuring proper treatment is essential to transform the sludge into a safer and beneficial product for land application while minimizing potential adverse impacts.

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REFERENCES

Arvas, Ö., S. Z. Çelebi and I. H. Yilmaz, (2011), Effect of sewage sludge and synthetic fertilizer on pH, available N and P in pasture soils in semi-arid area, Turkey. African Journal of Biotechnology, 10 (73): 16508–16515

Bowszys, T., Wierzbowska, J., Sternik, P. and Busse M. K. (2015), Effect of The Application of Sewage Sludge Composton The Content And Leaching of Zinc and Copper from Soils Under Agricultural Use, Journal of Ecological Engineering 16(1), 1–7

Brady N. C. and Weil R. R. (2002), The Nature and Properties of Soils. Pearson Education. 13th ed. 387- 391

Deenik, J. L. Cooney, M. J. (2016), The Potential Benefits and Limitations of Corn Cob and Sewage Sludge Biochars in an Infertile Oxisol, Sustainability, 8 (2), 131

Dolgen D., M., Alpaslan, N. and Delen, N. (2007), Agricultural recycling of treatment-plant sludge: A case study for avegetable-processing factory Journal of Environmental Management 84,274–281

Edori O. S. and Kpee F. (2017), Index models assessment of heavy metal pollution in soils within selected abattoirs in Port Harcourt, Rivers State, Nigeria. *Singapore J. Sci. Res.*, 7, 9-15

Ekama, G.A., Marais, G.V.R., (1984), Nature of Municipal Wastewaters. Theory, Design, and Operation of Nutrient Removal Activated Sludge Processes. Water Research Commission, Pretoria.

Głodniok, M.; Deska, M.; Kaszycki, P. (2021), Impact of the Stabilized Sewage Sludge-Based Granulated Fertilizer on Sinapis alba Growth and Biomass Chemical Characteristics. Biol. Life Sci. Forum 3(35), 2-9

Goldan, E.; Nedeff, V.; Barsan, N.; Culea, M.; Tomozei, C.; Panainte-Lehadus, M.; Mosnegutu, E. (2022), Evaluation of the Use of Sewage Sludge Biochar as a Soil Amendment, A Review. Sustainability 14, 5309 -5331

Gray N. F. (2010), Water Technology: An Introduction for Environmental Scientists and Engineers. 3rd ed. IWA Publishing

Hakanson, L. (1980), An ecological risk index for aquatic pollution control. A Sedimentol. Approach. *Water Res.* 14, 975–1001

Hamdi, H., Hechmi, S.,Khelil, M. N., Zoghlami, I. R., Benzarti, S. Tlili, S.M., Hassen, A. and Jedidi, N. (2019), Repetitive land application of urban sewage sludge: Effect of amendment rates and soil texture on fertility and degradation parameters. Catena 172, 11–20

Han, H.; Hu, S.; Syed-Hassan, S.S.A.; Xiao, Y.; Wang, Y.; Xu, J.; Jiang, L.; Su, S.; Xiang, J. (2017), Effects of Reaction Conditions on the Emission Behaviors of Arsenic, Cadmium and Lead during Sewage Sludge Pyrolysis. Bioresour. Technol. 236, 138–14

Hseu Z. Y. (2004), Evaluating heavy metal contents in nine composts using four digestion methods. Bioresour. Technol. 95,53–59

Iticescu C., Georgescu, L. P. Murariu, G., Circiumaru, A., Timofti M. (2018), The Characteristics of Sewage Sludge Used on Agricultural Lands Recent Advances on Environment, Recent Advances on Environment, Chemical Engineering and Materials, AIP Conf. Proc. 2022, 020001-1–020001-8

Jamil, M. Qasim M., Umar, M. (2006), Utilization of Sewage Sludge on Organic Fertilizer in Sustainable Agriculture, J. of Appl. Science, 6(3), 531-535

Jena, V., Ghosh, S., Pande, A., K. Maldini A. and Matic, N., (2019). Geo-Accumulation Index of Heavy Metals in Pond Water Sediment of Raipur, Biosci. Biotech. Res. Comm. 12(3): 585-588

Kihila, J., Mtei, K. M. and Njau K. N. (2014), Wastewater treatment for reuse in urban agriculture; the case of Moshi Municipality, Tanzania, *Physics and Chemistry of the Earth* 72-75, 104-110

