

Analysis of some heavy metals and estimation of pollution indexes in open solid waste disposal site: The case of Bahir Dar City, Bahir Dar, Ethiopia

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Received: 14 July, 2024

Accepted: 17 December, 2024

Published: 10 January, 2025

Note:

This issue was initially scheduled for publication in October 2024 but was delayed due to an unforeseen internet shutdown in Bahir Dar.

ABSTRACT

Urban areas with high population and expansions of industrial activities are subject to a vast generation of municipal solid waste (MSW). This study attempts to analyze heavy metals (Pb, Ni, Cd, and Cr) concentration in the soil of the open solid waste dumping sites of Bahir Dar city and estimate the pollution index. A 0.5 kg of 4 soil samples were collected from the MSW dumping site. The three samples were collected from three corners of an equilateral triangle of 30 m length of the open solid waste dumping site and one sample 50 m away from the dumping site for every 15 cm interval (5-20 cm, 20-35 cm, and 35-50 cm). The collected samples from each corner for the same depth were well mixed and digested by the wet digestion method and then subject to Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) for the determination of heavy metals. Finally, the concentrations of the heavy metals in the solid waste were compared with the reference soil to estimate the pollution indexes. The results of ICP-OES of heavy metals in the dumping site in mean concentrations of mg/kg were found: 465.37 ± 27.5 , 232.17 ± 76.1 , 46.27 ± 18.21 , and 15.4 ± 14.09 for Cr, Pb, Ni, and Cd respectively. All the heavy metal concentrations were below the limit set by the Environmental Protection Authority of Victoria (EPA of Victoria) for the hazardous classification range for respective metals. The T-Test at $p < 0.05$, showed a significant difference in the mean concentration of the metals (Pb and Cr) between the soil taken from the dumping site and the control site (reference soil). However, Ni and Cd did not show significant differences. So, Pb and Cr have a higher degree of dispersion to the nearby farmland than Ni and Cd. Finally, the PI (pollution index) value of Cr and Pb fall in slight pollution, whereas Ni and Cd fall in moderate and very severe pollution, respectively, and will pose a negative effect on the soil of the nearby farmland, plants, and the environment. Thus, the contamination of these bodies by heavy metals will become a risk to human health through food chain and groundwater resources contamination. So, the municipal city has to construct a proper incineration plant or landfill that considers the future population growth of the city.

Keywords: ICP-OES, municipal solid waste, heavy metals, leachate, pollution indexes.

DOI: <https://dx.doi.org/10.4314/ejst.v17i3.5>

INTRODUCTION

The rapid population growth and the swift expansion of industrial activities in urban areas have led to a significant increase in the generation of municipal solid waste

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(MSW), posing serious challenges to the environment (Ahmad *et al.*, 2023). Municipal solid waste (MSW) is trash or garbage—consists of everyday items we use and then throw away as useless, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries (Ebistu and Minale, 2013; Tempest and Pando, 2013). These come from our homes, schools, hospitals, business centers, industries, and recreational centers. In recent days, the nature of this MSW has become more complex in its composition as well as in varieties. These include the presence of all organic and inorganic types such as toxic heavy metals, animal wastes, domestic discharges, industrial by-products, garbage, plastics, and the batteries we use for cell phones, cars, audio, visual instruments, and e-waste, etc. (Ebistu and Minale, 2013).

Solid waste composition varies substantially with socio-economic and disposal methods (Kaza and *et al.*, 2021; Matheson, 2022; Velis *et al.*, 2023). The total waste generation for lower-middle-income countries is higher than that of upper-middle-income countries, even though low-income countries produce less solid waste per capita in comparison to high-income countries (Kaza *et al.*, 2021; Matheson, 2022). According to this study, Ethiopia is labeled in the category of low-income countries, so the total waste produced in this country is expected to be high. Moreover, the problem is aggravated in this country due to the poor infrastructure to manage the MSW (Endalew and Tassie, 2018). Even, no proper way of sorting solid wastes before they are dumped in open dump sites (Pradhan, 2009; Endalew and Tassie, 2018). Bahir Dar, one of the most populous cities in the country, is subject to MSW management problems. Besides this, Bahir Dar became the political and economic center of Amhara Regional State after the year 1991 and is also subject to a high population explosion due to industrialization in Ethiopia (UNEP, 2011; Chinasho, 2015). This, in turn, led to the migration of people from rural villages to the city, which resulted in the generation of vast amounts MSW daily. The amount of MSW disposed in open dump sites is expected to increase in quantity as well as in variety shortly in this city. If the current growth rate of the city at 6.6 % continues, the city population will double within 11 years (UNEP, 2011; Lohri *et al.*, 2014)

