Journal of Water Resources, Engineering, Management and Policy
DOI: https://doi.org/10.56542/wi.jwempo.v1.i2.a1.2024

Original Article

Assessing Physicochemical and Heavy Metal Characteristics in Leachate and Groundwater around Pugu Kinyamwezi Dumpsite, Dar es Salaam

Gift Isaack Marandu[1*], Kassim Ramadhani Mussa[1], Offoro Neema Kimambo[1], and Amina Amri Hamad[1]

[1] Sokoine University of Agriculture, College of Natural and Applied Science, Department of Geography and Environmental Studies P.O.BOX 3038, Morogoro, Tanzania.
***Corresponding Author**: giftmarandu98@gmail.com

Received: 20 March 2024 / Accepted: 28 October 2024 / Published: 20 December 2024

Abstract
This study aimed to investigate the extent and dynamics of groundwater contamination around the Pugu-Kinyamwezi dumpsite in Dar es Salaam, Tanzania. Specifically, it evaluated the physicochemical and heavy metal characteristics of leachate during the dry and wet seasons and assessed its impacts on the surrounding groundwater reservoirs across both seasons. Field sampling of leachate and groundwater was conducted in four directions around the dumpsite during both dry and wet seasons, with sixteen groundwater and three leachate samples collected per season. Physicochemical analyses (pH, TDS and EC) were performed onsite, and heavy metal analyses (Pb, Cr, Cd and Cu) were carried out in the laboratory. Results showed that leachate exhibited higher concentrations of physicochemical and heavy metal parameters during the wet season compared to the dry season. Similarly, groundwater contamination levels were generally higher in the wet season, except for one direction where concentrations were significantly lower during the wet season. Groundwater contamination exceeded WHO drinking water quality thresholds, rendering it unsuitable for consumption. Positive correlations between physicochemical and heavy metal parameters in groundwater indicated waste leaching influence, while decreasing concentrations with distance from the dumpsite highlighted localized impacts. Principal Component Analysis (PCA) revealed significant contributions from surface runoff and direct infiltration. These findings underscore the urgent need for improved waste management and remediation strategies to mitigate environmental risks.

Keywords: Pugu-Kinyamwezi dumpsite, leachate infiltration, groundwater contamination, environmental risks.

1 Introduction

Groundwater entails water that exists and moves freely in the pore spaces and fractures in rocks and sediments beneath the Earth's surface (Razavi et al., 2019). The usage of groundwater emanates from domestic, agricultural, and industrial activities (Amano et al., 2022). Factors like landuse changes, saltwater intrusions and urbanization accelerated by human, threaten groundwater quality (Majolagbe et al., 2016). Due to urbanization, there comes high generation of solid wastes which leads to poor solid waste disposal (Sankoh et al., 2023). The presence of open dumpsites especially in Africa has led to groundwater contamination through leachate infiltration (Alao, 2023).

Globally, open dumpsites have been reported to significantly impact groundwater quality. For instance, in the Philippines, the Payatas dumpsite has caused severe groundwater contamination due to hazardous leachate infiltration (Omeiza et al., 2022). Similarly, in India, the Ghaziabad dumpsite has been reported to leach harmful chemicals into the groundwater (Zeng et al., 2021). In Africa, the problem is equally severe. The Olusosun dumpsite in Lagos, Nigeria, and the Dandora dumpsite in Nairobi, Kenya, have both led to significant groundwater pollution (Onwukeme et al., 2021; Olal, 2023). In Tanzania, the Vingunguti dumpsite in Dar es Salaam and the Kigogo dumpsite in Mwanza have been reported to cause groundwater contamination due to leachate (Mbwilo & Mahenge, 2022). Both of these sites have reported groundwater contamination, which has led to health-related diseases among consumers.

Leachate infiltration occurs when wastes on a dumping site are subjected to moisture or precipitation which in turn leads to the formation of water-based solutions infiltrating to the groundwater and contaminate it (Adeolu et al., 2011). Nevertheless, leachates physicochemical and heavy metal characteristics are influenced by several factors. The nature and quantities of wastes dumped in the area, bacterial activities on waste decomposition, seasons and dumpsite operations are some of the key factors influencing leachate composition (Okeke, 2021; Smahi et al., 2013). Leachates are composed of high concentrations of heavy metals, macro components, xenobiotic organic and inorganic ions and hence they may cause environmental problems like soil, water and air pollution (Al-Wabel et al., 2011; Abiriga et al., 2020).

Although leachate infiltration presents a significant risk to groundwater, its influence typically diminishes from proximal to distal sources. Consequently, nearby sources are at greater risk compared to those farther away (Essien et al., 2022). To establish the link between leachate movement and groundwater pollution it is important to take into consideration the measurement of both leachate and groundwater characteristics (Nagarajan et al., 2012). Such studies are scanty, nonetheless. Further research in this scope would provide insights into the extent of contamination and help develop mitigation strategies to protect groundwater resources and public health.

Many countries especially developing countries like Nigeria, Kenya, India, Philippines face a problem of leachate infiltration into the groundwater (Alao, 2023; Omeizaet al., 2022 & Olal, 2023). Wastes are disposed in uncontrolled manner without proper infrastructure or environmental safeguard (Aluko et al., 2022). This arises due to inadequate investments and limited expertise in constructing appropriate dumpsites (Yasin & Usman, 2017). In Tanzania, for instance, Pugu Kinyamwezi open dumpsite is likely to affect groundwater through leachate infiltration due to the absence of base liner, leachate collection systems, soil cover which puts at risk the safety, environmental and public health (Membe, 2015). The dumpsite might be impacting water sources through leachate movement.

The presence of heavy metals in leachate may accelerate groundwater contamination through them hence leachate characterization is important in order to know the impact of the dumpsite (Al-Wabel et al., 2011). In this respect Alao et al., 2023 analyzed leachate and groundwater around the dumpsite and revealed that leachate have high concentrations of Cd, As, Mn and Pb which were also found in the groundwater around the dumpsite. Moreover, high concentrations of Pb, Hg and Cu were found in Indian with high concentrations for both leachate and groundwater with Pb being the highest in terms of concentration (Alam et al., 2020). Reportedly, groundwater near the Pugu Kinyamwezi dumpsite is impacted by heavy metals namely Lead, chromium and Cadmium which may cause health related problems to the consumers (Yhdego & Mwashambwa, 2019). Nevertheless, the findings were too general to conclude that the pollution originated from the dumpsite as there was insufficient leachate characterization. Moreover, several seasonal influences such as water runoff, leachate percolation, and atmospheric deposition can hinder the movement of leachate into groundwater (Sankoh et al., 2023). This too was not considered in the study.

