

Metallic Constituents, Human Cancer Risk Assessment, and *Allium Cepa* Genotoxicity Bioassay of a Municipal Dumpsite Soil and Simulated Leachate in Anyigba, Kogi State, Nigeria

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ABSTRACT

This study investigated heavy metal contamination in soil from the Anyigba municipal dumpsite, located within Anyigba Main Market, Kogi State, Nigeria, and assessed associated human health risks and plant-based cytogenotoxicity. Composite soil samples were collected using grid sampling, while simulated leachate was prepared through aqueous extraction. Fifteen metals were analysed using inductively coupled plasma optical emission spectrometry (ICP-OES). Human health risks were evaluated using the Hazard Quotient (HQ), Hazard Index (HI), and Lifetime Cancer Risk (LCR) for ingestion, inhalation, and dermal exposure among children and adults, following the USEPA framework. Leachate cytogenotoxicity was assessed using the *Allium cepa* root tip assay at 20, 40, and 60% concentrations. Iron (97.42 mg/kg), manganese (66.04 mg/kg), zinc (42.84 mg/kg), silver (31.71 mg/kg), and copper (13.39 mg/kg) were the predominant soil metals. Copper, zinc, iron, manganese, and chromium exceeded permissible limits in both soil and leachate. Children exhibited HI values above unity for manganese (6.73), copper (4.72), iron (3.02), and zinc (2.26), primarily through ingestion, whereas adult HI values remained below 1.0. Chromium presented unacceptable cancer risks for children (TLCR = 7.23×10^{-4}) and adults (TLCR = 1.06×10^{-4}). The *Allium cepa* assay revealed concentration-dependent toxicity, with root growth inhibition reaching 92.73% and mitotic index decreasing from 11.75% in controls to 2.25% at 60% leachate concentration. These findings identify the dumpsite as a potential source of significant environmental contamination and human health risks, particularly for children, highlighting the urgent need for remediation and effective environmental regulatory enforcement.

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INTRODUCTION

Urbanization and population increase are two of Nigeria's biggest problems because it leads to increase in waste production (Ike *et al.*, 2018; Auwalu and Bello, 2023). Waste is produced and disposed of in an unsegregated manner, posing serious risks to ecosystems and public health (Gupta *et al.*, 2024). In developing nations including Nigeria, rapid urbanization and population expansion have greatly increased the amount and complexity of municipal solid waste (MSW), putting tremendous strain on waste management systems. Over 32 million tons of solid wastes are produced in Nigeria each year, but the infrastructure for collection and treatment is mainly insufficient to handle this amount (NESREA, 2009; 2011). Due to low operating costs, a lack of recycling strategies, and insufficient policies and regulations, open dumpsites continue to be the most common disposal method in the majority of Nigerian towns and cities, despite being environmentally inappropriate. Waste is frequently deposited without engineered containment or environmental safeguards (Nnaji, 2015; Ibor *et al.*, 2020; Alao *et al.*, 2024). Dumpsites are

intricate storage facilities for a variety of waste types, such as home trash, industrial waste, agricultural wastes, and medical and technological waste, all of which may include heterogeneous variety of dangerous chemical components. Inorganic contaminants such as heavy metals are a particularly persistent class of pollutants, non-biodegradable that can accumulate in soil indefinitely, penetrate the food chain, and have long term consequences on the environment and human health (Nriagu and Pacyna, 1988; Ekere *et al.*, 2020).

Rainfall infiltration through dumpsite waste produces leachate, a metal-laden liquid that percolates through the soil profile and may reach groundwater or surface water used by neighboring communities (Mor *et al.*, 2006; Ganiyu *et al.*, 2016). Leachate is a highly complex and heterogeneous wastewater that contains inorganic contaminants like heavy metals and polycyclic aromatic hydrocarbons (PAHs), along with xenobiotic organic compounds and opportunistic pathogens, many of which are considered emerging environmental contaminants (Oshode *et al.*, 2008). Additionally, weakly biodegradable chemical compounds

and humic-like molecules that linger in the environment are found in leachates. Because of their capacity to form complexes with heavy metals, these persistent components are hazardous even at low concentrations (Costa *et al.*, 2023). Long lasting pollution plumes that may stretch several kilometers from dumpsites are created as these leachate pollutants migrate through various environmental pathways, affecting soil, surface water, and groundwater systems. They also infiltrate soils and percolate into aquifers. The amount of precipitation, surface runoff, and groundwater infiltration through and around dumpsite systems are the main factors that determine the amount of leachate produced.