In this city often uses unsafe solid waste disposal practices. Open waste dumping sites are still the only means of disposal of solid waste in addition to the burning of some solid wastes informally practiced (Valerie *et al.*, 2003; Ebistu and Minale, 2013). The “Eriamecharia” (Sebat Amit) open waste dumping site, which is located in the south direction, 7 km far away from the city of Bahir Dar, wastes are dumped in an uncontrolled manner and without provision for leachate and gas control system. This site is unfenced, with no boundary to nearby farmlands, and since it is located in tropical savanna climate, it can easily generate leachate. This leachate may have a composition of soluble heavy metals and organic waste that can easily leak into the groundwater sources as well as contaminate the nearby farmyards (Ebistu and Minale, 2013; Chinasho, 2015). Studies indicated that heavy metals deposition has raised serious

environmental concerns worldwide because bioaccumulation of these elements beyond the tolerance thresholds of living organisms poses a long-term risk to the earth's ecosystem (Chinasho, 2015; Haile and Gabbiye, 2021; Bouida *et al.*, 2022). The production and release of heavy metals into the environment are still increasing. The heavy metals commonly found in MSW open dumping sites include Cr, Cd, Pb, Hg, Ni, Cu, and Zn (Bouida *et al.*, 2022). However, the actual type and concentration vary from one to another. Some heavy metals could be poisonous or toxic to human beings since they can have a chance to enter the food chain through groundwater and soil contamination (Haile and Gabbiye, 2021; Bouida *et al.*, 2022).

The leachate produced from the MSW dumping site migrates and contaminates primarily the nearby soil during precipitation via infiltration, and it also infiltrates the groundwater zone. This leachate may contain soluble heavy metals of cadmium, manganese, chromium, lead, iron, and copper, which cause serious environmental damage since it is non-biodegradable ones they enter into the water or soil (Chinasho, 2015; Haile and Gabbiye, 2021; Bouida *et al.*, 2022). The common and major sources of heavy metals in MSW open dumping sites in recent days are batteries used for (cellophane, car, and audio-visual instruments), household hazards, hospital waste discharges, industrial wastes, paints, and dyes (Şan and Onay, 2001; Ebistu and Minale, 2013). Especially, contamination of soil in farmlands close to MSW open dumping sites is a serious problem since soils are considered the final sink for heavy metals, and also the leachate produced may get a chance to enter the food chain (Şan and Onay, 2001; Obiajunwa *et al.*, 2002). Assessment of contaminated soils of the nearby farmlands close to the MSW open dumping site for heavy metal contamination is essential before proposing other means of remediation strategies.

So this study attempts to determine the heavy metal concentration and estimates the pollution index in the "Eriamecharia" MSW open dumping site of Bahir Dar city located in Sebat Amit, by taking soil samples from the waste itself and the nearby farmlands.

MATERIAL AND METHODS

Description of the study area

Bahir Dar is located 11° 36' 0" North, 37° 23' 0" East on the bank of the third largest lake in East Africa and the head of the Blue Nile river called Lake Tana (Ayele *et al.*, 2016). The lake and its perspire have been designated biosphere reserve by UNESCO since 2015 (Wondie, 2018). The Bahir Dar city, along with the lake basin, is economically significant. As the city is the capital of the Amhara Regional State of the Federal Democratic Republic of Ethiopia, nowadays, people are migrating to the city, and many investors are attracted to the sector of industries to the city. The city had a population of 443,280 in the year 2024 (Central Statical Agency of Ethiopia, Amhara Statistical Data, 2024). It is estimated/projected that 222.2 tons per day of waste will be

generated in the city in 2022 (Tassie Wegedie, 2018). According to the study by Tassie Wegedie (2018), the municipality collects and disposes of 58 % of the waste generated in Bahir Dar City in a day during the survey period. No proper waste segregation at the source, even if the collection of waste is done house to house (Tassie Wegedie, 2018). The collected waste from all corners of the city is transported to the only open dumping site located 5 to 7 km away from the town, namely Eriamechari, commonly called “Sebat Amit” which is close to the farm yards of local people (Haile and Gabbiye, 2021).

The dumping site is located at 11.54° North latitude and 37.38° East longitude with 1801 m a ground elevation above mean sea level (Haile and Gabbiye, 2021). The dimensions of this unpredictable shape removal site is 384 m (by the side of the farmland that is known for Eriamecharia) and 174 m (by the roadside of Sebat Amit towards Addis Ababa). Around the dumping site, 3053 females and 3348 males an aggregate of 6401 populaces have been living (Central Statistical Agency, 2007; Central Statistical Agency of Ethiopia, 2007). The dumping site is depicted in Figure 1.

