George *et al. Discover Water* (2025) 5:78
https://doi.org/10.1007/s43832-025-00274-2

Discover Water

RESEARCH **Open Access**

Assessment of groundwater quality near a dumpsite and evaluation of human health risk in southeast Maseru, Lesotho

Maeti Antoinette George[1*], Qatsa Leshota[1] and Stella Thoala[1]

*Correspondence:
Maeti Antoinette George
maetigeorge@gmail.com
[1]Department of Environmental Health, The National University of Lesotho, Roma 180, Maseru, Lesotho

Abstract

Inadequate management of municipal solid waste (MSW) is a global environmental concern for human health and ecosystems. In Lesotho, open dumping is the oldest method of solid waste disposal that threatens nearby water bodies, especially groundwater. There is under-presentation of monitoring data from the Ts'osane dumpsite, and this study intended to address the gap. The study investigated groundwater quality and level of non-carcinogenic health hazard for residents who consume the groundwater. Chemical oxygen demand (COD), chlorides (Cl), copper (Cu), electrical conductivity (EC), iron (Fe), lead (Pb) and pH) were analysed from 30 samples for five private boreholes within the 900 m radius from the dumpsite, following the American Public Health Association (APHA) standard methods. Data analysis entailed descriptive analysis, and correlation coefficient established relationships amongst the parameters. Hazard Quotient (HQ) and Hazard Index (HI) were used to assess communities' risk. The results were as follows: Cl (191–288.7 mg/L), COD (54–82.25 mg/L), Fe (0.18–1.22 mg/L) and Pb (0.05–0.08 mg/L) and were in the order Pb > Fe > COD > Cl. The mean of 1173 µS/cm for EC was slightly below the permissible threshold of 1500 µS/cm. Cl, COD, Fe and Pb exceeded the World Health Organisation (WHO) limit for drinking water. The dumpsite may have influenced groundwater quality, however, health risk assessment revealed that HQ and HI were below 1, indicating a low likelihood of adverse health effects. The study recommends utilisation of anti-seepage systems to avert further seepage of pollutants into groundwater.

Keywords Dumpsites, Municipal waste, Environmental pollution, Groundwater, Lead, Iron, Health risk assessment, Human health

1 Introduction

Municipal solid waste management has proven to be a challenge for developing and underdeveloped countries, exacerbated by underfunding for waste management and/or treatment prior to disposal. Stemming from inadequate funding support and low prioritisation given to solid waste management, some countries resort to open disposal of waste into dumpsites, and these are not engineered [1]. Unlined dumpsites are not able to trap leachate, and they have become rampant methods of solid waste disposal, which also impact negatively the air, soil and water, together with human health. In other regions and countries such as Lesotho, included, abandoned quarries and mining pits are utilised for dumping waste [2–5].

Poor waste management begins from lack of segregation at point of waste generation, absence of waste collection structures, and indiscriminate disposal into the environment. The problem is exacerbated by increase in population size, industrialisation, urbanisation and sometimes poverty [2, 5, 6]. Global anthropogenic pollutant enrichment of the environment by dumpsites consequently threatens water quality. Globally, an estimated 1.5 billion population rely on groundwater for drinking [7, 8]. It is further estimated that groundwater meets at least 60% of global daily needs for the rural population [9]. Climate change threatens water security globally, including Lesotho. Furthermore, there is intermittent supply of water from the water utilily, and groundwater seems to be a promising source, and this calls for its protection against various forms of pollution.

In Aduramigba Estate, within the Southwestern part of the Osun state in Nigeria, a dumpsite contaminated water, and physicochemical properties analysed were pH, EC, trace metals and some ions [10]. From these, chlorides exceed the WHO allowable value of 250 mg/L at 268.87 mg/L [11]. A study in Alexandria, Egypt also recorded Cl at 11,387 mg/L [12].

Groundwater at Ts'osane sustains some urban livelihoods, and these include domestic and agricultural activities [13]. Due to augmentation of domestic, industrial, pharmaceutical waste disposal at the Ts'osane dumpsite, groundwater can be laden with organic pollutants and potential toxic elements (PTEs). It has been reported that, collectively, PTEs like mercury, copper, cadmium and lead are cumulative poisonous [14], and are exceptionally toxic and carcinogenic [15–17].

In April 2024, Ts'osane residents protested against risks associated with unknown hazardous pollutants due to lack of surveillance at the dumpsite and surrounding areas. It is specified that, one of the inappropriate regions for landfill sites is those within 40 m of a permanent on intermittent water body or in an area overlying an aquifer with a drinking water quality groundwater that is vulnerable to pollution [18]. The same report further restricts landfills within 250 m of residential areas, schools or hospitals which are not associated with the landfill facilities.

Depending on their source, pollutants may contain potentially toxic elements (PTEs). When in excess in the human body, these PTEs are carcinogenic. Non-carcinogenic diseases include diarrhoea, vomiting, abdominal pain, and kidney destruction [19, 20]. PTEs are able to migrate from soil, which acts as an environmental media for translocation to other environments like water. Some PTEs are also carcinogenic [21, 22] and also considered hazardous if consumed [23]. They are persistent in the environment, bio-accumulative and also bio-magnify [24] thus degrading the environment and threatening human health when consumed. Another issue that is under debate is bioavailability of PTEs, a characteristic that, when well-researched, could be used for risk assessment [25] and ultimately be included in policies in order to protect human health. When groundwater quality is affected, there could be a burden of diseases for the communities.

A previous study has been undertaken in the year 2008 within the same study area, and TDS, EC, SO_4, NO_3, Fe and alkalinity were within the acceptable limits, whereas Pb was beyond the WHO levels for drinking water [2]. This study monitors water quality as a follow up to the 2008 research. There has been no groundwater monitoring following this period amidst disposal of industrial, medicinal and other types of waste in the area. This study brings novelty through integration of human health risk (HHR) and hazard quotient (HQ), together with heavy metal analysis of groundwater in the study area, which have previously not been reported.

2 Materials and methods

2.1 Study area

Ts'osane dumpsite is located south-east of Maseru, the main town of Lesotho. It is upstream of the Maqalika Reservoir (latitude 29°18′50.28″ S and longitude 27°32′28.63″ E) as shown in Fig. 1. The dumpsite covers about 50,000 m^2 of area within an abandoned quarry mine. There also exists a dolerite dyke running within the dumpsite in the north- easterly direction. Further down to the west of the dumpsite, Mohokare River is situated (Fig. 1). The fractured dolerite rocks (medium-grained intrusive basic igneous rock) have a dual nature. The first one is its ability to form a seal that makes them impermeable, thus forming groundwater reservoirs [26] and the second is their permeability [27]. The permeable nature is the characteristic that renders the dumpsite position risky, since some communities in the area utilise groundwater for domestic purposes including consumption. Leachate from the dumpsite is the potential source of groundwater pollution. Some residents still utilise groundwater as their sole source of water for drinking and other domestic purposes. The Department of Water Affairs (DWA) had monitoring wells for groundwater quality and levels, and monitoring effected every three months [28] but they are no longer in operation, making it difficult to establish robust water quality monitoring.