Kowalska J. B, Mazurek R. , Gąsiorek M. and Zaleski T. (2018), Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination-a review. Environ Geochem Health 40(6),2395–2420

Lacatusu, R. (2000), Appraising Levels of Soil Contaminationand Pollution with Heavy metals. In: Land Iformation Systems for Planning the Sustainable Use of Land Resources, Heinike, H. J., Eckselman, W., Thomasson, A. J., Jones, R. J. A., Montanarella, L. and Buckeley, B. (Eds), Office of OfficialPublication of the European Communities, Luxembourg, pp:393 - 402

lvarenga, P., Farto, M., Mourinha, C. and Palma, P. (2016), Beneficial Use of Dewatered and Composted Sewage Sludge as Soil Amendments:

Behaviour of Metals in Soils and Their Uptake by Plants. Waste Biomass Valoriz. 7, 1189–1201

Ma, T.; Zhang, Y.; Hu, Q.; Han, M.; Li, X.; Zhang, Y.; Li, Z.; Shi, R. (2022), Accumulation Characteristics and Pollution Evaluation of Soil Heavy Metals in Different Land Use Types: Study on the Whole Region of Tianjin. Int. J. Environ. Res. Public Health, 19,10013

McGrath, D., Postma, L., McCormack, R.J. and Dowdall, C. (2000), Analysis of Irish sewage sludges: Suitability of Sludge for use in agriculture. Irish Journal of Agricultural and Food Research 39(1), 73-78

Mehmood, S.; Ahmed, W.; Juha M.; Alatalo, M.J.; Mahmood, M.; Muhammad, I.; Ditta, A.; Ali, F.E.; Abdelrahman, H.; Slaný, M.; Antoniadis, V. (2022), Herbal plants- and rice straw-derived biochars reduced metal mobilization in fishpond sediments and improved their potential as fertilizers. Sci. Total Environ. 826, 154043

Metcalf M. and Eddy, D. (1991), Wastewater engineering: Treatment disposal and reuse. New York: McGraw-Hill

Gomez A., Leschber R. and L’hermite P. (1986), Sampling problems for the chemical analysis of sludge, solid, and plants, Commission of European Communities, Elsevier Applied Science Publishers, pp: 168-93

APHA, AWWA, WEF (1998). Standard method for the examination of water and wastewater, 20th E

Milik, J., Pasela, R., Lachowicz, M. and Chalamońsk, M. (2017), The Concentration of trace elements in sewage sludge from wastewater treatment plant in Gniewino, *Journal of Ecological Engineering* 18 (5), 118–124

Mkude I. T., Onoyinka, A. A. and Kodom K. (2021), Assessment of selected heavy metals in water and sediment along Wami river, Tanzania, *Tanzania Journal of Science and Technology*, 4(1), 1 - 15

Momeni, S., Alimohammadi M., Naddafi, K., Nabizadeh R., Changani F. Zarei, A. and Rahmatinia M. (2019), Study of sludge from the largest wastewater treatment plant in the Middle East (Southern Tehran, Iran) based on chemical and microbiological parameters for use in agriculture, Desalination and Water Treatment 160, 153–160

Muchuweti, A.; Birkett, J. W.; Chinyanga, E.; Zvauya, R.; Scrimshaw, M. D.; Lester, J. N. (2006), Heavy metal content of vegetables irrigated with mixtures of wastewater and sewage sludge in Zimbabwe: Implications for human health. *Agric. Ecosyst. Environ.* 112, 41–48.

Muller, G. (1969). Index of geoaccumulation in sediments of the Rhine River. Geol. J., 2, 109–118

Nassef, M., Hannigan, R., EL Sayed, K. A., Tahawy, M. S. (2007), Determination of some heavy metals in the environment of Sadat industrial city. Proceeding of the 2nd 17

Environmental Physics 18 Conference 14 (152), 145–152

Nilsson, C. and Dahlström H. (2005), Treatment and disposal methods for wastewater sludge in the area of Beijing, China. M.Sc. Thesis, Department of Water and Environmental Engineering, Lund Institute of Technology, Sweden

Obladen M, Kampmann W, Renz H. (1998), Zinc deficiency in rapidly growing preterm infants. Acta Paediatr 87:685–91.