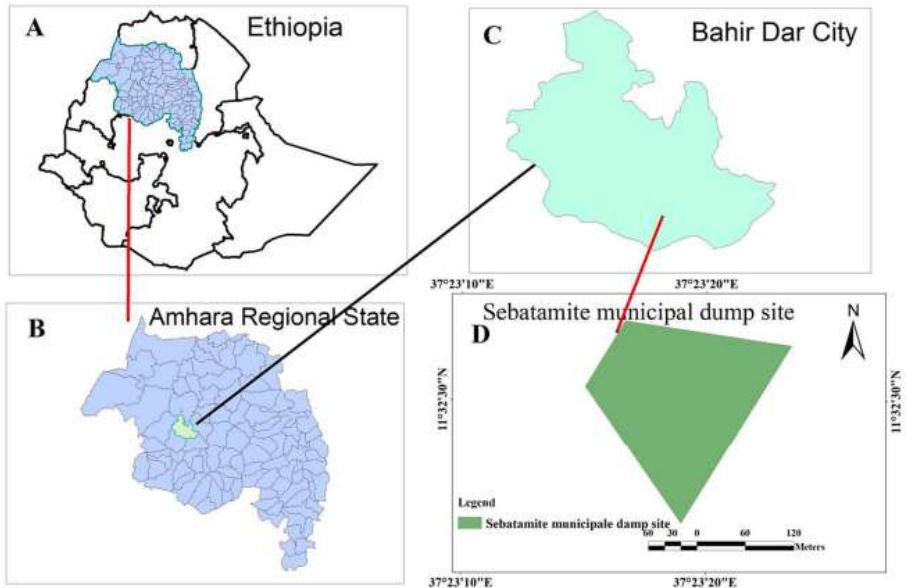


Figure 1. A map of the study area (Sitotaw *et al.*, 2024)

The Bahir Dar municipal city is responsible for the domestic as well as industrial wastes generated from 20 kebeles in the city. Eriamechari (Located in Sebat Amit) dumping site received in most cases unsorted wastes, including private waste 12610 kg/day, business 4202 kg/day, specialist co-op 988 kg/day, civil waste 1044 kg/day, all out 22,774 kg/day (Forum For Enviroment and UNEP, 2010; Haile and Gabbiye, 2021).

The waste is collected from the 20 Keble's via truck. The collected wastes are transported by truck and dumped without compaction and segregation. The dumped waste in the dumping site is even exposed to windblown because no coverage is done in the middle or upper of the waste deposited. There is no geo membrane lining at the bottom to prevent leachate. There is no appropriate buffer zone between the dumping site and the farmlands and residential area. Since the dumping site is unfenced, it is accessible by rag pickers, scavengers, by some domestic animals like dogs, cattle, cows for scavenging food wastes (Ebistu and Minale, 2013; Biruk, 2017; Haile and Gabbaye, 2021).

Reagents, chemicals and instrumentation

All reagents used were of analytical grade. (69-72%) HNO_3 and (37%) HCl were used for digestion of the samples. $\text{Pb}(\text{NO}_3)_2$, $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$, $\text{Ni}(\text{NO}_3)_2$, and $\text{K}_2\text{Cr}_2\text{O}_4$ were used to prepare an intermediate standard solution of Cd, Ni, Pb, and Cr. Distilled water was used to dilute the sample, prepare intermediate metal standard solutions, and rinse glassware and sample bottles before analysis. The necessary apparatus for sample preparation and digestion, including electronic beam balance (Nimbus, NBL-254i, and UK), the crucible, Whatman No.41 filter paper, oven (model: Ambala Cantt-133001 HR, India, and refrigerator (digital inverter technology Samsung model DA99-00630E0 USA) were used. An inductively coupled plasma optical emission spectrometer (Agilent Technology Spain) was used to analyze heavy metals in the digested sample.

Sample preparation for analysis

Sample collection

There are different soil sampling methods, such as circular plot method, square and triangular method, etc. We collected the sample with the triangular method in June, 2018 as indicated in (Lawrence *et al.*, 2020). A total of 4 samples were collected. Sampling points were selected as the corners of an equilateral triangle of 30 m in length. A stainless steel axle was used to dig the soil. Then, it was washed with distilled water before the next sample was collected. A 0.5 kg sample was collected for every 15 cm interval (05-20 cm, 20-35 cm and 35-50 cm) as indicated (Mekonnen, Haddis and Zeine, 2020). The samples were mixed for each depth collected from the three corners. One control sample was taken from the bare land in adjacent to the dump site in the eastern direction at a distance of 50 m from the border of the dumping site. This sample was taken purposely to assess the degree of dispersion of heavy metal from the dump site to the nearby environment as indicated (Mekonnen, Haddis and Zeine, 2020)

Sample digestion

The collected soil samples were crushed with a corning crucible (USA, 60322) and placed on a plastic sheet, oven-dried for three hours, and then sieved through a 0.2 mm mesh size to remove stones and derbies. The samples were digested by acidifying with

concentrated HNO₃ (69-72%) and 37% HCl (Town, Town and Town, 2024). In the procedure, 0.5 g of sample was taken into a 250 mL beaker and 7.5 mL HCl, and 2.5 mL HNO₃ were added to each sample and heated on a hot plate hood at 110 °C for 3 hours (Town, Town and Town, 2024). Then, the sample was filtered using Whatman filter paper with 41 mm mechanically. The digested samples were cooled and diluted to 50 mL and stored in a refrigerator until analysis using ICP-OES.