Studies have reported high amounts of heavy metals in dumpsite soils and related matrices. Abandoned urban dumpsites have shown enrichment factors and geo-accumulation indices indicating moderate to very strong contamination by cadmium, lead, zinc, and copper (Nwankwoala, 2013; Ekere *et al.*, 2020; Okechukwu and Onwukeme, 2025), dumpsite effluents in southeast Nigeria have metals exceeding WHO and NESREA irrigation and drinking water limits, with hazard indices greater than 1.0 for both adults and children (Ibe *et al.*, 2021; Okechukwu and Onwukeme, 2025). Leachate derived pollutants have been shown to migrate into shallow aquifers within 500 meters of dumpsite boundaries by integrated geophysical and hydrochemical investigations in Ibadan, Lagos, and Enugu (Ganiyu *et al.*, 2016; Nwankwoala, 2013), highlighting the vulnerability of groundwater relied upon by nearby communities.

Exposure to dumpsite leachate have been associated with adverse public health effects, including developmental abnormalities, reproductive problems, and genotoxicity (Alimba and Bakare, 2016; Ademola *et al.*, 2020; Escalante-Mane *et al.*, 2022). According to epidemiological studies, there are positive correlation between leachate pollution from dumpsites and organisms' health through bioaccumulation and biomagnifications of dumpsite pollutants released into the ecosystem, which have the potential to harm human and animal health by entering the food chain and having negative effects at every trophic level, (Ibor *et al.*, 2020; Peddi *et al.*, 2022). Leachates chemicals have been shown to be biologically hazardous to living cells (Sales Junior *et al.*, 2024). Biopollutant poisoning related symptoms and diseases such as gastrointestinal disorders, anemia, skeletal deformities, pneumonitis, hypertension, cancer, neurological diseases, diarrhea, cardiovascular and renal diseases, ataxia, vomiting and convulsions, depression, asthma, congenital abnormalities, neonatal deaths, birth defects, low birth weight, stillbirth, and spontaneous abortion have been linked to dumpsite leachate constituents (Ghosh *et al.*, 2015; Khalil *et al.*, 2018; Siddiqua *et al.*, 2022).

Contaminants from waste decomposition are directly or indirectly linked to DNA damage and toxicological damage associated with a variety of pathological lesion processes that extend beyond individual but continue to be active through successive generations (Alimba *et al.*, 2022; Onoja *et al.*, 2026). Examples include the incidents of cancer, liver issues, and low birth weights among Niagara, USA residents exposed to chemicals released from Love Canal landfills (Gill and Mix, 2020). These residents were exposed to dangerous chemicals in dumpsite leachate. Thus, the components of dumpsite leachate may be genotoxic, causing genomic instabilities, epigenetic changes, and free radicals production in exposed tissues (Ogunlaja *et al.*, 2019; Bakare *et al.*, 2025; Onoja *et al.*, 2026). They may also cause lipid peroxidation, which can result in various forms of toxicity and cell death in plants, animals, and human cell lines. However, there is little

information regarding the risks of leachate exposure to human health in Kogi State.

The Anyigba dumpsite has been a mixed dumpsite for residential/domestic, commercial, medical, agricultural, pharmaceutical, industrial, and institutional garbage for many years. It is located in the major market, Dekina LGA, Kogi State, Nigeria. Because the dumpsite lacks lining, an underground drainage system to collect its leachate, and/or leachate treatment infrastructure, the leachate percolates into the soil because it is anticipated that the soil in and around the facility will accumulate contaminants over time, exposing nearby residents through soil contact, groundwater consumption, or inhalation of resuspended dust where underground water can become contaminated and flow straight into the surrounding waterbodies. This dumpsite existed without prior hydro-geophysical assessment of its appropriateness as a dumpsite, particularly with regard to its potential effects on the nearby groundwater. This could lead to accumulation of toxic substances in the soil, leachate, water from surrounding ponds or water bodies, and in edible crops grown on farms around the dumpsite vicinity. Thus far, there has been no information on the toxic effects of leachates, elutriates, and or water from the dumpsite on living organisms.