The opacity and insufficiency of studies which assessed the seasonal and spatial variation of physicochemical and heavy metal characteristics of both leachate and groundwater at Pugu-Kinyamwezi dumpsite motivated the design of this study to fill in this noticeable knowledge gap and contribute to the understanding of the contribution of leachate composition to groundwater contamination from

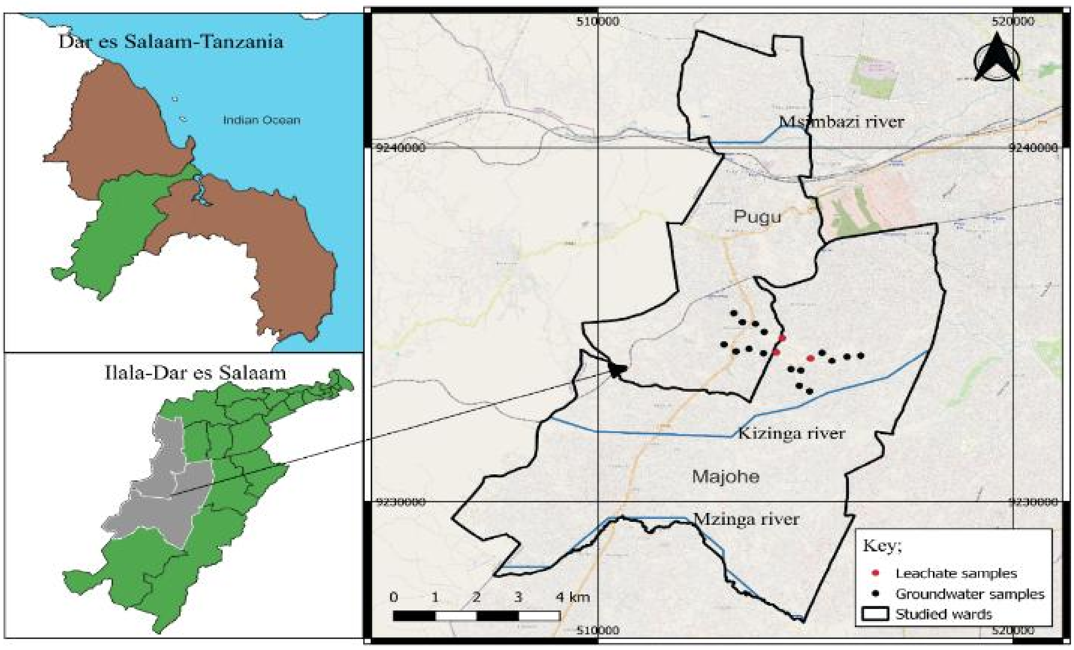

Fig ure 1. Study area map showing the sampling points

shallow aquifer around the Pugu-Kinyamwezi.

This study, therefore focused on deriving the linkage between physicochemical and heavy metal

Figure 1. Study area map showing the sampling points

characteristics of dumpsite leachate and groundwater around the dumpsite, considering the effect of seasons and distance from the dumpsite. The study involved measurements of leachate generated from the dumpsite together with the groundwater around it. This study is objected to fill the existing gap in understanding the relationship between leachate and groundwater contamination and to provide new insights into the seasonal and spatial variability of these pollutants. By addressing these gaps, this study aims to contribute novel findings that will inform better management and mitigation strategies for protecting groundwater resources and public health.

2 Materials and Methods

2.1 Description of the Study Area

The Pugu Kinyamwezi dumpsite operated under Dar es Salaam City Council, lies at longitude 39°08′ E and latitude 06°56′ S, spanning 75 hectares between Pugu ward and Majohe ward in Ilala Municipality, approximately 25 km from Dar es Salaam City Centre. Originally planned as a sanitary landfill, it currently functions as an open dumping site (Yhdego, 2019). The area experiences a bimodal rainfall pattern, with an average annual rainfall of about 1,100 mm, characterized by long, heavy rains from March to May, with a peak in April, and short, light rains from October to December (Mtoni et al., 2013). Geologically, the site comprises lower Miocene Kaolinitic Sandstone, featuring thick-bedded reddish-brown sandstone with minor siltstone, shale, and limestone (Mtoni et al., 2013). Hydrologically, the dumpsite is situated between two streams: Kinyamwezi stream to the North and Nyamaronda stream to the South, both fed by upstream water from

Pugu and Kazimzumbwi forest reserves (Yhdego, 2019). Additionally, it lies between two rivers: characteristics were analyzed onsite while the heavy metals were analyzed in the laboratory.

Table 1. Description of sampling points

Sampling Points	Sampling Name	Latitude	Longitude
North L	Northern Leachate	6°55’54.01”	39°8’22.50”
South L	Southern Leachate	6°55’50.64”	39°7’49.34”
West L	Western Leachate	6°55’33.98”	39°7’39.90”
GW N1	Groundwater North 1	6°55’53.86”	39°8’23.74”
GW N2	Groundwater North 2	6°55’53.19”	39°8’24.02”
GW N3	Groundwater North 3	6°55’53.57”	39°8’24.44”
GW N4	Groundwater North 4	6°55’54.02”	39°8’25.54”
GW S1	Groundwater South 1	6°55’55.31”	39°7’39.29”
GW S2	Groundwater South 2	6°55’49.56”	39°7’34.80”
GW S3	Groundwater South 3	6°55’48.41”	39°7’37.29”
GW S4	Groundwater South 4	6°55’49.20”	39°7’29.89”
GW E1	Groundwater East 1	6°56’4.65”	39°8’4.85”
GW E2	Groundwater East 2	6°56’4.54”	39°8’7.24”
GW E3	Groundwater East 3	6°56’5.64”	39°8’7.35”
GW E4	Groundwater East 4	6°56’7.70”	39°8’8.95”
GW W1	Groundwater West 1	6°55’33.03”	39°7’37.55”
GW W2	Groundwater West 2	6°55’30.98”	39°7’36.95”
GW W3	Groundwater West 3	6°55’31.61”	39°7’32.89”
GW W4	Groundwater West 4	6°55’33.08”	39°7’31.14”

Msimbazi River to the North and Kizinga River to the South, with potential pollution from dumpsite leachate affecting these water bodies through surface runoff or groundwater-surface water interaction, particularly impacting the closer Kizinga River (Figure 1).

2.2 Study Design and Sampling Techniques

To investigate the extent of groundwater contamination, field sampling of leachates and groundwater was done in two season’s dry and wet seasons, considering the four directions of the dumpsite. Leachate samples were collected from the north, south, and west, while groundwater samples were collected from the north, south, west, and east relative to the dumpsite. A leachate sample was not collected from the Eastern direction due to inaccessibility to the direction. The sampling points were designated according to the directions North L, South L and West L for leachate samples (Table 1) and N1 to N4, S1-S4, W1-W4, E1-E4 for groundwater samples (Table 2), and Physicochemical

A total of 16 groundwater samples and three (3) leachate samples were collected around and within the Pugu-Kinyamwezi dumpsite during the dry and wet seasons. Before sampling, the wells were purged for five minutes to eliminate stagnant water. Groundwater and leachate samples for heavy metal analyses were collected on nitric acid pre-cleaned plastic bottles and stored in a cooler containing ice cubes according to the standard method APHA14 (Vishwakarma et al., 2023). The samples were then transported into the laboratory pre-filtered and stored prior to heavy metal analysis.

The geographic locations of the sampling points were determined using a hand-held Global Positioning System (GPS) at a reference datum of the World Geodetic Survey of 1984 (WGS84) Geographic Coordinate System. The Potential for Hydrogen (pH), Electrical Conductivity (EC), and Total Dissolved Solids (TDS) were measured during sample collection using a multi-parameter pH meter, HACH HQ 40D and Conductivity meter, HACH HQ 30D respectively. The heavy metal elements Lead (Pb), Chromium (Cr), Cadmium (Cd) and Copper (Cu) were analyzed using an Atomic Absorption Spectrophotometer (AAS Analyst 100) at the University of Ardhi laboratory, Dar es Salaam, Tanzania.