Procedure for pH measurement

The pH was measured by taking 10 g of air-dried (< 2 mm) soil samples, which were added into 100 ml beakers. Then 20 mL of distilled water was added to it and stirred for 1 min, and then it was allowed to settle for 1hr to equilibrate. Finally, the pH was measured on the upper part of the suspension as indicated (FAO, 2023).

Data analysis

All analyses were carried out in triplicate, and the data was expressed as means \pm standard deviations (SD). Data were calculated as mean \pm standard deviation (SD), RSD was calculated using a formula = (Standard deviation/mean *100), and the rest analysis was performed using SPSS version 20, and some tests such as a two-tailed T-test and one-way ANOVA were used for data analyzing.

Estimation of contamination/pollution index (MPI) of heavy metal in soils

According to Ediene & Umoetok (2017), the contamination level commonly known as the pollution index of the heavy metal to the surrounding soil or the nearby soil is calculated as:

$$\text{MPI} = \frac{\text{Concentration of metals in soil}}{\text{Reference soil (control)}}$$

Where MPI= contamination level or pollution index

According to Lacatusu (2000) cited in Ediene & Umoetok (2017) the interval of contamination/pollution index of heavy metals in soil and its implication is given in Table 1.

Table 1. Interval of contamination/pollution index of heavy metals in soil and its significance

No negative effect on soil, plant and environment		Poses negative effect on soil, plant and environment	
MPI	Significance	MPI	Significance
<0.1	Very slight contamination	1.1-2.0	Slight pollution
0.1-0.3	Slight contamination	2.1-4.0	Moderate pollution
0.3-0.5	Moderate contamination	4.1-8.0	Sever pollution
0.5-0.8	Sever contamination	8.1-16.0	Very sever pollution
0.8-1.0	Very sever contamination	>16.0	Excessive pollution

Source: Lacatusu (2000) cited in Ediene & Umoetok (2017)

RESULTS AND DISCUSSION

pH value of the soil sample

pH affects the availability of heavy metals in solid wastes (Ai *et al.*, 2019). As indicated in Table 2, the mean value of the solid waste dumping site of this study is found to be 6.42 ± 0.52 . It falls in a slightly acidic medium. This value i.e., 6.42 ± 0.52 , is lower than a similar study carried out in Reppi solid waste disposal site found in Addis Ababa city (8.17 ± 0.95), which falls in slightly basic medium (Beyene and Banerjee, 2011). The variation in the two solid waste dumping sites; that is, the Bahir Dar solid waste dumping site is slightly acidic compared to the Addis Abeba City dumping site may be attributed to the difference in the amount and type of the leachate released in the two dumping site (Kasassi *et al.*, 2008; Beyene and Banerjee, 2011). Moreover, the sampling point is more prone to the leachate i.e. the shallow sampling points (S1 and S2) are more acidic than S3 (the deepest) see Table 2. According to the study by Beyene & Banerjee (2011) and Kasassi *et al.*(2008) leachate is acidic and will reduce the soil pH. However, soil pH less than 8.5 is suitable for solid waste dumping sites. Therefore, the Bahir Dar solid waste dumping site is suitable for dumping waste concerning its pH value regardless of minor differences in pH values across depths (among the three sampling points).

Table 2. pH of the soil sample from solid waste dumping site and control sample site

Sample area depth in cm	Sample 1 (5-20)	Sample 2 (20-35)	Sample 3 (35-50)	Mean \pm SD	Range	Control
pH	5.82	6.68	6.76	6.42 ± 0.52	5.82-6.76	7.56

Heavy metal concentration

The mean concentration of heavy metals for each sample and the mean of three sample locations (Pb, Ni, Cd, and Cr) and their RSD value are presented in Table 3. The percentage relative standard deviations (% RSD) of the measurements were calculated for Ni, Pb, Cr, and Cd, and it was nearly or below 10%. This implies that the measured data for each heavy metal determination in the solid waste samples were highly precise. In the same table, heavy metal concentration in the soil sample of the solid waste dumping site is in the order of $Cr > Pb > Ni > Cd$ (Table 3). That is, the mean concentrations of these metals were found to be Pb: 232.16 ± 76.18 , Ni: 46.27 ± 18.2 , Cd: 15.4 ± 14.1 and Cr: 443.13 ± 30.6 . The details of each heavy metal concentration are presented in subsequent subsections.