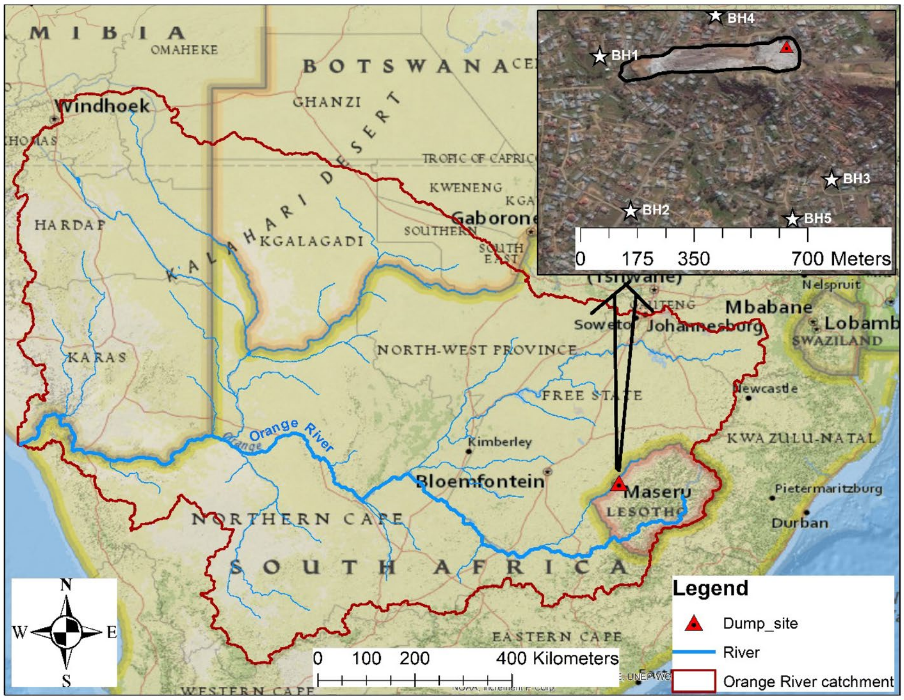


Fig. 1 Location of the Ts'osane dumpsite and water sampling sites. SOURCE: (Authors)

This active dumpsite is a depository for unsorted municipal waste from the Maseru City Council (MCC) and industrial (e-waste and textile waste) from Maseru industries and factories. This threatens groundwater bodies owing to leachate that may consist of a plethora of PTEs like cadmium, chromium, lead and mercury [29]. Apart from risk from infiltration of leachate into water bodies, scavengers have access into the site for solid waste sorting and collection, and this further puts their health at risk. Most importantly is uncharacterised dumping of solid waste, whereby a range of electronic, textile and domestic, and organic waste is dumped at the site, and attracting scavengers in this manner. Waste dumped at the site has been categorised as plastic (20%), paper (20%), e-waste (16%), ash (10%), metals (9%), food (7%), textiles (7%), medicinal waste (2%) and glassware (1%) (George, 2024) [manuscript submitted for publication]. Residents in the study area were actively participating in brick construction and agricultural activities that utilised lead-based pesticides and fertilisers, the latter being prominent around borehole number 5.

2.2 Data collection

2.2.1 Observations and surveys

Observations and surveys were done in order to categorise solid waste which was classified by source as residential, health care waste, construction, industrial and others. The latter entailed waste that did not fall under the other four main categories. Furthermore, it was noteworthy to assess activities which took place around the dumpsite. The sampling sites (private boreholes) around the dumpsite were also identified, noting their GPS coordinates and distances from the dumpsite (Table 1).

2.2.2 Water sampling

Water samples were taken from five private boreholes BH1, BH2, BH3, BH4 and BH5 at Ts'osane, due to absence of monitoring boreholes in the area. Three boreholes (BH2, BH3 and BH5) were topographically upstream of the dumpsite (Fig. 1). BH5 was the furthest from the dumpsite, and was selected as a control site. Two other boreholes (BH1, BH4) were downstream of the dumpsite. GPS coordinates and distance from the dumpsite for the boreholes are shown in Table 1 below:

All the boreholes were still in use, so there was immediate sampling without removal of stagnant water. The study followed internationally accepted protocols, and sampling was done for six months (March to August, 2024) in accordance with the APHA [31] methods. March is the wet month, and April to May are hydrologically mid-wet in Lesotho, whereas June to August are dry months [30]. A total of 30 water samples were analysed, and i*n-situ* water analysis was done for temperature, EC, salinity and pH utilising a glass thermometer, conductivity meter model HI 8033 and pH meter model HI 8424, respectively.

Table 1 Details of sampling sites coordinates

Sampling point	Longitude	Latitude	Distance from dumpsite (metres)
BH1	S29°18′51.164″	E27°32′10.031″	87
BH2	S29º19′6.57″	E027º32′13.106″	600
BH3	S29º19′3.465″	E027º54′25.36″	800
BH4	S29º18′47.042″	E027º32′21.576″	230
BH5	S29º19′7.394″	E027º32′29.242″	900

Water samples were collected using 500 mL polythene bottles which had been washed with soap without metals, and rinsed with distilled water. The bottles were soaked in 10% nitric acid for a night prior to sampling. Before collection of samples, groundwater was used to rinse each bottle. The sampling bottles were labelled and water was carefully stored at 4 °C and transported to the laboratory for laboratory analyses. Chlorides, COD, copper, iron and lead were analysed in the laboratory following standard methods [31] (Sect. 2.2.3).

2.2.3 Quality control measures

Instruments calibration were performed prior to each analytical assessment according to APHA [31] standards and manufacturer specifications. The Atomic Absorption Spectrometry (AAS) was calibrated for each analysis using a blank and 5 standard solutions. Calibration verification standards were analysed after every 5 samples to ensure stability such that results would be within ± 10% of the true value [31]. Blank water samples free of the analyte were carried through the entire analytical procedure, including digestion for COD, and were analysed with each batch of samples. All blanks were below detection limits indicating negligible contamination. For water parameters that could not be analysed instantly, samples were stored in a cooler box with ice medium to arrest any reactions between sampling and analysis. When analysis could not be done within 24 h of refrigeration, samples were acidified with nitric acid to a pH less than 2 [31] for iron and lead, and H_2SO_4 for COD. There was no need to preserve water for chlorides, but water was refrigerated and analysed within one week. All samples were analysed in triplicate for each water parameter, and the average calculated.

2.2.4 Water laboratory analysis

Prior to laboratory analysis, the water was filtered through a filter of 0.1–2.0 microns pore size, and standard procedures followed for all analyses [31]. Ions were isolated by precipitation and dissolution for chlorides analysis, and this was achieved through titration against silver nitrate solution following methods for water analysis [31]. In this method, silver nitrate reacts with chloride to form silver chloride. For chemical oxygen demand (COD), potassium dichromate ($K_2Cr_2O_7$) was added to heated sulphuric acid (H_2SO_4) medium using a HACH COD reactor for 2 h. This was followed with cooling of the mixture prior to adding to water samples. Readings were taken using a HACH (model DR-2000) spectrophotometer. Excess $K_2Cr_2O_7$ may be added to ensure that all organic matter (OM) in the sample is completely oxidized, thus making the method more suitable. This is achieved through titration of the $K_2Cr_2O_7$ with ferrous ammonium sulphate [32]. AAS method was used for copper analysis due to freedom from interferences [31]. Iron analysis was done following the direct AAS method, where the filtered sample was atomised without any pre-treatment, and lead analysis was performed following AAS procedures.