Therefore, this study became crucial given the dumpsite's location within the market vicinity, the significant residential exposure of local animal and human populations, and the possibility of human biomagnification of harmful substances from edible crops produced on and surrounding the dumpsite. This study examined the cytogenotoxicity from the dumpsite in plant bioassay, metallic constituents' analysis, and the non-carcinogenic and carcinogenic risks of human exposure to the toxic metals analyzed in the leachate as part of a multidisciplinary investigation on the toxicological implications of solid waste dumpsites on environmental, human, and public health. This allowed for the systematic quantification of risk across multiple exposure pathways using indices like the Hazard Quotient (HQ), Hazard Index (HI), and Lifetime Cancer Risk (LCR) (Ekere *et al.*, 2020; Alabi *et al.*, 2025). Plant based genotoxicity tests (*Allium cepa* root tip assay) is a sensitive biological indicator of the cytotoxic and clastogenic capacity of complex environmental pollutants, including those found in leachate (Samuel *et al.*, 2010; Atapattu and Jayawardena, 2026). As an affordable addition to chemical analysis and mammalian toxicology, the assay is a proven model for identifying chromosome abnormalities, mitotic index depression, and root growth inhibition induced by heavy metals and other pollutants (Samuel *et al.*, 2010; Musarrat *et al.*, 2011). It is therefore hypothesised that dumpsite leachate contains potentially toxic metals at levels capable of inducing cytotoxic and genotoxic effects in *Allium cepa*, induced by root growth inhibition, reduced mitotic index, and increased chromosomal aberrations, while human health risk assessment can reveal varying degrees of non-carcinogenic and carcinogenic risks across exposure routes.

MATERIALS AND METHODS

Study Area

The study was conducted at the municipal dumpsite within Anyigba Main Market, located in Dekina Local Government Area, Kogi State, Nigeria, at coordinates approximately 7°29'N latitude and 7°10'E longitude (7.4934°N, 7.1736°E) (Figure 1). The dumpsite occupies approximately 0.5–1.0 ha within the market perimeter and operates as an open, unlined, largely unmanaged facility receiving daily solid waste from the market and surrounding commercial and residential areas,

without engineered containment, leachate collection or cover materials.

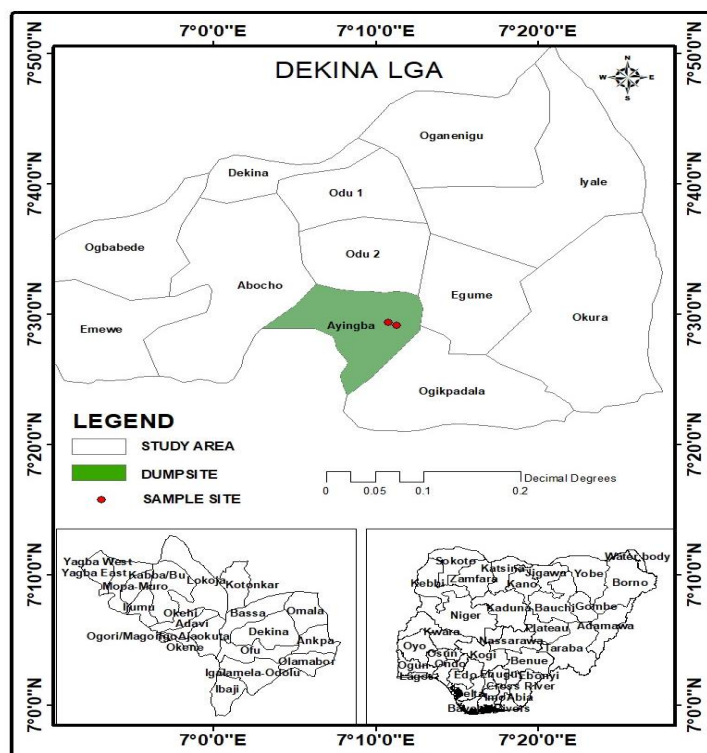


Figure 1: Map of the study area

Sample Collection and Leachate Simulation

Dumpsite soil was sampled using a systematic grid approach. The site was subdivided into a grid, and composite topsoil samples (0–15 cm depth) were collected at twenty (20) randomly selected points using sterile stainless steel augers and spatulas. Sub-samples were homogenised into a single composite sample, placed in labeled plastic containers, transported to the laboratory and air-dried for two (2) weeks at room temperature, grind and sifted using a 500 µm (pore size) sieve to obtain fine powder used for soil leachate simulation. The leachates were prepared from the homogenous soil mixture according to toxicity characteristic leaching procedure (TCLP), the leachate simulation extraction procedure as modified by Bakare *et al.*, (2007) and Alimba *et al.*, (2016). Briefly, 500g of the grinded samples was weighed out into a 4L flask and 2000 ml of distilled water (w/v) was added to the soil sample for a period of 72 hours with regular mechanical stirring at interval using glass rod. After 72 hours, it was sieved with 63 µm size sieve to obtain homogeneous mixtures for each landfill. The suspensions was allowed to settle for at least an hour to sediment visible particles, and then the supernatant filtered with 2.5 µm Whatman filters paper to remove suspended particles or debris to obtain a clear filtrate. The simulated leachates were then designated as 100% concentrations as stock samples and stored at 4°C pending usage for the experiments.