Chromium

Chromium (Cr), with a concentration range of 424.2-477.8 mg/kg, is found highest in comparison to the other in the dumping site (Table 3); this might be attributed to the nature and varieties of waste dumped in the dumping site like tanneries, pigment

oxidant, ceramics, and catalyst, pieces of plated metal in Garages, e-waste and derbies of textiles from the industrial wastes.

Table 3. pH, the mean concentration of heavy metals (Pb, Ni, Cd, and Cr) in mg /kg & RSD at three and control sample sites

Depth (cm)		Pb	Ni	Cd	Cr
S ₁ (5-20)	Mean conc.	311.6±5.1	63.2±3.2	31.1±1.5	477.8±7.07
	RSD	2.0	6.1	5.9	1.5
S ₂ (20-35)	Mean conc.	159.7±7.6	48.6±5.3	3.8±0.1	424.2±47.9
	RSD	5.9	7.7	1.5	1.9
S ₃ (35-50)	Mean conc.	225.2±21.2	27.0±1.7	11.3±1.0	427.4±27.6
	RSD	9.4	11.0	10.4	1.5
Mean±SD	Mean conc.	*232.2±76.2	*46.3±18.2	*15.4±14.1	*443.1±30.6
Range	Mean conc.	159.7-311.6	27.0-63.2	3.8-31.1	424.2-77.8
	RSD	2.0-9.4	6.1-11.0	1.5-10.4	1.5-1.9
Control	Mean conc.	142.8±0.2	12.0±1.1	1.6±0.1	260.0 ±3.9
	RSD	1.6	9.2	4.5	8.3

*Mean of the mean concentration of each heavy metals

According to Biruk (2017), this dumping site, the composition and the varieties of the wastes dumped are household, commercial, industrial, construction, leftovers, clinical, e-waste, and agricultural waste (Biruk, 2017). Moreover, the T-test value $T_{exp} (9.3) > T_{crit} (4.31)$ at $\alpha = 0.05$ showed a significant difference between the mean concentration of Cr in the soil of solid waste dumping site and in the soil of the control site (Table 4). This difference may be attributed to the formation of stable Cr organic complexes between the organic matter present in the solid waste with Cr in the disposal site. As a result, Cr is dispersed towards the control site, especially during the rainy season (Zhang *et al.*, 2022).

Table 4. Results of t-tests (at 95% confidence level)

Elements	Mean concentration of solid waste sample (mg/kg)	Control sample	t-value
Pb	232.17	14.28	4.96 ^a
Ni	46.27	12.00	0.657
Cd	15.40	1.57	1.63
Cr	465.36	46.45	9.5 ^a

All values are expressed in mg/kg. The t-value at two degrees of freedom is 4.31, indicating a significant difference at the 95% confidence level ($\alpha = 0.05$). Furthermore, the standard deviation for chromium (Cr) across the depth sampling points is 29%, demonstrating a significant deviation from the mean (Table 5). This suggests that the leaching ability of Cr is significant both vertically and horizontally.

In general, the result of this study is higher than compared to the study by Cortez & Ching (2014) which reported a concentration of Cr = 53.28 mg/kg. But it is lower than the concentration reported from the Reppi solid waste dumping site (found in Addis

Ababa) in different sampling points with a range of 46 (mg/kg) to 561 (mg/kg) with a mean value of 243.5 (mg/kg) (Beyene and Banerjee, 2011). In addition, the mean value of Cr, i.e. 443.13 reported by this study, is slightly lower than the limit set by the Environmental Protection Authority of Victoria (EPA of Victoria) for the hazardous classification range 500-2000 mg/kg for Cr (Seyoum and Adeloju, 2014).

Table 5. Across-depth heavy metal dispersion capability in mg/kg

Across depth	Cr	Pb	Ni	Cd
Standard deviation	0.29	0.59	0.23	0.12
% Standard deviation	29%	59%	23%	12%

Lead (Pb)

Lead (Pb), with a concentration range of 159.7-311.6 mg/kg is found the second highest in comparison to the rest two heavy metals in the dumping site; this might be due to the nature and varieties of waste dumped in the dumping site may have more used car batteries due to the increments of consumption of automobile/car batteries nowadays in the global world (European Commission DG ENV., 2002; Cortez and Ching, 2014). According to Cortez & Ching (2014) and European Commission DG ENV (2002) in addition to automobile batteries, many different products containing lead like construction and demolition derbris, electronic waste, light and lamps and paints and coatings will end up in waste management cycle and became a source of lead to incineration plants and/or landfills. Important sources of plastics, fishing tools, lead crystal glass, ceramics, solders, pieces of lead flashing, and many other minor products are in line with the composition of the Bahir Dar city solid waste dumping site (Eriamecharia), which are household, commercial, industrial, construction, leftovers, e-wastes, and agricultural waste (Biruk, 2017). Moreover, the location of the Eriamecharia solid dumping site close to the main road that passes from Bahir Dar to Addis Abeba exposed the dumping site to deposit lead-containing dust particles in the soil that have a relatively short residence time in the atmosphere.