2.2.1 Physiochemical and Heavy Metal Analysis of Leachate and Groundwater

Leachate and groundwater samples were collected in 1-liter polyethylene bottles that had been rinsed with the respective samples and acidified with nitric acid. The samples were stored at 4°C prior to heavy metal analysis in the laboratory. The process of acidification helps prevent metal adsorption on the walls of sampling bottles, minimizes biological activities, and prevents precipitation, thereby retaining metals in the sample for accurate analysis (Vishwakarma et al., 2023). All the samples were analyzed for the contents of Pb, Cr, Cd and Cu using an AAS at the Chemistry laboratory of Ardhi University - environmental engineering laboratory. The pH meter was calibrated using pH 4, 7, and 10 buffer standard solutions before sample analysis, ensuring accurate pH measurements. Similarly, the conductivity meter was calibrated using 1413 µS/cm and 12.88 mS/cm standard conductivity solutions. The probes were first cleaned with distilled water and then immersed in the respective standard solutions, ensuring thorough calibration by stirring until the meter displayed the suggested concentrations. Following calibration, the samples were analyzed for pH, electrical conductivity (EC), and total dissolved solids (TDS), allowing for precise measurement and analysis of these parameters in the samples. In the laboratory the samples were pre-filtered using 0.45-micron cellulose filters and stored at 4°C. The reagents utilized included distilled water, aqua regia (mixed at a ratio of 1 part concentrated hydrochloric acid (HCI) to 3 parts concentrated nitric acid), and sulfuric acid (H_2SO4) for the purposes of sample digestion and extraction. The instrument's detection limit was established at 0.01 mg/L, ensuring it could detect even minute concentrations of metals, while consistently achieving an accuracy of over 98% across all experimental analyses.

2.2.2 Statistical analysis

Descriptive statistics, correlation and principal component analyses were the three major statistical analyses carried out in this study. The Statistical Package for Social Sciences (SPSS.20) software was used to generate the descriptive statistics, Pearson's correlation model and Principal components.

Descriptive statistics were used to compare the means of both leachate and groundwater data across different seasons to investigate seasonal variations Pearson's correlation was used to quantitatively evaluate the interrelationships between the physicochemical parameters and heavy metal together with distances indicated further in equations 1 and 2.

$$\text{Mean} = \sum Xi/n \qquad (1)$$

Were,
Xi= ith observation
n= Number of Observations

Correlational analysis which will be used in this study is as shown on the equation ii below;

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y^2-(\sum y)^2]}} \qquad (2)$$

Where:
r = Correlation coefficient
N = Number of observations
x, y = Data points

PCA was utilized to verify the infiltration of leachates into groundwater. Employing Varimax with Kaiser Normalization technique, PCA reduced dataset dimensionality, aiding in confirming this infiltration. As Sankohet al. (2023) noted, PCA was employed to discern correlations among physicochemical properties and heavy metals, thereby identifying the primary processes influencing groundwater quality.

According to Markic et al. (2015), a general guideline dictates that only factors possessing eigenvectors surpassing one are extracted for subsequent analyses. The principal component of data vector X, comprising I observations of J variables, can be expressed through score and vector representations, as depicted in Equation. (3).

$$\chi = TP' + E \quad (3)$$

In this formulation, the variables in matrix X undergo standardization. T (I, J) represents the matrix of J principal components, while P′ denotes the transpose of the initial dataset. Additionally, E signifies the residual matrix.

3 Results and Discussion

3.1 Physicochemical and Heavy Metals Concentrations in Leachate

The characteristics of the leachate samples collected at the dumpsite area during the dry and wet seasons are as presented in Table 2. The concentration of parameters varies in both the dry and the wet season in the Northern, Southern and Western directions of the dumpsite.

3.3.1 pH

The results in Table 2 show that the leachate pH concentrations are statistically different during the seasons and were higher during the wet season ranging from 9.2 to 9.69 as compared to the dry season, which ranges from 8.2 to 8.55 in both directions of the dumping site. The pH range indicates that the leachate is alkaline irrespective of the season. Arguably, the increase of leachate pH during the wet over dry season might be due to the increase of microbial activities, particularly waste deterioration and degradation which is highly influenced/catalyzed by rainfall (Kamble et al., 2020). Further to that, Rashid et al. (2022) demonstrated that the age of the landfill can be inferred from the pH of leachate as either old (> 7.5), medium (5.5 - 7.5) and or young aged (< 5.5) years. From the leachate results where pH is higher in both directions and with seasons, implies that the dumpsite is at the stage where leachate is converted into methane and carbon dioxide as a result it causes the rise of pH (methanogenic phase). During this stage the heavy metals are removed by precipitation and complexation accelerated by the high pH values (Zahari & Hameed, 2005).

3.3.2 TDS and EC

TDS and EC were lower during the wet season over the dry season in the Northern and Western directions but slightly higher in the Southern direction as indicated in Table 2. EC concentrations ranged from 29000 to 46000 mg/L during the dry season and 26130 to 48009 during the wet season. The concentration of TDS during the dry season ranged from 14750 to 23180 mg/L while in the wet season it ranged from 13050 to 24102 mg/L. Lower values in the Northern and Western directions can be attributed to influx of rainwater into the leachate which causes dilution and decrease the concentrations of dissolved solids (Zeng et al., 2021). Higher values in the Southern direction result from the continuous dumping of newly coming wastes from the collection points, as it is the most active part of the dumping site. High TDS concentrations > 10,000 in the samples indicates that leachate contains high amount of salts, minerals and heavy metals (Sanga et al., 2022). Moreover, high concentrations of TDS and EC in the Southern direction sample in both seasons might be due to short storage time as it is the most active part of the dumpsite hence contributes more to the dissolved material in the leachate. Elevated levels of TDS and EC in the leachate samples signify potential hazards to the surrounding environment, indicating that untreated leachate poses a threat to contamination. Therefore, it is imperative to implement treatment measures to mitigate these risks and ensure the safety of the environment.

3.3.3 Heavy Metals

The ongoing disposal of fresh waste from collection points, particularly in the most active area of the dumping site, persist. Pb concentrations ranged from 0.44 to 1.16 mg/L and 0.823 to 22.7 mg/L during the dry and wet seasons, respectively (Table 3). Furthermore, Cd concentrations fluctuated between 0.014 to 0.026 and 0.019 to 0.138 mg/L while Cu levels ranged from 0.025 to 0.189 and 0.358 to 5.454

mg/L during the dry and wet seasons, respectively. Cr concentrations were lower in the wet season and higher in the dry season, ranging from 0.262 to 1.275 mg/L and 0.036 to 1.3 mg/L during the dry and wet seasons, respectively. The concentrations of Pb, Cr, Cd and Cu in leachate were higher during the wet season than the dry season in both directions of the dumpsite and they are statistically different at p>0.01<0.05. Pb was detected in higher concentrations than other metals in the leachate samples. The vibrant activities in Dar es Salaam, driven by its high population, encompass a wide range of sectors such as art, construction, industry, media, and fashion. Many of the products and materials generated in these sectors contain Pb. As these materials reach the end of their useful life, they are often discarded and end up in dumpsites. Consequently, the accumulation of lead-containing waste in dumpsites leads to elevated concentrations of Pb in the leachate. Higher concentrations of Cu in the leachate suggest that most of the wastes dumped at this dumpsite contain mostly lead and copper containing materials.