Heavy Metal Analysis

One (1) g of air-dried, sieved (2 mm) soil was digested using aqua regia (HCl : HNO₃, 3:1) at 90 °C for 2 hours; leachate samples were digested similarly. Digests were filtered, cooled and made up to 50 mL with deionised water. Heavy metal concentrations (Cu, Cd, Ni, Zn, Fe, Mn, Cr, Co, As, Al, Se, Hg, Ag, Be and Ba) were determined by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES;

PerkinElmer Optima 4100 DV, Labtam Plasmalab-8440, Mordialloc, Victoria, Australia), and metal concentrations were determined by calibration against standard solutions (1000 mg/L, trace metal grade) in accordance with standard analytical methods (APHA, 2005).

Human Health Risk Assessment

Human health risk was assessed following Mohammadi *et al.*, (2020) and Bakare *et al.*, (2025). The lifetime carcinogenic risk (LCR), non-carcinogenic target hazard quotient (THQ), hazard index (HI), and average daily dosage (ADD) factors were used to estimate the risk of human exposure to the analysed toxic metals in the leachate.

Non-Carcinogenic Risk Assessment (ADD, THQ and HI)

Average Daily Dose (ADD)

ADD of three exposure pathways of leachate, including inhalation (ADD_{inh}), dermal contact (ADD_{derm}), and ingestion (ADD_{ing}) of metals in mg/kg/day, was calculated by using the following formulae. The average daily dose (ADD) for each metal and pathway was calculated as:

$$\text{ADD}_{\text{ing}} = C \times \frac{\text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \quad (1)$$

$$\text{ADD}_{\text{inh}} = C \times \frac{\text{InhR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT} \times \text{PEF}} \quad (2)$$

$$\text{ADD}_{\text{derm}} = C \times \frac{\text{SA} \times \text{AF} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times 10^{-6} \quad (3)$$

Where C = metal concentration in (mg/kg), IR = ingestion rate, EF = exposure frequency in days/year (180), ED = exposure duration of 6 years for children and 24 years for adults, BW = average body weight (15 and 70 kg for child and adult, respectively), AT = average time (365 × ED), InhR = inhalation rate in mg/cm² (20 for both adults and children), PEF = particulate emission factor in m³kg⁻¹ (1.36 × 10⁹ for both adults and children), SA = surface area of the exposed

skin in cm² (2145 and 1150 for adults and children, respectively), AF = soil to skin adherence factor in mg/cm² (0.2 and 0.07 for adult and children, respectively), and ABS = dermal absorption factor. Exposure parameters for children and adults were obtained from the USEPA (2011)

Total Hazard Quotient and Index

The total hazard quotient (THQ), which is commonly used to quantify the possible non-carcinogenic risk of metal exposure in humans in three separate pathways, is calculated as the ratio of ADD (from three exposure pathways) to RfD (chronic reference dose for each metal in mg/kg BW/day):

$$THQ = \frac{ADD(\text{ingestion, inhalation, or dermal})}{RfD} \quad (4)$$

THQ < 1 indicates that there is no substantial health risk to the exposed population.

The hazard index (HI) which is used to calculate the overall possible non-carcinogenic risk of various pollutants over the exposure routes, is equal to the sum of all expected hazard quotients (HQs) through the oral, dermal, and inhalation pathways, i.e.:

$$HI = \sum HQ = HQ_{\text{ing}} + HQ_{\text{inh}} + HQ_{\text{derm}} \quad (5)$$

When HI is less than 1, there is no significant risk of non-carcinogenic effects; however, when HI is greater than 1, there is a chance that non-carcinogenic effects will occur, and the likelihood rises as HI increases.

Carcinogenic Risk Assessment

The cumulative life cancer risk rating for each exposure route was calculated using the following method to estimate the cancer risk for lifetime exposure (LCR) to the metals:

$$LCR = ADD(\text{ingestion, inhalation, or dermal}) \times CSF$$

$$TLCR = \sum \text{cancer risk} = \text{cancer risk}_{\text{ing}} + \text{cancer risk}_{\text{inh}} + \text{cancer risk}_{\text{derm}} \quad (6)$$

Where CSF for each metal for three exposure pathways is the cancer slope factor. LCR > 1 × 10⁻⁴, TLCR < 10⁻⁶, and TLCR 1 × 10⁻⁶ to 1 × 10⁻⁴ indicate high risk of developing cancer, no carcinogenic risk, and acceptable risk to humans, respectively.