2.2.5 Ethical approval

This study received ethical clearance from The National University of Lesotho Institutional Review Board (NUL-IRB) and was approved by The Ministry of Health No.: NUL/ENV/2024/08. All the experiments were approved by the IRB, and followed the APHA

Table 2 Oral reference dose (RfD) for heavy metals in the study area

Metal	RfD (mg/kg/day)
Lead (Pb)	0.004
Iron (Fe)	0.7
Copper (Cu)	0.04

Source: USEPA [34]

Table 3 Input parameters for CDI characterisation

Parameter	Symbol	Units	Adult	Children
Ingestion Rate	IR	L/day	2.0	1.0
Exposure Frequency	EF	Days/year	350	350
Exposure Duration	ED	Years	30	6
Body weight	Bw	Kg	70	15
Averaging Time	AT (ED × 365)	Days	10,950	2190

Source: USEPA [34]

[31] guidelines. No experiments were performed on humans and/or human tissue. No personal identifying, and no information was gathered from community members.

2.3 Health risk assessment

Human health risk assessment was the tool used for evaluation of potential human health risk in the study area. The assessment was carried out on the basis that the pollutants primarily get absorbed into the human body through drinking the water. Reference dose (RfD) for lead was 0.004 mg/kg/day, 0.7 mg/kg/day for iron [33], and 0.04 mg/kg/day for copper [34] as shown in Table 2. Chronic Daily Intake (CDI) and hazard quotient (HQ) were calculated, where $HQ > 1$ implied high potential for non-cancer health risk, whereas $HQ < 1$ reflected low potential for non-cancer health problems. More than one toxicant is analysed in this study, so interactions amongst them were taken into consideration, and assumed to have additive effect if consumed. The HQs were therefore summed in order to obtain hazard index (HI) for all heavy metals in the study area (Eq. 3).

Chronic daily intake (CDI) and Health quotient (HQ) were calculated by Eqs. 1 [33] and 2 [34] respectively.

Parameters that were used for calculations are presented in Tables 2 and 3.

$$HQ = \frac{chronic\ daily\ intake}{Reference\ dose} \tag{1}$$

where CDI refers to Chronic Daily Intake, being the daily dose of heavy metals in mg/L that consumers might be exposed, and calculated as shown in Eq. 2.

$$CDI = \frac{Cw \times IR \times EF \times ED}{Bw \times AT} \tag{2}$$

where Cw is the observed concentration from boreholes; IR is ingestion rate (2L/day for adults and 1L/day for children), EF is exposure frequency (350 days in one year), ED is exposure duration (30 for adults and 6 for children), Bw is body weight (70 kg for adults and 15 kg for children), and AT is averaging time (calculated as ED by 365) as shown in Table 3. HQ was considered present if it was above 1.00. Non-carcinogenic effect was also considered negligible if $HI < 1.0$ and HI was calculated as shown in Eq. 3.

$$HI = \sum_{i=1}^{n} (\mathrm{HQ})\, i \tag{3}$$

where HI is the hazard index for all toxic metals analysed in the study and n is the total number of metals.

2.4 Data analysis

Descriptive analyses were used for distribution of water parameters within the dumpsite area, using frequencies and percentages for samples that were beyond and within WHO water standards for drinking water. The WHO permissible drinking water standards were compared with the observed water parameter levels.

Correlation coefficient was used in order to establish existence of relationships amongst water quality parameters in the four sampling points. Principal component analysis (PCA) was used to provide factor loadings and for more information regarding significant factors that influence water quality in the study area. The analyses were carried at confidence limit of 95%. Kaiser normalisation was used for determination of principal components (PCs) utilising eigenvalues above 1, using Statistical Package for Social Science (SPSS) software version 23.0. Component loadings that are above 0.75 were considered to be the strongest, those between 0.50 and 0.74 as moderate, and those between 0.3 and 0.50 as the weak components [35].

3 Results and discussion

3.1 Groundwater physicochemical analysis in the study area.

Table 4 shows a summary of borehole physicochemical parameters, and the minimum, maximum and mean concentrations of physicochemical parameters per sampling point (borehole) are shown in Table 5. The results showed that 50%, 100%, 65%, 95%, and 45% of pH, COD, Cl, lead and iron sample levels respectively, exceed the WHO limits for drinking water in the study area.

Mean values for pH varied between 8.03 (BH2) and 9.1 (BH5), and the maximum level was slightly beyond the allowable threshold of 8.5 (Fig. 2a). These results show slight alkalinity of groundwater in the area, and a likelihood of availability of heavy metals precipitating [36]. Table 6 shows that there was a strong positive correlation between pH and lead ($r = 0.913$) at p value < 0.00001, and the relationship was significant. This might indicate how pH might affect groundwater lead toxicity, whereas pH might also increase, rendering water alkaline.

Mean COD ranged from 54 mg/L (BH4) to 82.25 mg/L (BH1), and exceeded the WHO limit of 10 mg/L (Fig. 2b). Biodegradable waste and other oxidisable pollutants

Table 4 Summary of mean values for all sampling points (Boreholes)

	BH1	BH2	BH3	BH4	BH5	Mean	SD	Error Bars
Temperature	20	19.98	21	19.7	20.5	20.24	0.515248	0.230
pH	8.6	8.03	8.45	8.44	9.1	8.524	0.385396	0.172
EC	1335	1176	1207	1054	1091	1173	109.9894	49.102
COD	82.25	69	67.5	54	76.5	69.85	10.67064	4.764
Cl	281.7	266.8	288.7	231.5	191	251.9	40.57682	18.115
Lead	0.05	0.057	0.06	0.06	0.083	0.062	0.01243	0.005
Copper	0.06	0.06	0.05	0.053	0.035	0.052	0.010262	0.004
Iron	1.22	1.018	0.34	0.18	0.23	0.598	0.484767	0.216

Table 5 Spatial distribution of groundwater physicochemical parameters

Parameter	BH1 (87 m)			BH2 (600 m)			BH3 (800 m)			BH4 (230 m)			BH5 (900 m)			WHO limit	% of samples beyond WHO limit
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean		
Temp (°C)	18.9	20.7	20	18.8	21.4	19.98	17.8	24.2	21	18.3	21.6	19.7	19.6	22.1	20.5	27–30	
pH	7.8	9.1	8.6	7.6	8.5	8.03	8.1	8.7	8.45	7.34	9.3	8.44	8.5	9.7	9.1	6.5–8.5	50
EC (µS/cm)	1260	1450	1335	1034	1298	1176	956	1334	1207	999	1048	1054	1003	1193	1091	1500	0
COD (mg/L)	79	88	82.25	66	79	69	62	75	67.5	48	59	54	78	80	76.5	10	100
Cl (mg/L)	255.7	304.4	281.7	252	287	266.8	284.2	312.4	288.7	230	234	231.5	128	287.8	191	250	65
Pb (mg/L)	0.03	0.09	0.05	0.031	0.089	0.057	0.04	0.111	0.06	0.034	0.079	0.06	0.074	0.094	0.083	0.01	95
Cu (mg/L)	0.03	0.07	0.06	0.044	0.074	0.06	0.03	0.074	0.05	0.043	0.064	0.053	0.027	0.036	0.035	2	0
Fe (mg/L)	0.87	1.98	1.22	0.78	1.34	1.018	0.25	0.54	0.34	0.117	0.242	0.18	0.201	0.273	0.23	< 0.3	45

in leachate from the dumpsite might have contributed to significantly high COD in the study area [37, 38]. However, high COD does not directly cause health problems, but an attempt to disinfect water with high COD utilising chlorine-based disinfectants forms Trihalomethanes (THMs) which are carcinogenic [39].