From the field observation the Pugu-Kinyamwezi receives a diverse of wastes from domestic to industrial sources which contributes to different heavy metals on the leachate. To contextualize our findings, we compared them with various studies conducted on dumpsites globally. For instance, research conducted in Cairo documented fluctuating concentrations of Pb, Cd, Cr, Fe, and Zn in dumpsite leachate (Hussieny et al., 2022). Similarly, investigations at the Mtoni dumpsite highlighted elevated levels of Pb and Cu in the leachate (Shemdoe, 2010), while the study at Iringa Municipal Solid Waste Dumpsite identified significant concentrations of Pb, Cr, and Cu (Sanga, 2022). Another study conducted at an uncontrolled landfill in Ludhiana, India reveals high concentrations of Cu, Pb,

Table 2: Leachates mean physico-chemical and heavy metal parameters on the dry and wet season

Parameters	Seasons and t-test	Northern Side Concentration	Southern Side Concentrations	Western Sid Concentratio
EC (mg/L)	Dry	29010	45995	32500
	Wet	26130	48054	18290
	t-value	**18.13***	**-20.78****	**50.13****
TDS (mg/L)	Dry	14750	23180	16743
	Wet	13050	24102	9320
	t-value	**14.45***	**-50.23****	**14.92***
pH	Dry	8.47	8.2	8.55
	Wet	9.69	9.39	9.2
	t-value	**-1.96***	**15.44****	**-18.01***
Pb (mg/L)	Dry	0.44	1.16	0.653
	Wet	0.823	22.70	0.926
	t-value	**-27.41****	**-94.86****	**-27.73****
Cr (mg/L)	Dry	0.262	1.275	1.121
	Wet	0.239	1.3	0.036
	t-value	**4.20***	**-1.75**	**98.92****
Cd (mg/L)	Dry	0.021	0.026	0.014
	Wet	0.019	0.138	0.029
	t-value	**1.40**	**-45.80****	**-11***
Cu (mg/L)	Dry	0.025	0.12	0.189
	Wet	0.358	5.454	0.367
	t-value	**-54.50****	**64.07****	**-34.60****

**-Significant at 1% significance level and *-Significant at 5% significance level

Cd and Cr in the dumpsite leachate (Mavakalla et al., 2016).

Moses (2015) noted that the disposal of lead acid batteries, spent petroleum products, chemicals used in photography processing, Pb-based paints, and pipes contributes to heightened lead concentrations in leachate. Moreover, copper contamination stems from various sources such as copper-coated pipes, residues from coal burning, sewage, fungicidal treatments, mining activities, particles from car brakes, and industrial discharges (Panagos et al., 2018). As elucidated earlier, the southern region of the dumpsite, being the most active area for waste disposal, exhibits consistently high concentrations of heavy metals throughout the year. This continuous dumping contributes substantially to the increased presence of dissolved metals in the leachate.

From the results it can be seen that heavy metals in the leachates follow the trend of Pb > Cr > Cu and Cd. The trend informs that the wastes dumped at the Pugu-Kinyamwezi dumpsite contains high quantity of lead containing products like paints, batteries and photography processing chemicals. The high amount of chromium can be attributed to dumping of leather tanning waste materials, electroplating effluents and automobile wastes like exhausts of diesel tankers (Asuma & Aweto, 2013). Copper concentrations might be due to dumping of copper coated pipes, coal burning residues, and sewages, fungicidal treatments, mining activities, particles from car brakes and industrial sources (Panagos et al., 2018). Albeit least in concentrations, the presence of cadmium in the leachate can be attributed to dumping of nickel-cadmium batteries, discarded materials like plastics, stereos and televisions as it has been reported in previous studies (e.g. Agbemafle et al., 2020). The deficient operational practices at the Pugu-Kinyamwezi dumpsite, characterized by the absence of base liners and leachate collection systems, coupled with inadequate waste compaction activities exacerbate chemical and microbial interactions. These interactions significantly elevate the concentrations of heavy metals within the leachate.

3.2 Physicochemical and Heavy Metals Concentrations in Groundwater

Table 3 presents the physico-chemical and heavy metal parameters observed in groundwater samples collected from the Northern, Southern, Eastern, and Western directions of the Pugu-Kinyamwezi dumpsite during both the dry and wet seasons. These samples were compared against the standards set by the Tanzania Bureau of Standards (TBS) and the World Health Organization (WHO) to evaluate their suitability for various uses. Descriptive statistics for each parameter in different seasons and directions, along with their respective t-values, are provided in Table 3.

3.2.1 pH

From a pH standpoint, it was noted that the mean pH values exhibited higher levels during the wet season, ranging from 6.59 to 7.88, compared to the dry season, where they ranged from 5.32 to 5.98, as depicted in Table 5. These observed differences were statistically significant in both directions at $p<0.01$. This trend was consistent across all directions of the dumping site, with the mean pH being higher during the wet season than the dry season. The groundwater pH tended towards neutrality, during the wet season, whereas during the dry season, it leaned slightly towards acidity. The elevation of groundwater pH during the wet season compared to the dry season can be attributed to the influence of rainfall, which enhances the degradation of wastes, thus increasing the pH (Zahari& Hameed, 2005). Additionally, Zhang et al. (2020) noted that rainfall tends to dilute and neutralize acidic or basic components. Notably, despite these fluctuations, the mean pH values in the groundwater samples remained within the permissible limits outlined by TBS and WHO guidelines, which typically range from 5.5 to 8.5.

3.2.2 TDS and EC

During the wet season, higher concentrations of EC and TDS were observed compared to the dry season. Notably, statistically significant differences in concentrations were found in the Eastern direction only (p=0.005). Specifically, the mean concentrations of EC were recorded as 1904 mg/L (dry season) and 2456.2 mg/L (wet season), while TDS concentrations were 980.75 mg/L (dry season) and 1213.75 mg/L (wet season). This increase in EC and TDS levels during the wet season can be attributed to enhanced groundwater recharge and intensified weathering activities (Makwe&Chup, 2013).

Furthermore, the elevated concentrations of EC and TDS during the wet season, particularly in the Eastern direction, may be linked to increased leachate mobility facilitated by rainfall and subsequent spread into groundwater along the natural flow direction. Similar findings were reported by Adeoluet al. (2011) and Moret al. (2006) in studies conducted around dumpsites, where EC and TDS were identified as indicators of groundwater pollution originating from the dumpsite.