The mean concentration of Pb reported in the dumping site 232.16 ± 76.18 is higher than that of the soil sample taken from the control site soil i.e. 142.8 ± 0.24 (Table 3). The T-test value i.e. $T_{exp} (4.96) > T_{crit} (4.31)$ at $\alpha = 0.05$ showed a significant difference between the mean concentration of Pb in the solid waste dumping site and the control site (Table 4). This may be attributed to the mobility of Pb metal in solid waste towards the nearby farmland (control site). Whereas the standard deviation of Pb (59%) across depth in the three sampling points implies that it has a higher mean deviation (Table 5). That means there is variation in the concentration of Pb in the samples taken from three depths. This may be attributed to the leachate that has the potential to infiltrate as like of it is dispersed sideways to the control site. Comparison of the result of this study i.e. 232.16 ± 76.18 , with other similar works, indicated that it is slightly larger than the result i.e. 223.8 ± 146.73 mg/kg reported by Shemdoo (2010) for the Mtoni solid

dumping site, which is found in the border of the Indian Ocean in Darussalam, Tanzania. However, the mean concentration of Pb in this study was slightly lower than compared to the result i.e., 280 mg/kg reported by (Imasuen and Omorogieva, 2013) of the solid waste dumping site found in Ivory Coast. The difference might be due to the quantity and constitute of municipal solid waste that contains Pb contents such as lead batteries, lead-based paints, plastics, *e-waste*, and old and used pipes available in their dump site for the observed high levels of Pb (Esakku *et al.*, 2003). Moreover, the mean value of Pb i.e. 232.16 reported by this study is slightly lower than the limit set by the Environmental Protection Authority of Victoria (EPA of Victoria) for the hazardous classification range i.e. 1500-6000 mg/kg for Pb (Seyoum and Adeloju, 2014).

Cadmium (Cd)

Most of the cadmium produced today is obtained from zinc byproducts and recovered from spent nickel-cadmium batteries. The general trend in global cadmium consumption over the last two decades has been a steep increase in the use of cadmium for batteries and a decrease in its use for other applications (European Commission DG ENV., 2002). As indicated in Table 3, cadmium has a mean concentration of 15.4 with a range of 3.83 - 31.1 mg/kg in the three sampling points. The mean concentration of Cd reported in this dumping site 15.4 is higher than that of the soil sample taken from the control site soil 1.57 (Table 3). The concentration of cadmium in this solid waste is associated with the type and composition of the wastes present on the dumping site which are household, commercial, industrial, construction, leftovers, clinical, e-wastes and agricultural waste (Biruk, 2017). The T-test value i.e. $T_{exp} (1.63) < T_{crit} (4.31)$ at $\alpha = 0.05$ did not show a significant difference between the mean concentration of Cadmium in the solid waste dumping site and the control site (Table 4). This implies that the open landfill solid waste disposal site contributes less to the increment of concentration of Cd in the surrounding soil (farmlands). Whereas, the standard deviation of Cd across the depth in three sampling points is 12% which is relatively small (Table 5). That means no significant variation of Cd concentration in three samples taken across depth ways. So Cd has less potential to be dispersed vertically this is true also to its less potential to dispersed horizontally. Since no significance difference was observed between the mean concentration of Cd in the soil sample taken from the dumping site and the soil sample taken from the control site (see Table 4).

The result reported by Akobundu (2013) for Enyimba solid waste Dumpsite in Aba, which is found in Southeastern Nigeria, the concentration of Cd falls between 0.18-2.6 mg/kg with a mean concentration Cd of 1.4 mg/kg is lower than reported by this study i.e. mean concentration 15.4 mg/kg. However, the result i.e., Cd concentration ranging from 28.56 ± 17.95 to 40.17 ± 18.21 mg/kg from two different refuse dumpsites located at two different extremes of Akure Town, the Ondo State capital in Nigeria, reported by (Victoria, 2002) higher than compared to the mean Cd concentration reported by this study. Besides these, the mean value of Cd, i.e. 15.4 mg/kg by this study, is lower than

the limit set by Environmental Protection Authority of Victoria (EPA of Victoria) for the hazardous classification range i.e. 100-400 mg/kg for Cd (Seyoum and Adeloju, 2014).