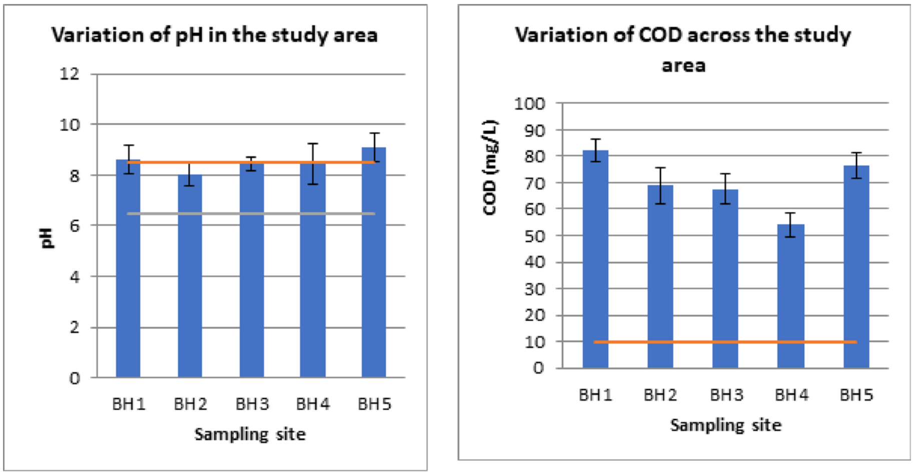
These results are in agreement with a study in Ethiopia [12] with COD level of 75 mg/L. A moderate correlation existed between COD and iron ($r = 0.604$) at $p = 0.017$, and EC ($r = 0.571$) at $p = 0.026$ and these reflected a significant correlation. This could explain that EC and iron play a significant role towards high COD in water bodies.

The mean level of chlorides varied from 191.03 mg/L (BH5) to 288.7 mg/L in BH3 (Fig. 3a) and the mean maximum level was beyond the permissible limit of 250 mg/L. High chloride levels could be due to elevated total dissolved solids (TDS). TDS is the total amount of soluble hydrogen carbonate ions, chloride salts, calcium, magnesium, potassium, volatile solids, non-volatile solids and sulphates. On their own, chlorides are toxic and affect taste when concentration is between 200 and 300 mg/L, and do not have specific health problems while below 1000 mg/L [11]. Elevated chloride levels could accelerate the corrosion of pipes in borehole systems, potentially leading to increased leaching of heavy metals into drinking water. There was a strong positive correlation between chlorides and EC ($r = 0.840$) at $p < 0.000089$ and copper ($r = 0.780$) at $p = 0.00006$, and a moderate one with iron ($r = 0.588$) at $p = 0.021$ (Table 6). The relationship between chlorides and copper, and with iron was significant, and could highlight contribution of copper and iron to high chloride level in the groundwater. High EC in the groundwater could show high enrichment of salts in the area.

The range of 1054 µS/cm (BH4) to 1335 µS/cm (BH1) for EC was observed (Fig. 3b), this was within the WHO limit of 1500 µS/cm. This depicts low ability of water to conduct electricity and hence low enrichment with salts [7]. A study in Central-Western Guanzhong Basin, China found the lowest EC of 201 µS/cm [40]. Similar studies obtained EC in the range 283–1044 µS/cm [41] and this might reflect slight migration of leachate from the dumpsite into groundwater. A strong positive correlation existed between EC and chlorides ($r = 0.840$) and iron ($r = 0.704$) at $p = 0.00339$, showing a moderate correlation with COD ($r = 0.571$) at $p = 0.026$, and copper ($r = 0.568$) at $p = 0.027$. This association might highlight the role played by chlorides, COD, and copper on EC of the groundwater. Other water characteristics that may be associated with high copper levels.

are high temperatures and low pH [42].

Mean values for lead were in the range of 0.05 mg/L (BH1) to 0.083 mg/L (BH5) as shown in Fig. 4a, exceeding the WHO limit of 0.01 mg/L. High concentration of lead in the groundwater is attributable to leaching from the dumpsite, and the main source might be e-waste materials like batteries, together with lead-based paints [43, 44]. The control site (BH5) exhibited a high concentration of lead, and this could be attributable to agricultural activities in the area, which utilised lead-based fertiliser and pesticides. However, the hydrogeological properties of the study area are primarily of igneous formation, and could have contributed to high levels of lead through deposition into groundwater. Other metals which are found in igneous hydrology and could be deposited into the groundwater include iron, arsenic, cadmium and zinc, to mention a few. Lead is capable of dissolving and increasing concentration of other ions, thus increasing EC of water. Lead accumulates in teeth, bones, skin and spinal cord tissues [45, 46]



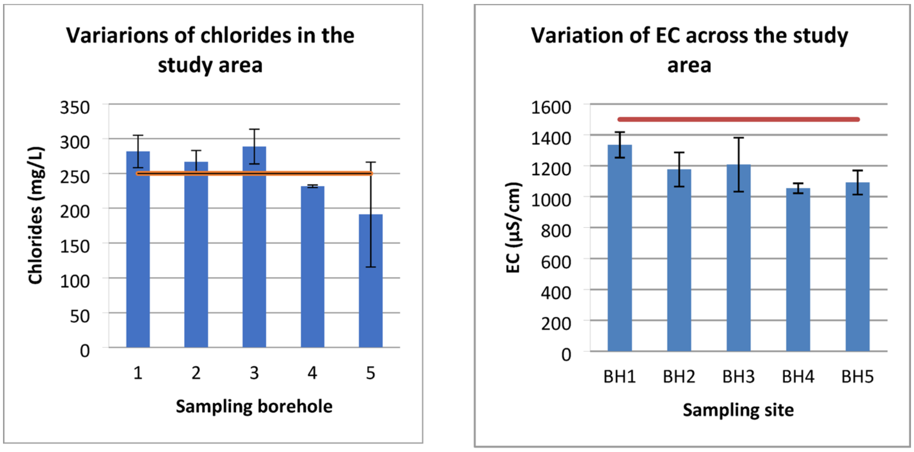
(a) Red line: 8.5 threshold for pH
Green line denotes the 6.5 minimum for pH