During the dry season, the mean concentrations of EC were significantly elevated, registering at 2987.75 mg/L in the Northern direction and 3942.5 mg/L in the Western direction, both surpassing the permissible limits set by WHO. Similarly, in the wet season, the Northern side exhibited a mean EC of 3356.25 mg/L, while the Southern and Western directions recorded concentrations of 2651 mg/L and 3700.25 mg/L, respectively, all exceeding WHO thresholds. With the exception of the Eastern direction, where levels remained within acceptable limits, all other directions demonstrated EC and TDS concentrations above TBS permissible thresholds in both seasons. Furthermore, in the Northern and Western directions during both seasons, TDS concentrations exceeded WHO

Table 3. Groundwater mean physicochemical and heavy metal parameters during dry and wet seasons

Parameter	Wells no.	Season and t-value	GW N	GW S	GW E	GW W
EC µS/cm	4	Dry	2987.75	2364.25	1904	3942.5
		Wet	3356.25	2651	2456.2	3700.25
		t-value	**0.657**	**0.752**	**2.26***	**0.21**
TDS (mg/L)	4	Dry	1492	1194.25	980.75	1980
		Wet	2280	1328.38	1213.75	1854
		t-value	**1.28**	**0.69**	**1.21***	**1.11**
pH	4	Dry	5.61	6.11	5.32	5.98
		Wet	7.53	7.88	6.59	7.00
		t-value	**4.72***	**22.49****	**3.96***	**2.07***
Pb (mg/L)	4	Dry	0.016	0.08	0.067	bdl
		Wet	0.047	0.172	0.027	0.04
		t-value	**1.02**	**1.93***	**1.80***	**1.37**
Cr (mg/L)	4	Dry	bdl	0.08	Bdl	bdl
		Wet	0.05	bdl	0.05	0.01
		t-value	**0.91**	**0.87**	**0.91**	**-**
Cd (mg/L)	4	Dry	bdl	bdl	Bdl	0.06
		Wet	0.03	0.03	0.07	0.05
		t-value	**1**	**1**	**1.24**	**0.21**
Cu (mg/L)	4	Dry	bdl	0.02	Bdl	bdl
		Wet	0.05	0.081	bdl	bdl
		t-value	**1.07**	**1.81***	**-**	**-**

thresholds. These heightened concentrations above WHO and TBS standards indicate the presence of elevated salinity, mineral content, and contaminants. Consequently, such elevated levels render the groundwater unsuitable for both drinking purposes and irrigation activities, highlighting significant concerns regarding water quality and public health implications (Zhai, 2022).

3.2.3 Heavy metals

As illustrated in Table 3, heavy metal concentrations were notably higher during the wet season compared to the dry season across all directions, except for the Eastern direction concerning Pb. Statistical analysis, presented in Table 5, revealed significant differences in mean values of these heavy metals, particularly in the Southern and Eastern directions ($p < 0.05$ and $p < 0.01$, respectively).

In the Southern direction, mean concentrations of Pb and Cu were elevated during the wet season (0.171 mg/L and 0.081 mg/L, respectively) compared to the dry season (0.08 mg/L and 0.02 mg/L, respectively). This increase in heavy metal concentrations during the wet season is attributed to the precipitation effect, which leads to a rise in the water table and subsequent leaching of heavy metals into the groundwater (Zhai, 2022). Conversely, in the Eastern direction, the mean concentration of Pb was lower during the wet season (0.027 mg/L) compared to the dry season (0.067 mg/L), indicating a possible dilution effect of rainfall. Additionally, the presence of a sturdy concrete wall surrounding the Eastern part of the dumpsite may inhibit surface leachate movement into the groundwater, potentially influencing the observed concentrations. This is supported by a study conducted at a Nigerian open dumpsite, which revealed that due to the lack of a fence surrounding the dumpsite, there is free surface leachate movement from the dumpsite, posing a high risk of contamination to surface water and groundwater (Daniel et al., 2021). Sanitary landfills are typically fenced, serving as important barriers to prevent surface leachate migration into the surrounding environment (Emalyaet al., 2022).

Furthermore, Pb concentrations peaked in the Southern direction's groundwater samples during the wet season (0.172 mg/L), suggesting substantial leachate migration into the groundwater, consistent with the higher concentrations of Pb in leachates during the wet season in this direction (Table 3). These findings corroborate the notion of leachate migration from the dumpsite into the groundwater, supported by previous reports of heavy metal presence in leachates at high concentrations.

It's important to note that concentrations of Pb, and Cd in groundwater exceeded WHO permissible limits of 0.001 mg/L, 0.05 mg/L, and 0.003 mg/L, respectively, in both seasons hence the water unsuitable for drinking. Similar studies have reported elevated concentrations of heavy metals in groundwater. For instance, Lorestani et al. (2020) found high levels of Arsenic (As), Cadmium (Cd), Mercury (Hg), and Lead (Pb) in groundwater, exceeding WHO guidelines. Similarly, Ndimbo et al. (2016) documented varying concentrations of Pb, Cr, and Cd above WHO thresholds in groundwater. Additionally, a study conducted in Iringa revealed elevated levels of Pb, Iron (Fe), Cr, and Cd in groundwater around the dumpsite (Sanga et al., 2022). The presence of these heavy metals in groundwater above WHO standards raises concerns about potential bdl means below detection limit which was 0.01 for the instrument used **-Significant at 1% significance level and *-Significant at 5% significance level health risks, including cancer, neurological disorders, and liver and kidney dysfunction (Muneneet al., 2023).

Although Cr and Cu concentrations remained within TBS guidelines of 1 mg/L and 2 mg/L, respectively, as indicated in Table 4, the presence of these metals in groundwater, even at levels below regulatory limits, poses risks of bioaccumulation and bio magnification. These processes can amplify health impacts on consumers of drinking water and agricultural products irrigated with contaminated water. The bdl means below detection limit which was 0.01 for the instrument used

3.3 Statistical Analyses

3.3.1 Correlations Analysis

The significant positive correlations between EC and TDS in both dry and wet seasons highlight the influence of dissolved solids and ions on groundwater conductivity. In the dry season, the correlation between EC and TDS is nearly perfect (0.99), while in the wet season, it remains strong but slightly lower (0.89). This suggests that higher ionic content results in higher EC, indicating that leaching from the dumpsite significantly contributes to elevated EC and TDS levels, consistent with studies by Zhang et al. (2022). The lower correlation during the wet season is likely due to the dilution effect from increased rainfall.

Additionally, significant positive correlations between EC and heavy metals Pb (0.53) and Cu (0.55) during the wet season indicate that these metals are predominantly ionized in groundwater, enhancing EC. A notable positive correlation between TDS and Pb (0.51) suggests that a substantial portion of dissolved solids comprises Pb. Similar findings by Donuma et al. (2023) and Gebresilasie et al. (2021) support the influence of EC and TDS on these metals.

In the dry season, a negative correlation between pH and Cr (-0.68) implies that Cr concentration increases as pH decreases, due to the increased solubility of Cr in acidic conditions (Zhang et al., 2020). A positive correlation between Cu and Cr (0.57) suggests a shared source or transport pathway, likely from the dumpsite, supporting the co-transport of these pollutants within the groundwater system.