Nickel (Ni)

As indicated in Table 3, Nickel (Ni) has a mean concentration of 46.27 mg/kg with a range of 27.0- 63.2 mg/kg in the three sampling points. The mean concentration of Ni reported in the dumping site i.e., 46.27 mg/kg, is higher than that of the soil sample taken from the control site soil i.e., 12 ± 1.1 (Table 3). The T-test value i.e., T_{exp} (0.657) $< T_{crit}$ (4.31) at $\alpha = 0.05$ did not show a significant difference between the mean concentration of Nickel in the solid waste dumping site and the control site (Table 4). Even if the variation in concentration of Ni between the control and dumping site was not significant, the slight increment of concentration of Nickel observed in the sample soil taken from the dumping site than that of the soil sample taken in the control site was associated with composition and types of the wastes. In most cases, the dumping sites receive various wastes like municipal solid waste, clinical waste, and industrial wastes that aggravate the availability of Nickel (Erses *et al.*, 2005; Haque, 2016). Whereas the standard deviation from the mean across the depth in Nickel concentration, i.e. 23%, is slightly high (Table 5) which means there is a slight variation in Ni concentration across the depth in three sampling points. This may be attributed to the leachate has the potential to dispersed vertically to a small extent than it dispersed horizontally. No significant difference was observed between the mean concentration of Ni in the soil sample taken from the dumping site and the soil sample taken from the control site (see Table 4).

The concentration of nickel reported by this study i.e., 27.0- 63.2 mg/kg with a mean value of 46.27 mg/kg is slightly higher than the value reported by Esakku *et al.* (2003) i.e., 21.00-50.00 mg/kg with a mean concentration 32.80 mg/kg for “Perungudi dumping site found near Chennai in India. However, the result of this study was slightly lower than the value reported by Prechthai *et al.* (2008) i.e., 24.2-94.0 mg/kg with a mean concentration of 48.4 mg/kg. According to Esakku *et al.* (2003), many domestic cleaning products such as soaps (100 - 700 mg/kg), powdered detergents (400 - 700 mg/kg and powdered bleach (800 mg/kg) are important sources of Ni in urban areas soils taken from “Dhaka and Khulna” dumping sites found in Bangladesh. Even though the dumping sites by its nature, receive various wastes like municipal solid waste, clinical waste, and industrial wastes that aggravate the availability of nickel (Erses *et al.*, 2005; Haque, 2016). In general, the mean concentration of Ni reported by this study is i.e. 46.7 is lower than the limit set by the Environmental Protection Authority of Victoria (EPA of Victoria) for the hazardous classification range for Nickel i.e., 3000-12000 mg/kg (Seyoum and Adeloju, 2014). In general, heavy metals availability and their concentration in solid waste dumping sites as well as their concentration is closely associated with the type and composition of the waste dumped in solid waste dumping

sites (Erses *et al.*, 2005; Esakku *et al.*, 2005; Prechthai, Parkpian, and Visvanathan, 2008; Gyabaah *et al.*, 2023). According to these studies, the nature and varieties of waste dumped in the dumping site like tanneries, pigment oxidants, ceramics, catalysts, pieces of plated metal in Garages, e-waste, derbies of textiles from industrial wastes, clinical waste, and domestic wastes such as detergents, perfumes, and foodstuffs contribute their share for the different types of heavy metal available in solid wastes. For instance, domestic cleaning products such as soaps (100 - 700 mg/kg), powdered detergents (400 - 700 mg/kg), and powdered bleach (800 mg/kg) are important sources of Ni in solid waste dumping sites (Prechthai, Parkpian and Visvanathan, 2008). The mean value of Pb, Cr, Ni and Cd reported by this study is lower than the limit set by Environmental Protection Authority of Victoria (EPA of Victoria) for the hazardous classification range for respective metals.

The dispersing ability of heavy metals towards the nearby soil (the control site/farmland) depends on many factors like pH of the solid waste, rainfall, temperature, the nature of the waste, and the nature of landfill (Kasassi *et al.*, 2008; Prechthai, Parkpian and Visvanathan, 2008; Cortez and Ching, 2014; Ai *et al.*, 2019; Zhang *et al.*, 2022; Gyabaah *et al.*, 2023). In this study, Cadmium and Nickel have a low dispersing potential compared to lead and chromium. This may be attributed to the formation of stable Cr organic complexes between the organic matter present in the solid waste with Cr in the disposal site as a result it enables Cr to be dispersed towards the control site during the rainy season (Zhang *et al.*, 2022). In addition, the location of Eriamecharia of the solid dumping site close to the main road that passes from Bahir Dar to Addis Abeba exposed the dumping site to deposit lead-containing dust particles in the soil that have a relatively short residence time in the atmosphere. Whereas the across-depth dispersing ability of heavy metals is closely associated with infiltration during the rainy season (Haile and Gabbiye, 2021; Gyabaah *et al.*, 2023; Becik *et al.*, 2024).

Estimation of contamination/pollution index (MPI) of heavy metal in soils

The key to assess soil contamination with heavy metals lays in the use of pollution indexes tools. Pollution indexes are widely considered as a useful tool for the comprehensive evaluation of the degree of contamination of soil with different heavy metals that leachate from the solid waste dumping site (Ediene and Umoetok, 2017; Kowalska *et al.*, 2018). As indicated in the methodology section $MPI = \text{Concentration of metals in soil} / \text{Reference soil (control site)}$ and the result for this is presented in Table 6.