(b) Red line: 10mg/L COD threshold

Fig. 2 Variations of pH and COD within the study area

Table 6 Correlation matrix for Ts'osane groundwater quality

Parameter	Temperature	pH	EC	COD	Chlorides	Lead	Copper	Iron
Temperature	1.000							
pH	0.286	1.000						
EC	0.210	−0.514	1.000					
COD	0.243	0.339	0.571	1.000				
Chlorides	0.145	−0.839	0.840	0.113	1.000			
Lead	0.404	0.913	−0.626	0.019	−0.837	1.000		
Copper	−0.496	−0.904	0.568	−0.057	0.780	−0.995	1.000	
Iron	−0.324	−0.424	0.704	0.604	0.588	−0.748	0.737	1.000

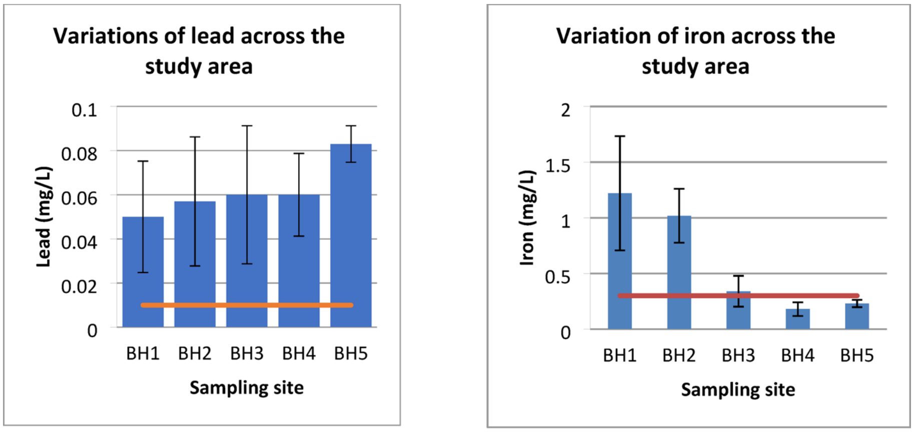


(a) Red line: 250 mg/L threshold for Cl

(b) Red line: 1500µS/cm threshold

Fig. 3 Mean concentrations of chlorides and EC in the sampled boreholes

thus prolonging its toxicity in the human body. Besides, lead disrupts calcium absorption, thus risking bone strength and fracture [47]. Other health problems from lead pollution in drinking water include headaches, fatigue, decreased IQ, damage to the central nervous system, reproductive system and liver, and anaemia [48, 49]. Children's



(a) Red line: 0.01 mg/L threshold (b) Red line: 0.3 mg/L threshold

Fig. 4 Lead and iron variations within the study area

bodies absorb lead faster than adults, and their central nervous system (CNS) and brain are still developing, thus making them the most vulnerable group to lead pollution in water, even for short-term exposure [6]. Findings from this study are in conformity with those obtained by various studies by Murtaza & Sabihakhurram [50] in Pakistan (0.04 mg/L); Boateng et al. [51] in Kumasi, Ghana (1.56 to 3.57 mg/L); Abdullahi et al. [41] at 0.865 mg/l in Nigeria and Olafisoye [52] at 0.16 mg/L in Kumasi, Ghana. In this study, lead had a strong positive correlation with pH ($r = 0.913$) with $p < 0.00001$, and a moderate correlation with temperature ($r = 0.404$) at $p = 0.135$ which reflects that the correlation is not significant. A positive correlation of lead with pH might show contribution of acidic conditions to lead toxicity. Insignificant correlation of lead with temperature might imply that lead toxicity is not highly influenced by temperature, implying a need for further research with regard to other possible sources of lead. Other underlying issues could be water chemistry, soil composition and these have to be studied and monitored.

A range of 0.18 mg/L (BH4) to 1.22 mg/L (BH1) was recorded for iron (Fig. 4b), and the mean maximum value exceeded the WHO permissible level of 0.3 mg/L. High levels of iron in the area suggest that waste contains scrap metals and e-waste materials like electrical cables, and the dumpsite leachate could have introduced iron (Fe) into groundwater [53, 54]. However, hydrogeological nature of the study area might have contributed to high levels of iron, which is frequently deposited into groundwater from earth's surface. Boateng et al. [51] reported much higher Fe (10.88 to 25.61 mg/L) in Ghana. High levels of iron in drinking water cause bronchitis, nausea, stomach upsets and liver damage [55].

Mean values for copper varied from 0.035 mg/L (BH5) to 0.06 mg/L (BH1 & 2) and the results were within the allowable WHO concentration of 2 mg/L, and water was suitable for human consumption. Acceptable levels of copper were found in similar studies by Abd El-Salam and Abu-Zuid [12]. Boateng et al. [51] obtained Cu of 1.73 to 1.98 mg/L, quite higher than in this study.

3.2 Health risk assessment

CDI values for lead, iron and copper ranged from 0.00137 to 0.00227; 0.00334 to 0.027 for iron and 0.000959 to 0.00164 for lead, iron and copper respectively (Table 7). Similar

Table 7 CDI, Health Quotient and Hazard Index of groundwater

Sampling site	Population	CDI			HQ values			HI
		Lead	Iron	Copper	Lead	Iron	Copper	
BH1	Adult	0.00137	0.033	0.0016	0.342	4.775	0.041	0.431
	Children	0	0	0	0	0	0	0
BH2	Adult	0.0015	0.027	0.0016	0.390	3.984	0.041	0.0470
	Children	0	0	0	0	0	0	0
BH3	Adult	0.0016	0.0093	0.00137	0.411	1.331	0.0342	0.458
	Children	0	0	0	0	0	0	0
BH4	Adult	0.0016	0.0049	0.00096	0.411	0.704	0.0239	0.441
	Children	0	0	0	0	0	0	0
BH5 control	Adult	0.0022	0.0063	0.00142	0.568	0.900	0.036	0.613
	Children	0	0		0	0	0	0

studies by Adeyeye et al. [55] and Onyele [56] detected iron CDI of 0.02, and lead CDI value of 0.00466 in North eastern China and South eastern Nigeria respectively, whereas Oyem [33] recorded CDI of 0.0075 for lead in Agbor and Owa, in Nigeria.

Findings of this study show that the heavy metal order is Fe > Pd > Cu. The CDI is below RfD values for all the heavy metals, and findings reflected zero (0) for children, thus reflected negligible risk for water consumption in the study area.

Hazard Quotient for lead, iron and copper was between 0.342 and 0.568; 0.0070 and 0.0478; and 0.0239 and 0.0410 respectively. HQ below 1.00 suggests that there is low potential for non-cancer health risks for residents at Ts'osane, with regard to lead, iron and copper exposure. Similar studies by Njoku et al. [20] and Jessica et al. [48] concur with this study, where HQ below 1.00 was obtained for lead, iron and copper in Ogun State, Nigeria boreholes and Islamabad, Pakistan respectively. Hazard index was recorded as 0.431 (BH1), 0.470 (BH2), 0.458 (BH3), 0.441 (BH4), and 0.616 (BH5). The HI below 1.00 might indicate that long-term health risk is low in the study area and non-carcinogenic adverse effects are negligible. A similar study by Njoku [20] obtained negligible HI for groundwater in Ogun State, Nigeria. On the contrary, studies by Zhang [39] and Boateng [51] obtained HI that was above 1.00.