Table 4. Correlation coefficients for different physicochemical and heavy metal parameters in groundwater during the dry and wet season.

a) Dry season

	EC	pH	TDS	Pb	Cr	Cd	Cu
EC	1.00						
pH	-0.39	1.00					
TDS	**0.99***	-0.32	1.00				
Pb	0.24	-0.24	0.25	1.00			
Cr	0.37	**-0.68***	0.39	0.36	1.00		
Cd	0.05	-0.17	0.05	-0.02	-0.15	1.00	
Cu	0.16	0.04	0.16	0.06	0.04	-0.19	1.00

b) Wet season

	EC	pH	TDS	Pb	Cr	Cd	Cu
EC	1.00						
pH	-0.39	1.00					
TDS	**0.99***	-0.32	1.00				
Pb	0.24	-0.24	0.25	1.00			
Cr	0.37	**-0.68***	0.39	0.36	1.00		
Cd	0.05	-0.17	0.05	-0.02	-0.15	1.00	
Cu	0.16	0.04	0.16	0.06	0.04	-0.19	1.00

*-Significant at 5% significance level

Table 5. Pearson's correlation coefficients between the distance of sampling wells from landfill and physicochemical parameters in groundwater in the dry and wet seasons.

	Seasons	pH	TDS	EC	Pb	Cr	Cd	Cu
N. Distance	Dry	-0.59	-0.84	-0.83	**-0.93***	0.75	0.17	0.75
	Wet	0.73	-0.84	-0.83	**-0.85***	-	0.62	-0.32
S. Distance	Dry	-0.77	-0.59	-0.56	-0.53	-0.64	-0.24	-0.57
	Wet	**-0.93***	-0.52	-0.51	-0.63	-0.67	-0.32	-0.15
E. Distance	Dry	-0.75	**-0.97***	**-0.98***	**-0.85***	-	-	-
	Wet	**-0.96***	**-0.99***	**-0.99***	**-0.52**	0.30	-0.78	-
W. Distance	Dry	0.69	-0.87	-0.87	-	-	-	-0.23
	Wet	0.31	-0.80	-0.80	-0.35	-0.34	0.80	-0.16

*-Significant at 5% significance level

3.3.2 Spatial Variability of the physicochemical and heavy metals concentrations in groundwater

Table 5 summarizes Pearson's correlations between the physicochemical and heavy metal parameters in the groundwater and the distances of the sampling points from the dumpsite. The correlations of groundwater's TDS and EC with distance from the dumpsite were negative and significant in the Eastern direction of the dumpsite (-0.97, -0.98) and (-0.99, -0.99) in the dry and wet seasons respectively. This implies that increase of distance from the dumpsite decrease the concentrations of dissolved solids in the groundwater and vice versa. This is similar to the study conducted at Solos landfill Lagos which revealed that EC and TDS have the behavior of decreasing with increasing distance from the dumpsite (Adeolu et al., 2011).pH showed the similar behavior of decreasing concentration with distance in the Southern (-0.93) and Eastern(-0.96) directions during the dry season only. Decrease in pH concentration with distance from the dumpsite was similarly observed and reported by Abiriga et al. (2020) which is due to the decrease in bicarbonate due to buffering capacity.

Heavy metals also had the similar behavior of decreasing concentrations with distance from the dumping site in the Northern and Eastern directions. The reason for the significance of the Northern (50-166) m and Eastern (26-135) m directions only is due to the fact the groundwater sampled at these directions is somewhat close to the dumpsite compared to the Southern (350-605) m and Western (40-271) m directions where the wells are far from the dumpsite as shown in Table 1. Pb had the significant negative correlation in these directions during both the dry (-0.93,-0.85) and wet (-0.85,-0.52) seasons in the Northern and Eastern directions respectively. This was similarly reported by Nyiramigisha, (2021), and Agbeshie et al. (2020).

3.3.3 Principal Component Analysis

Principal component analysis was also performed in order to identify pollutant sources into the groundwater by identifying elements with similar physicochemical and as well as geochemical behaviors. Three principal components with eigenvectors greater than 1 were extracted from the analysis in both dry and wet season, accounting for 73.6% and 79.2% of the total variance in the dry and wet seasons respectively. The loadings of each principal component are as shown in Table 6a and 6b.

The loadings of the first principal component (PC1) in the dry season accounted for 38.9% of the total variance and had high positive loading for TDS (0.94), EC (0.95).In the wet season the PC1 accounted for 37.0% of the total variance and had a positive loading for TDS (0.97), EC (0.92) and moderate for Pb (0.62) and Cu (0.51).Thus, PC1 reveals that groundwater is characterized with highly impacted by Cu and Pb ions originating from the dumping site leachate as indicated by high concentrations of EC and TDS in the wet season. It has been reported that copper ions exhibit a heightened affinity for conducting electricity when they are in a solution (Pramanik et al., 2020).

The second factor (PC2) in the dry season accounted for 18.3% of the total variance with high positive loading for Cr (0.85), and moderate for pH (-0.75) and Pb (0.62) while in the wet season it accounted for 25.2% with high positive loading for pH (0.82) and moderate positive for Pb (0.62) and negative for Cr (-0.73). This implies that decrease in pH increases the concentrations of Pb and Cr in the groundwater during dry season while in the wet season increase in pH decreases Cr concentrations.

Table 1: **Principal components with Varimax Rotation Matrix results in the dry and wet seasons**

a) Dry season

Variables	PC1	PC2	PC3
EC	**0.95***	0.24	-
TDS	**0.94***	0.26	-
Cr	0.17	**0.88***	0.11
pH	-0.21	**-0.75***	0.16
Pb	-	**0.62***	-
Cd	0.19	-0.13	**-0.88***
Cu	0.36	-0.20	**0.65***
Eigenvalue	2.70	1.30	1.10
Variance %	38.90	18.30	16.40
Cumulative %	38.90	57.20	73.60

b) Wet season

Variables	PC1	PC2	PC3
EC	**0.97***	-0.13	-
TDS	**0.92***	-	-
Cr	**0.62***	**0.62***	0.19
pH	-0.12	**0.82***	0.11
Pb	0.11	**-0.73***	0.51
Cd	0.14	-0.12	**-0.82***
Cu	**0.52***	-0.33	**0.60***
Eigenvalue	2.60	1.80	1.20
Variance %	37.00	25.20	17.00
Cumulative %	37.00	62.20	79.20

*- High loadings

Table 6. Principal components with Varimax Rotation Matrix results in the dry and wet

This is because acidic environment enhances dissolution, precipitation and desorption of these metals from the soil particles or minerals especially Cr metal as previously reported by Idehai (2015).

The third factor (PC3) accounted for 16.4% of the total variance in the dry season with high positive loadings for Cd (-0.88) and positive moderate loading for Cu (0.63) while the wet season accounted for 17% with high negative loading for Cd (-0.82) and positive moderate loading for Cu (0.60) and Pb (0.51). In both seasons Cd is strongly negative correlated with PC3 indicating that it is easily removed from groundwater. This is due to Cd ability in ligand formation as compared to other metals when in water hence its concentrations decrease in groundwater (Jiang et al., 2023).

Moreover, significant correlations between heavy metals suggests pollutants are from the same origin which by this case is the dumpsite and indicates that these heavy metals are in a dissolved form and they enter the groundwater through same processes which are direct infiltration and surface runoff (Zhang et al., 2022) According to Elemile (2021), PCA is suitable when the Kaiser–Meyer–Olkin (KMO) and Barlett tests are more 0.5 and less than 0.05, respectively. The KMO of this analysis were 0.53, 0.58 and 0.000, 0.000 respectively hence suitable. Also Elemile (2021), further explained that the correlations are classified as strong when the correlations are >0.75, moderate when between 0.5-0.75 and weak from 0.3 to 0.49. To that effect, all the correlations considered in this study were the ones with the correlations from moderate to strong.