As the value of the MPI indicates, value of Cadmium falls in the range of severe pollution, Nickel falls in the range of moderate pollution whereas lead and chromium fall in the slight pollution indexes range. So according to these indexes, the index value of Cadmium, nickel, chromium, and lead will pose a negative effect on the soil of the nearby farmland, plant, and environment (Ediene and Umoetok, 2017). That means the Eriamecharia (Sebat Amit) solid waste dumping site has the potential to contaminate the

control sites that are close to/adjacent to the dumping site. However, according to the report by Locatusu (2000) cited in Ediene & Umoetok (2017) if the indexes value falls in the range of < 0.1 Very slight contamination, 0.10 – 0.25 Slight contamination, 0.26 – 0.5 Moderate contamination, 0.51 – 0.75 Severe contamination and 0.76 – 1.00 Very severe contamination it has no negative effect on soil, plant, and environment of the surrounding environment to the dumping site (Table 1).

Table 6. Contamination/pollution index (MPI) of heavy metal in soils of the municipal dump site in Bahir Dar

Heavy metals	Mean concentration (mg/kg)	Concentration in control site (mk/kg)	MPI of this study	Class interval of this study falls in Lacatusu 2000 cited in Ediene & Umoetok (2017)	Significance in Lacatusu 2000 cited in Ediene & Umoetok (2017) – level of pollution
Pb	232.16	142.8	1.625	1.1 - 2.0	Slight
Ni	46.27	12	3.855	2.1-4.00	Moderate
Cd	15.4	1.57	9.80	8.1-16	Very severe
Cr	443.13	260.0	1.7	1.1 to 2.0	Slight

CONCLUSION AND RECOMMENDATION \

Eriamecharia (Sebat Amit), an open solid waste dumping site that serves Bahir Dar City, is suitable for dumping wastes concerning its pH value regardless of minor differences in pH value across depth. The mean concentration of the heavy metals in the soil sample of the solid waste dumping site is in the order of Cr > Pb > Ni > Cd with a mean concentration of Cr: 443.13±30.6, Pb: 232.16 ± 76.18, Ni: 46.27±18.2 and Cd: 15.4 ±14.1. However, the mean concentration of all heavy metals under this investigation is slightly lower than the limit set by the EPA for the hazardous classification range for these metals. On the other hand, the dispersing ability of heavy metals lead and Chromium towards the nearby soil (the control site/farmland) is higher than that of Nickel and Cadmium. This leads these metals to have the potential to contaminate the adjacent farmlands. At the same time, the standard deviation value of the across-depth dispersing ability of heavy metals implies that all heavy metals have less dispersion ability vertically which is associated especially with infiltration during the rainy season. The comprehensive evaluation of the degree of contamination (MPI) of soil with different heavy metals that leachate from the solid waste dumping site value indicates that Cadmium falls in the range of severe pollution, Nickel falls in the range of moderate pollution whereas Lead and chromium fall in the range of slight pollution indexes. So according to these indexes, the index value of Cadmium, nickel, chromium, and lead will pose a negative effect on the soil of the nearby farmland, plant, and environment. That means the Eriamecharia (Sebat Amit) solid waste dumping site has the potential to contaminate the control site (nearby farmlands) that are adjacent to the dumping site. So preventive measures will have to be taken by the municipal city or other concerned bodies working related to environmental protection by constructing proper landfill or

incineration plant for Bahir Dar city that takes into account the future population growth rate of the city.

ACKNOWLEDGMENTS

The author's would like to express their gratitude to the late Prof. Meareg Amare for providing essential laboratory equipment's for sample digestion, preservation, and transportation. Also, thanks go to the "Tana Basin Development office" Research Institute Laboratory and the laboratory technical assistance of the institute for their help in the analysis of the sample in ICP-OES.

DECLARATION

Consent to Participate

All participants of the study were properly informed and agreed to participate without any pressure or coercion.

Consent to Publish

The Authors agreed to publish the manuscript in an open access journal at no cost to the authors or benefit from a discounted article publishing charge.

Availability of Data

The data needed for the study can be available upon reasonable request from the corresponding author.

Conflict of Interest

All the authors declared that there was no relevant financial or non-financial interest.

Funding

"Analysis of heavy metals and estimation of pollution indexes in open solid waste disposal site: the Case of Bahir Dar City, Bahir Dar, Ethiopia," an m.sc student research work supported by ministry of education. the 1st author, mr. lijalem beyal has granted sponsorship for study MSc study in analytical Chemistry from Amhara National Regional state Education Bureau.

Author Contribution

Lijalem Belay contributed in conceptualization, designing of the experiment, data curation, data analysis, original draft writing, Hailu Sheferaw contributed in

conceptualization, designing of the experiment, data analysis and presenting data; Muluken Aklilu contributed in reviewing and editing the paper.

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