3.3 Potential sources of heavy metals in groundwater (Principal Component Analysis)

The mean values of water quality parameters were subjected to principal component analysis (PCA) as a multivariate technique, with Varimax Rotation [57, 58] in order to get the key parameters that may influence water quality within the study area. Three components were derived from the PCA (Table 8). The first principal component (PC1) explains 59.89% of variance, while the second principal component explains 25.09% variance, and together account for 84.98% of the total variance. Highest loadings in the first PC were copper, chlorides, iron and EC (Table 8) in that order. This indicates that copper is the dominant variable that influences the first PC. Highest loadings in the second PC were COD, temperature and iron, and COD was the dominant variable. COD could imply that pollution is being influenced by organics.

This analysis therefore points to copper and COD as the significant water quality parameters that influence groundwater quality in the area. The positive correlations amongst the heavy metals, EC and COD as discussed in Sect. 3.1 are in support of this finding, and, chlorides, iron and EC, and temperature are the other significant parameters for management of pollution in the study area. Nevertheless, physicochemical water

Table 8 Component loadings of water quality parameters

Parameter	Component		
	1	2	3
Temperature	− 0.276	**0.630**	**0.709**
pH	− 0.866	0.397	− 0.299
EC	**0.780**	**0.558**	0.157
COD	0.159	**0.905**	− 0.395
Chlorides	**0.897**	0.149	0.414
Lead	− 0.976	0.203	0.207
Copper	**0.956**	− 0.272	− 0.096
Iron	**0.809**	0.326	− 0.464
Eigenvalues	4.787	1.927	1.169
% of variance	59.838	24.091	14.613
Cumulative variance %	59.838	83.928	98.541

analysis results portray the highest risk from the listed parameters as lead, and not copper, and this calls for close monitoring of the metal.

4 Conclusions and recommendations

The study concludes that groundwater at Ts'osane has high levels of chlorides, COD, iron and lead. The other conclusion drawn is that even though lead and iron pollution is typical of waste from dumpsites, it is insufficient to tie groundwater pollution on the dumpsite alone. The groundwater pollution status and response could depend on hydrogeology and geological conditions of the study area, together with other anthropogenic activities. Residents who consume groundwater from some of the boreholes investigated in this study are vulnerable to health problems, and sustainable management of groundwater resources is vital. The health risk assessment has shown that groundwater in the study area is not entirely suitable for human consumption due to high levels lead and iron. However, CDI, HQ and HI are negligible, indicating non-carcinogenic risk to residents. It should also be reflected that long-term exposure to these heavy metals could lead to water toxicity due to bioaccumulation and biomagnification, and might pose health threats to the residents.

From these findings, the study recommends the following:

1. Extended and frequent monitoring of groundwater resources that incorporates other heavy metals;
2. Urgent re-location of the dumpsite and rehabilitation of the area within the dumpsite, as a measure that reduces further migration of pollutants into water bodies;
3. Future dumpsites have to be lined to prevent leachate from infiltrating into the ground and polluting groundwater; leachate collection systems have to be installed too, and lining material should prevent sideways movement towards available surface water bodies;
4. Lesotho should consider closing operations in dumpsites that are in proximity to residential areas, in order to prevent environmental pollution, which leads towards communities' diseases and/or deaths;
5. Institutes of higher learning, research institutes/ scientists and government must collaborate and evaluate and monitor water resources' pollution, incorporating issues of variations in climatic conditions. These will strengthen informed policies regarding protection of the environment and human health;

6. In the long-run, planning and population growth of countries have to be taken into consideration when siting dumpsites, and;
7. Environmental and health policies have to implemented, so as to protect human health from adverse effects of pollution.

5 Limitations

1. Waste at Ts'osane has not been characterised, and this is one of the knowledge gaps that need to be addressed by future studies in order to ascertain that the dumpsite is the main source of groundwater pollution.
2. The study was limited to copper, iron and lead as heavy metals in the study area. This gap that needs to be addressed by future studies in order to draw comprehensive conclusions.
3. Other climatic and geological factors that may lower or speed up decomposition of decaying matter and seepage of leachate into groundwater were not taken into consideration, and future studies should consider them.

Author contribution

Conceptualization, M.G., Q.L. and S.T.; Methodology, M.G., Q.L. and S.T.; validation, M.G. and Q.L., S.T.; formal analysis, M.G.; investigation, Q.L., S.T.; resources, M.G.; data curation, M.G.; writing—original draft preparation, Q.L. and S.T.; writing-review and editing, M.G.; visualization, M.G., supervision, M.G. All authors have reviewed the manuscript.

Funding

This research received no external funding.

Data availability

The data that support the findings of this study are available on request from the corresponding author.

Declarations

Ethics approval and consent to participate

This study received ethical clearance from The National University of Lesotho Institutional Review Board (NUL—IRB) and was approved by The Ministry of Health No.: NUL/ENV/2024/08.

Consent for publication

This is not applicable.

Competing interests

The authors declare no competing interests.

Received: 19 February 2025 / Accepted: 1 August 2025

References

1. Majolagbe A, Adeyi A, Osibanjo O, Adams A, Ojuri O. Pollution vulnerability and health risk assessment of groundwater around an engineering landfill in Lagos, Nigeria. Chem Int. 2017;3(1):56–68.
2. Mohobane T. The characteristics and impacts of landfill leachate from Horotiu, New Zealand and Maseru, Lesotho: A comparative study. New Zealand: MSc thesis. The University of Waikato. 2008.
3. Abdus-Salam N. Assessment of heavy metals pollution in dumpsites in Ilorin metropolis. Ethiop J Environ Stud Manag. 2009;2(2):92–9.
4. Chang J, Lee N, Yoon SP, Choi J, Hur G, Lee JY. Improvement of the utilization of abandoned quarry as landfill facilities. J Korea Soc Waste Manag. 2023;40(2):115–23.
5. Sharma A, Gupta A, Ganguly R. Impact of open dumping of municipal solid waste on soil properties in mountainous region. J Rock Mech Geotech Eng. 2018;10(4):725–39.
6. Agrawal P, Singhal S, Sharma R. Heavy metal contamination in groundwater sources. In: Madhav S, Singh P, editors. Groundwater geochemistry: pollution and remediation methods. Hoboken: John Wiley & Sons Ltd.; 2021. p. 57–78. https://doi.org/10.1002/9781119709732.
7. Adimalla N, Wu J. Groundwater quality and associated health risks in a semi-arid region of South India: implication to sustainable groundwater management. Hum Ecol Risk Assess. 2019;25(1–2):191–216. https://doi.org/10.1080/10807039.2018.1546550.
8. Mukherjee I, Singh U. Groundwater fluoride contamination, probable release, and containment mechanisms: a review on Indian context. Environ Geochem Health. 2018;40(6):2259–301. https://doi.org/10.1007/s10653-018-0096-x.