According to Elemile (2021), PCA is suitable when the Kaiser–Meyer–Olkin (KMO) and Barlett tests are more 0.5 and less than 0.05, respectively. The KMO of this analysis were 0.53, 0.58 and 0.000, 0.00, respectively hence suitable. Also, Elemile (2021), further explained that the correlations are classified as strong when the correlations are >0.75, moderate when between 0.5-0.75 and weak from 0.3 to 0.49. To that effect, all the correlations considered in this study were the ones with the correlations from moderate to strong.

4 Conclusions

The study assessed the physicochemical and heavy metal composition of leachate and groundwater to understand the impact of the Pugu-Kinyamwezi dumpsite on surrounding groundwater resources during both the dry and wet seasons. The findings revealed a direct link between the dumpsite and groundwater contamination in both seasons. Pb was identified as the metal with the highest concentrations in both groundwater and leachate across seasons.

The results highlight severe groundwater contamination issues associated with the Pugu-Kinyamwezi dumpsite, characterized by elevated levels of heavy metals and dissolved solids in the groundwater. Correlation analyses confirm that dumpsite activities are a significant source of groundwater pollution, with leachate playing a key role in this contamination. Spatial variability analysis indicates that the dumpsite's impact on groundwater quality is localized, underscoring the urgent need for remediation measures.

Relocating the dumpsite to areas farther from residential zones and ensuring its proper construction according to established standards are critical steps to address the contamination issue. Such actions would minimize potential health risks to nearby residents and reduce further groundwater pollution. Constructing a new dumpsite in compliance with stringent standards will help prevent leachate seepage and protect groundwater quality.

Furthermore, effective containment and management of leachate, along with engineering interventions to prevent further infiltration, are essential to safeguard groundwater resources. Collaborative efforts among stakeholders are vital to implement sustainable waste management practices and mitigate the adverse effects of groundwater pollution on public health and the environment.

Acknowledgements

The authors express sincere gratitude to the Ilala Municipal Council for granting them permission to collect site data and leachate samples from the Pugu-Kinyamwezi Dumpsite in Ilala, Dar es Salaam, Tanzania. Similarly, they are thankful to the Ardhi University laboratory staff, with special gratitude to Mr Addo Ndimbo.

Funding: This research was self-sponsored by the authors

Conflict of Interest: The authors declare no conflicts of interest related to this research.

References

Abiriga, D., Vestgarden, L. S., & Klempe, H., (2020). Groundwater contamination from a municipal landfill: Effect of age, landfill closure, and season on groundwater chemistry. Science of the Total Environment.doi:https://doi.org/10.1016/j.scitotenv.2020.140307

Adeolu, A., Ada, O., Gbenga, A., & Otitolojum, A. (2011). Assessment of groundwater contamination by leachate near a municipal solid waste landfill. 933–940. https://doi.org/10.5897/AJEST11.272.

Agbemafle, R., Aggor-woananu, S. E., Akutey, O., & Bentum, J. K. (2020). Research Article Heavy Metal Concentrations in Leachates and Crops Grown Around Waste Dumpsites in Sekondi-Takoradi in the Western Region of Ghana. Research Journal of Environmental Toxicology. https://doi.org/10.3923/rjet.2020.16.25.

Agbeshie, A. A., Adjei, R., Anokye, J., & Banunle, A. (2020). Municipal waste dumpsite: Impact on soil properties and heavy metal concentrations, Sunyani, Ghana. Scientific African, 8, e00390.

Alam, P., Sharholy, M., & Ahmad, K. (2020). A study on the landfill leachate and its impact on groundwater quality of Ghazipur area, New Delhi, India. In Recent Developments in Waste Management: Select Proceedings of Recycle 2018 (pp. 345-358). Springer Singapore.

Alao, J. O. (2023). Impacts of open dumpsite leachates on soil and groundwater quality. doi:https://doi.org/10.1016/j.gsd.2022.100877.

Aluko, O. O., Obafemi, T. H., Obiajunwa, C. J., Obiajunwa, O, P.,Obisanya, O. A., Odanye, H. O.

& Odeleye, O. A. (2022). Solid waste management and health hazards associated with residence around open dumpsites in heterogeneous urban settlements in Southwest Nigeria. International Journal of Environmental Health Research. doi:https://doi.org/10.1080/09603123.2021.1879738

Al-Wabel, M.I., Al Yehya, W. S., Al-Farraj, A. S., & El-Maghraby, S.E. (2011). Characteristics of landfill leachates and bio-solids of municipal solid waste (MSW) in Riyadh City, Saudi Arabia. Journal of the Saudi Society of Agricultural Sciences. doi:https://doi.org/10.1016/j.jssas.2011.03.009

Asuma, O., and Aweto, K. (2013). Leachate Characterization and Assessment of Groundwater and Surface Water Qualities Near Municipal Solid Waste Dump Site in Effurun, Delta State , Nigeria. 1997, 126–135.

Daniel, A. N., Ekeleme, I. K., Onuigbo, C. M., Ikpeazu, V. O., & Obiekezie, S. O. (2021). Review on effect of dumpsite leachate to the environmental and public health implication. GSC Advanced Research and Reviews, 7(2), 051-060.

Donuma, K. U., Ma, L., Bu, C., & George, L. Y. (2023). Impact and Health Risk Assessment of Groundwater in the Vicinity of Dumpsites in Keffi Metropolis, Nigeria. Journal of Geoscience and Environment Protection, 11(8), 85-113.

Emalya, N., Munawar, E., Rinaldi, W., & Yunardi, Y. (2022). Landfill leachate management in Indonesia: a review. In IOP Conference Series: Materials Science and Engineering (Vol. 845, No. 1, p. 012032). IOP Publishing.

Essien, J. P., Ikpe, D. I., Inam, E. D., Okon, A. O., Ebong, A., & Id, N. U. B. (2022). Occurrence and spatial distribution of heavy metals in landfill leachates and impacted freshwater ecosystem : An environmental and human health threat. 1–18. https://doi.org/10.1371/journal.pone.0263279.

Gebresilasie, K. G., Berhe, G. G., Tesfay, A. H., & Gebre, S. E. (2021). Assessment of Some Physicochemical Parameters and Heavy Metals in Hand-Dug Well Water Samples of Kafta Humera Woreda , Tigray , Ethiopia. 2021.

Idehai, I. M. (2015). Evaluation of Heavy Element Levels in Leachate, Soil and Groundwater in the Lagos Landfill Areas of Nigeria. 3(2), 1–21. https://doi.org/10.9734/JGEESI/2015/19197.

Kamble, B. S., Raj, P., Rama, S., & Kurakalva, M. (2020). Evaluation of seasonal and temporal variations of groundwater quality around Jawaharnagar municipal solid waste dumpsite of Hyderabad city, India. SN Applied Sciences, 2(3), 1–22. https://doi.org/10.1007/s42452-020-2199-0.

Lorestani, B., Merrikhpour, H., & Cheraghi, M. (2020). Assessment of heavy metals concentration in groundwater and their associated health risks near an industrial area. https://doi.org/10.34172/EHEM.2020.09, 7(2), 67-77.