Olumuyiwa, O.O.; Simiso, D.; Omotayo, R.A.; Nindi, M. M. (2014), Assessing the enrichment of heavy metals in surface soil and plant (Digitaria eriantha) around coal-fired power plants in South Africa. *Environ. Sci. Pollut. Res.* 21, 4686–4696

Puzon G. J., Tokala R. K., Zhang H., Yonge D., Peyton B. M. and Xun L.(2008), Mobility and recalcitrance of organo-chromium(III) complexes. Chemosphere. 70(11), 2054–2059

Rajappa, B., Manjappa, S., Puttaiah, E.T., 2010. Monitoring of heavy metal concentration in groundwater of Hakinaka Taluk, India. *Contemporary Engineering Sciences* 3 (4), 183–190

Renaud, M.; Chelinho, S.; Alvarenga, P.; Mourinha, C.; Palma, P.; Sousa, J. P.; Natal-da-Luz, T. (2017), Organic wastes as soil amendments - Effects assessment towards soil invertebrates, J. *Hazard. Mater.* 330, 149–156

Roy,T., Singh, R.D., Biswas D.R. and Patra A.K. (2013), Effect of sewage sludge and inorganic fertilizers on productivity and micronutrients accumulation by Palak (Beta vulgaris) and their availability in a Typic Haplustept, *Journal of the Indian Society of Soil Science*, 61(3), 207-218

Ruiz-Gomez, N.; Ruiz-Gómez, N.; Quispe, V.; Ábrego, J.; Atienza-Martínez, M.; Murillo, M. B.; Gea, G. (2017), Co-pyrolysis of sewage sludge and manure, *Waste Manag.* 59, 211–221

Shrivastava S. K. and Banerjee D. K. (1998), Operationally determined speciation of copper and zinc in sewage sludge, *Chemical Speciation and Bioavailability* 10(4), 137 – 143

Singh, R. P. and Agrawal, M. (2010), Variations in heavy metal accumulation, growth and yield of rice plants grown at different sewage sludge amendment rates. *Ecotoxicol. Environ. Saf.* 73, 632–64

Singh, R. P. and Agrawal, M. (2017), Effects of sewage sludge amendment on heavy metal accumulation and consequent responses of beta vulgaris plants. *Chemosphere* 67, 2229–2240

Solomons N. W. (2001), Dietary sources of zinc and factors affecting its bioavailability Food and Nutrition Bulletin, 22(2), 139 – 154

Tanzania Standards for Receiving Water, Effluents and soils (TZS 789:2003). Tanzania Bureau of Standards

Tiruneh, A. T, Fadiran A. O. and Mtshali J. S. (2014), Evaluation of the risk of heavy metals in sewage sludge intended for agricultural application in Swaziland, *International Journal of Environmental Sciences* 5(1), 197 - 216

Tsadilas, C. Samaras, V. Evangelou, E. Shaheen, S. M. (2014), Influence of Fly Ash and Sewage Sludge Application on Wheat Biomass Production, Nutrients Availability and Soil Properties. *Int J Coal SciTechnol*, 1(2): 221-226

Urra, J.; Alkorta, I.; Mijangos, I.; Epelde, L.; Garbisu, C. (2019), Application of Sewage Sludge to Agricultural Soil Increases the Abundance of Antibiotic Resistance Genes without altering the composition of prokaryotic communities. *Sci. Total. Environ*. 10, 1410–142

World Health Organization, (1996), Health criteria and other supporting information," in guidelines for drinking-water quality, pp. 206–215, World Health Organization, Geneva, Switzerland

Yaylal-Abanuz G. (2011) Heavy metal contamination of surface soil around Gebze industrial area, Turkey. *Microchem J.,* 99, 82–92

You, M., Hu, Y. Yan, Y. and Yao J. (2021), Speciation characteristics and ecological risk assessment of heavy metals in municipal sludge of Huainan, China, *Molecules.* 26(21), 6711.

Zahran M. A. E., El-Amier Y. A., Elnaggar A. A., Mohamed H. A. E. and El-Alfy M. A. E. (2015) Assessment and distribution of heavy metals pollutants in Manzala Lake, Egypt. J Geosci Environ Protect 3,107–122

Zhang, Q. H. Yang, W. N. Ngo, H. H. Guo, W. S. Jin, P. K., Dzakpasu, M., Yang, S. J., Wang, Q., Wang, X.C., Ao, D. (2016), Current status of urban wastewater treatment plants in China, Environment International, 92–93, 11–22.