9. Grönwall J, Danert K. Regarding groundwater and drinking water access through a human rights lens: self-supply as a norm. Water. 2020. https://doi.org/10.3390/w12020419.
10. Oyelami A, Ojo A, Aladejana J, Agbede O. Assessing the effect of a dumpsite on groundwater quality: a case study of Aduramigba Estate within Osogbo Metropolis. J Environ Earth Sci. 2013;3:2224–3216.
11. WHO. Guidelines for drinking water quality. 4th ed. Geneva, Switzerland: World Health Organisation; 2011.
12. Abd El-Salam M, Abu-Zuid G. Impact of landfill leachate on the groundwater quality: a case study in Egypt. J Adv Res. 2015;6(4):579–86. https://doi.org/10.1016/j.jare.2014.02.003.
13. Lapworth J, Nkhuwa DC, Okotto-Okotto J, Pedley S, Stuart M, Tijani M, Wright J. Urban groundwater quality in sub-Saharan Africa: current status and implications for water security and public health. Hydrogeol J. 2017;25(4):1093–116. https://doi.org/10.1007/s10040-016-1516-6.
14. Yargholi B, Azimi A. Investigation of cadmium absorption and accumulation in different parts of some vegetables. Am Eurasian J Agric Environ Sci. 2008;3(3):357–64.
15. Hei T, Filipic M. Role of oxidative damage in the genotoxicity of arsenic. Free Radic Biol Med. 2004;37(5):574–81. https://doi.org/10.1016/j.freeradbiomed.2004.02.003.
16. Leonard S, Bower J, Shi X. Metal-induced toxicity, carcinogenesis, mechanisms and cellular responses. Mol Cell Biochem. 2004;255(1–2):3–10. https://doi.org/10.1023/B:MCBI.0000007255.72746.a6.
17. Wang Y, Fang J, Leorrnard S, Rao K. Cadmium inhibits the electron transfer chain and induces reactive oxygen species. Free Radic Biol Med. 2004;36(11):1434–43. https://doi.org/10.1016/j.freeradbiomed.2004.03.010.
18. EPA. Environmental guidelines: solid waste landfills, second edition 2016. Sydney: NSW Environment Protection Authority (EPA); 2016.
19. Andeobu L, Wibowo S, Grandhi S. Environmental and health consequences of E-waste dumping and recycling carried out by selected countries in Asia and Latin America. Sustainability. 2023;15:10405.
20. Njoku K, Osunkoya OO, Ude EO, Iheme PO, Onuaguluchi PN. Health risk assessment of groundwater from selected areas of Ijebu North, Ogun State, Nigeria. Aswan Univ J Environ Stud. 2024;5(1):1–14.
21. Fiore M, Conti G, Caltabiano R, Buffone A, Zuccarello P, Cormaci L, Cannizzaro MA, Ferrante M. Role of emerging environmental risk factors in thyroid cancer: a brief review. Int J Environ Res Public Health. 2019;16(7):1–18. https://doi.org/10.3390/ijerph16071185.
22. WHO. Arsenic. 2022. Retrieved from https://www.who.int/news-room/fact-sheets/detail/arsenic
23. Aswal R, Prasad M, Patel N, Srivastav A, Egbueri J, Kumar G, Ramola R. Occurrences, sources and health hazard estimation of potentially toxic elements in the groundwater of Garhwal Himalaya, India. Sci Rep. 2023;13(13069):1–21. https://doi.org/10.1038/s41598-023-40266-7.
24. de Lima M, Pereira W, de Souza E, Teixeira R, Palheta D, Faial K, Costa HF, Fernandes A. Bioaccumulation and human health risks of potentially toxic elements in fish species from the southeastern Carajás Mineral Province, Brazil. Environ Res. 2022;204(B):112024. https://doi.org/10.1016/j.envres.2021.112024.
25. Kim R-Y, Yoon J-K, Kim T-S, Yang J, Owens G, Kim K-R. Bioavailability of heavy metals in soils: definitions and practical implementation–a critical review. Environ Geochem Health. 2015;37(6):1041–61. https://doi.org/10.1007/s10653-015-9695-y.
26. Filho A, Mizusaki A, Antonioli L. Magmatism and petroleum exploration in the Brazilian Paleozoic basins. Mar Pet Geol. 2008;25(2):143–51. https://doi.org/10.1016/j.marpetgeo.2007.07.006.
27. Mège D, Rango T. Permanent groundwater storage in basaltic dyke fractures and termite mound viability. J Afr Earth Sci. 2010;57(1–2):127–42. https://doi.org/10.1016/j.jafrearsci.2009.07.014.
28. IGRAC. National groundwater monitoring programmes—a global overview of quantitative groundwater monitoring networks. Delft: International Groundwater Resources Assessment Center. 2024. Retrieved January 18, 2024, from NATIONAL GROUNDWATER MONITORING PROGRAMMES: https://www.un-igrac.org/resource/groundwater-monitoring-country-profile-lesotho
29. Emmanuel-Akerele H, Peter F. Microbial and physico-chemical assessment of soil and water around waste dump sites in Lagos. Int J Appl Biol. 2021;5(1):73–82.
30. The World Bank Group. Lesotho Climatology. [Online]. 2021.
31. APHA. Standard methods for the examination of water and wastewater. 21st ed. Washington, DC: American Public Health Association; 2005.
32. Sawyer CN, McCarty PL, Parkin GF. Chemistry for environmental engineering and science. 5th ed. New York: McGraw-Hill; 2003.
33. Oyem H, Oyem I, Usese A. Iron, manganese, cadmium, chromium, zinc and arsenic groundwater contents of Agbor and Owa communities of Nigeria. Springerplus. 2015;4:104.
34. USEPA. Environmental protection agency region integrated risk information system. Washington DC: USEPA; 2011.
35. Liu C, Lin K, Kuo Y. Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan. Sci Total Environ. 2003;313:77–89. https://doi.org/10.1016/S0048-9697(02)00683-6.
36. Hayton J. Industrial water treatment process technology. Oxford, UK: Butterworth-Heinemann; 2017.
37. Wu J, Zhang H, He P-J, Shao L-M. Insight into the heavy metal binding potential of dissolved organic matter in MSW leachate using EEM quenching combined with PARAFAC analysis. Water Res. 2011;45(4):1711–9. https://doi.org/10.1016/j.watres.2010.11.022.
38. Corsino S, Capodici M, Trapani D, Torregrossa M, Viviani G. Assessment of landfill leachate biodegradability and treatability by means of allochthonous and autochthonous biomasses. New Biotechnol. 2020;55:91–7. https://doi.org/10.1016/j.nbt.2019.10.007.
39. Parveen N, Chowdhury S, Goel S. Environmental impacts of the widespread use of chlorine-based disinfectants during the COVID-19 pandemic. Environ Sci Pollut Res. 2022;29:85742–60.
40. Zhang Q, Xu P, Qian H. Assessment of groundwater quality and human health risk (HHR) evaluation of nitrate in the Central-Western Guanzhong Basin, China. Int J Environ Res Public Health. 2019;16:4246.
41. Abdullahi N, Osazuwa I, Sule P. Application of integrated geophysical techniques in the investigation of groundwater contamination: a case study of municipal solid waste leachate. Ozean J Appl Sci. 2011;4(1):7–25.
42. Casper J. Copper toxicity and self-evaluation. 2024. Retrieved from Nutritional Balancing.Org: http://nutritionalbalancing.org/center/htma/science/articles/copper-toxicity.php