Majolagbe, A. O., Oketola, A., & Osibanjo, O. (2016). Vulnerability assessment of groundwater pollution in the vicinity of an active Vulnerability assessment of groundwater pollution in the vicinity of an active dumpsite (Olusosun), Lagos, Nigeria. October.

Makwe, E., & Chup, C. (2013). Seasonal variation in physico-chemical properties of groundwater around Karu Abattoir, C.D. 6(5), 489–497. http://dx.doi.org/10.4314/ejesm.v6i5.6.

Markic, D. N., Bjelic, D., Zugic, N., Carapina, H. S., & Pesic, Z. S. (2015). Assessment of the Impact Of Banjaluka Landfill On Groundwater Quality. 10(2), 271–280.

Membe, M. P. (2015). Solid Waste Management Dar es Salaam Tanzania. Head of Waste Management Department Dar Es Salaam City Council, 1–18.

Munene, E. N., Hashim, N. O., & Ambusso, W. N. (2023). Human health risk assessment of heavy metal concentration in surface water of Sosian

River, Eldoret town, Uasin-Gishu County Kenya. MethodsX, 11, 102298.

Moses I. I. (2015). Evaluation of Heavy Element Levels in Leachate, Soil and Groundwater in the Lagos Landfill Areas of Nigeria. DOI:10.9734/JGEESI/2015/19197.

Mtoni, Y., Chikira, I., & Charles, M. (2013). Saltwater intrusion and nitrate pollution in the coastal aquifer of Dar es Salaam, Tanzania. https://doi.org/10.1007/s12665-012-2197-7.

Mbwilo, E. C., & Mahenge, F. Y. (2022). Municipal Solid Waste Collection Services in Rapidly Growing Cities of Tanzania. Journal of the Geographical Association of Tanzania, 42(1).

Nagarajan, R., Thirumalaisamy, S., & Lakshumanan, E. (2012). ENVIRONMENTAL HEALTH Impact of leachate on groundwater pollution due to non-engineered municipal solid waste landfill sites of erode city, Tamil Nadu, India. 1–12. https://doi.org/10.1186/1735-2746-9-35.

Ndimbo, A., Mbuligwe, S., & Mbuna, J. (2016). Physicochemical Characteristics and Heavy Metal Levels in Groundwater from Selected Areas of Dar Es Salaam City, Tanzania. CHIEF EDITOR, 29(2), 26-43.

Nyiramigisha, P. (2021, July). The concentration of heavy metals zinc and lead in the soil around the Putri Cempo landfill, Indonesia. In IOP Conference Series: Earth and Environmental Science (Vol. 824, No. 1, p. 012050). IOP Publishing.

Okeke, P. (2021). Environmental Implications of Leachates of Sewage Dumpsites in some parts of Environmental Implications of Leachates of Sewage Dumpsites in some parts of Owerri, Southeastern Nigeria. December. https://doi.org/10.13140/RG.2.2.27828.04483.

Omeiza, A. J., Abdulwahab, O. O., Nur, M. S., Danjuma, T. T., Jaiyeoba, E., Abdullahi, D. U., ... & Mary, E. T. (2022). Effect of an active open dumpsite on the earth's subsurface and groundwater resource. Asian Journal of Physical and Chemical Sciences, 10(2), 15-24.

Panagos, P., Ballabio, C., Id, E. L., Jones, A., Borrelli, P., Scarpa, S., Orgiazzi, A., & Montanarella, L. (2018). Potential Sources of Anthropogenic Copper Inputs to European Agricultural Soils. https://doi.org/10.3390/su10072380.

Pramanik, S., Konar, S., Chakraborty, K., Pal, T., & Das, S. (2020). Investigation of electrical conductance properties, non-covalent interactions and TDDFT calculation of a newly synthesized copper (II) metal complex. Journal of Molecular Structure, 1206, 127663. https://doi.org/10.1016/j.molstruc.2019.127663.

Rashid, S. W., Shwan, D. M. S., & Rashid, K. A. (2022). Physicochemical Characterization and Evaluation of Seasonal Variations of Landfill Leachate and Groundwater Quality around Tanjaro Open Dump Area of Sulaymaniyah City, Kurdistan, Iraq. 2022.

Razavi, W. K., Qasemi, M., Afsharnia, M., Farhang, M., & Ghaderpoori, M. (2019). Spatial distribution of fluoride and nitrate in groundwater and its associated human health risk assessment in residents living in. 170, 176–186. https://doi.org/10.5004/dwt.2019.24691.

Sanga, V. F., Pius C. F., & Kimbokota, F. (2022). Heavy metals pollution in leachates and its impacts on quality of groundwater around Iringa municipal solid waste dumpsite. Research square. doi:https://orcid.org/0000-0003-1019-7102.

Sankoh, A. A., Amara, J., Komba, T., Laar, C., Derkyi, N. S., Frazer-williams, R., Aziz, A., Amara, J., Komba, T., & Laar, C. (2023). Seasonal assessment of heavy metal contamination of groundwater in two major dumpsites in Sierra Leon.CogentEngineering, 10(1).https://doi.org/10.1080/23311916.2023.2185955.

Shemdoe, R. S. (2010). Heavy metal concentrations in soils and leachetes of Mtoni dumpsite bordering the Indian Ocean in Dar es Salaam, Tanzania. Scientific Research and Essays.

Smahi, D., Hammoumi, O. El, & Fekri, A. (2013). Assessment of the Impact of the Landfill on Groundwater Quality: A Case Study of the Mediouna Site, Casablanca, Morocco. 2013(April), 440–445.

Vishwakarma, A., Sharma, A., & Kushwah, S. S. (2023). Heavy Metal Contamination in Surface Water Bodies through Construction and Demolition Waste: A Case Study of City of Lakes–Bhopal, Madhya Pradesh, India. In Heavy Metal Toxicity: Environmental Concerns, Remediation and Opportunities (pp. 105-117). Singapore: Springer Nature Singapore.

Yasin, H., & Usman, M. (2017). Earth Science Pakistan (ESP) Site investigation of open dumping site of Municipal Solid Waste in Faisalabad. October, 23–26. https://doi.org/10.26480/esp.01.2017.23.25.

Yhdego,.M.(2019). Environmental Impact Assessment for the Proposed Sanitary Landfill at Pugu-Kinyamwezi, Dar es Salaam. Tanzania. A summary report for Dar es Salaam city council, Dar es Salaam .doi :doi10.13140/ RG.2.2. 27828.04483.

Yhdego, M. and Mwashamba., G. (2015). Final GIS based modeling of solid wastes dumping site in Dar es Salaam. doi:https://doi10.13140/RG.2.1.2404.4247.

Zahari, M. S. M., & Hameed, B. H. (2005). Removal of Ni, Cd , Pb , Zn and colour from aqueous solution using potential low cost adsorbent. 12(June), 248–257. https://doi.org/10.1007/s12665-021-09975-y.

Zeng, D., Chen, G., Zhou, P., Xu, H., Qiong, A., Duo, B., & Han, Z. (2021). Factors influencing groundwater contamination near municipal solid waste landfill sites in the Qinghai-Tibetan plateau. Ecotoxicology and Environmental Safety, 211, 111913.

Zhai, Y. (2022). Distribution, Genesis, and Human Health Risks of Groundwater Heavy Metals Impacted by the Typical Setting of Songnen Plain of NE China. doi:103390/ijerph19063571