43. Javahershenas M, Nabizadeh R, Alimohammadi M, Mahvi A. The effects of Lahijan landfill leachate on the quality of surface and groundwater resources. Int J Anal Chem. 2020. https://doi.org/10.1080/03067319.2020.1724984.
44. Obeng-Gyasi E. Sources of lead exposure in West Africa. Sci. 2022;4(3): 33. https://doi.org/10.3390/sci4030033.
45. Bellinger D. Neurological and behavioral consequences of childhood lead exposure. PLoS Med. 2008;5(5): e115. https://doi.org/10.1371/journal.pmed.0050115.
46. Obeng-Gyasi E, Ferguson A, Stamatakis K, Province M. Combined effect of lead exposure and allostatic load on cardiovascular disease mortality—a preliminary study. Int J Environ Res Public Health. 2021;18(13):6879. https://doi.org/10.3390/ijerph18136879.
47. Azam M, Ahmad A, Ahmed A, Khalid A, Saleem S. Health risk assessment of arsenic and lead contamination in drinking water: a study of Islamabad and Rawalpindi, Pakistan. Water Supply. 2024;24(6):2055–65. https://doi.org/10.2166/ws.2024.135.
48. Jessica B, Sinagra E, Blundell R. Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon. 2020;6(9):e04691. https://doi.org/10.1016/j.heliyon.2020.e04691.
49. Majumder A, Al Nayeem A, Islam M, Akter M, Carter W. Critical review of lead pollution in Bangladesh. J Health Pollut. 2021;11(31): 210902. https://doi.org/10.5696/2156-9614-11.31.210902.
50. Murtaza G, Sabihakhurram H. Assessment of heavy metals contamination in water, soil and plants around the landfill in Khanewal Pakistan. Int J Res Stud Sci Eng Technol. 2018;5(11):7–13.
51. Boateng T, Opoku F, Akoto O. Heavy metal contamination assessment of groundwater quality: a case of Oti landfill site, Kumasi. Appl Water Sci. 2019;9(33):33. https://doi.org/10.1007/s13201-019-0915-y.
52. Olafisoye E, Sunmonu L, Adagunodo T, Oladego O. Groundwater contaminats' investigation at Aarada Waste Disposal Site using geophysical and hydro-physicochemical approach. J Environ Sci Toxicol Food Technol. 2013;2(4):1–10.
53. Chakraborty S, Qamruzzaman M, Zaman MWU, Alam MdM, Hossain MdD, Pramanik BK, Nguyen LN, Nghiem LD, Ahmed MF, Zhou JL, Mondal MdIH, Hossain MA. Metals in e-waste: occurrence, fate, impacts and remediation technologies. Process Saf Environ Prot. 2022;162:230–52.
54. Islam M, Mostafa M, Muhammad T. Identification of sources and mobilization of trace elements in shallow groundwater of the Upper Ganges River Basin. J Chem Environ. 2023;1(2):14–29.
55. Adeyeye O, Xiao C, Zhang Z. State, source and triggering mechanism of iron and manganese pollution in groundwater of Changchun, Northeastern China. Environ Monit Assess. 2020;192:619. https://doi.org/10.1007/s10661-020-08571-0.
56. Onyele O, Anyanwu E. Human health risk assessment of some heavy metals in a rural spring, southeastern Nigeria. Afr J Environ Sci Res. 2018;1(1):5–23.
57. Kaizer H. The Varimax criterion for analytic rotation in factor analysis. Psychometrika. 1958;23(3):187–200.
58. Allen M. Factor Analysis: Varimax Rotation. The SAGE Encyclopedia of Communication Research Methods, 2017:4. https://doi.org/10.4135/9781483381411

Terms and Conditions

Springer Nature journal content, brought to you courtesy of Springer Nature Customer Service Center GmbH (“Springer Nature”).

Springer Nature supports a reasonable amount of sharing of research papers by authors, subscribers and authorised users (“Users”), for small-scale personal, non-commercial use provided that all copyright, trade and service marks and other proprietary notices are maintained. By accessing, sharing, receiving or otherwise using the Springer Nature journal content you agree to these terms of use (“Terms”). For these purposes, Springer Nature considers academic use (by researchers and students) to be non-commercial.

These Terms are supplementary and will apply in addition to any applicable website terms and conditions, a relevant site licence or a personal subscription. These Terms will prevail over any conflict or ambiguity with regards to the relevant terms, a site licence or a personal subscription (to the extent of the conflict or ambiguity only). For Creative Commons-licensed articles, the terms of the Creative Commons license used will apply.

We collect and use personal data to provide access to the Springer Nature journal content. We may also use these personal data internally within ResearchGate and Springer Nature and as agreed share it, in an anonymised way, for purposes of tracking, analysis and reporting. We will not otherwise disclose your personal data outside the ResearchGate or the Springer Nature group of companies unless we have your permission as detailed in the Privacy Policy.

While Users may use the Springer Nature journal content for small scale, personal non-commercial use, it is important to note that Users may not:

1. use such content for the purpose of providing other users with access on a regular or large scale basis or as a means to circumvent access control;
2. use such content where to do so would be considered a criminal or statutory offence in any jurisdiction, or gives rise to civil liability, or is otherwise unlawful;
3. falsely or misleadingly imply or suggest endorsement, approval , sponsorship, or association unless explicitly agreed to by Springer Nature in writing;
4. use bots or other automated methods to access the content or redirect messages
5. override any security feature or exclusionary protocol; or
6. share the content in order to create substitute for Springer Nature products or services or a systematic database of Springer Nature journal content.

In line with the restriction against commercial use, Springer Nature does not permit the creation of a product or service that creates revenue, royalties, rent or income from our content or its inclusion as part of a paid for service or for other commercial gain. Springer Nature journal content cannot be used for inter-library loans and librarians may not upload Springer Nature journal content on a large scale into their, or any other, institutional repository.

These terms of use are reviewed regularly and may be amended at any time. Springer Nature is not obligated to publish any information or content on this website and may remove it or features or functionality at our sole discretion, at any time with or without notice. Springer Nature may revoke this licence to you at any time and remove access to any copies of the Springer Nature journal content which have been saved.

To the fullest extent permitted by law, Springer Nature makes no warranties, representations or guarantees to Users, either express or implied with respect to the Springer nature journal content and all parties disclaim and waive any implied warranties or warranties imposed by law, including merchantability or fitness for any particular purpose.

Please note that these rights do not automatically extend to content, data or other material published by Springer Nature that may be licensed from third parties.

If you would like to use or distribute our Springer Nature journal content to a wider audience or on a regular basis or in any other manner not expressly permitted by these Terms, please contact Springer Nature at

onlineservice@springernature.com