Reference doses (RfDs) and cancer slope factors (CSFs) were obtained from Kamunda et al., 2016; Alabi et al., 2025; Eid et al 2024

Biological Materials Allium Cepa Root Tip Bioassay

The modified *Allium cepa* test according to Fiskesjo, (1997) and Bakare et al., (2022; 2025) was utilised for the evaluation of the cytogenotoxic effect of the leachate. Before the onset of the experiment, moderate uniformly sized onion bulbs of approximately 3 cm diameter (*Allium cepa*, L., 2n = 16, Family Amaryllidaceae) were procured commercially and sun-dried for three weeks. The outer dry scales of onion bulbs and the dry bottom plate were excised, leaving the ring of the primordial root intact. The bulbs were cleaned with fresh tap water to protect the primordial roots from drying. Seven (7) onion bulbs were used at each concentration of the leachate, out of which 5 with the best root growth were utilised for analysis of root growth inhibition and the CA analysis. Three concentrations (20, 40, and 60%) of the leachate were prepared (v/v, leachate/ tap water), and tap water was used as the negative control, with the root primordium in direct contact with the solution, for 72 hours at room temperature in 100 mL beakers containing the various concentrations of the leachate in the dark cupboard. The test liquid was replaced

every 24 h. After 72 h of growth, root lengths were measured and percentage root growth inhibition calculated.

The root growth in % of control was computed as

$$\frac{\text{Mean of treated roots length}}{\text{Mean of untreated roots length (control)}} \times \frac{100}{1} \quad (7)$$

For cytological analysis, 0.5–1 cm of the root apical meristem was harvested and fixed in Carnoy's fixative i.e. absolute ethanol: glacial acetic acid (3:1, v/v) for 24 h. The fixed root tips were hydrolysed in 1 N HCl at 60 °C for 10 mins and then rinsed with distilled water. The root tips were then squashed on a slide (two root tips per slide), and stained with acetocarmine for 10 min before a coverslip was gently placed on it. The coverslip edges were sealed using fingernail polish and examined by light microscopy (×1000, oil immersion). A minimum of 2000 cells per concentration were scored, and mitotic index (MI) calculated; the phase index for each mitotic stage (prophase, metaphase, anaphase, telophase) was also recorded. The root length values were thereafter utilised to determine the percentage root growth inhibition. The morphological effect of the leachate on the growing roots was also noted.

The mitotic index (MI) per total cells scored (2000) was calculated as:

$$\text{Mitotic Index (MI)} = \frac{\text{Number of dividing cells}}{\text{Total cells scored}} \times \frac{100}{1} \quad (8)$$

Mitotic inhibition was computed as

$$\text{Mitotic inhibition} = \frac{\text{Mitotic index in control} - \text{Mitotic index in treatment}}{\text{Mitotic index in control}} \times \frac{100}{1} \quad (9)$$

Statistical Analysis

Data are expressed as mean ± standard error of the mean (SEM). One way analysis of variance (ANOVA) was used to test for significant differences between treatment and control groups for root length and mitotic index, with post hoc comparisons by Tukey's HSD test. Significance was set at p < 0.05. Analyses were performed using SPSS version 20.0.

RESULTS AND DISCUSSION

Heavy Metal Concentrations in Soil and Leachate

Table 1 shows the heavy metals detected in both soil and simulated leachate from the Anyigba dumpsite, with substantial enrichment of selected metals in soil and measurable transfer into leachate, indicating potential environmental mobility. Metal concentrations were generally higher in soil than in the corresponding leachate, consistent with partial mobilisation during leachate simulation. Iron (97.42 ± 0.51 mg/kg), manganese (66.04 ± 0.35 mg/kg), zinc (42.84 ± 0.23 mg/kg) and silver (31.71 ± 0.17 mg/kg) were the predominant metals in soil, with copper also present at a relatively high concentration (13.39 ± 0.07 mg/kg). Trace levels of chromium, cobalt, selenium, lead, nickel, cadmium, arsenic, aluminium, mercury and barium were also recorded, while beryllium was below detection. The same metals dominated the leachate profile: iron (29.22 ± 0.19 mg/L), manganese (13.02 ± 0.13 mg/L), zinc (9.36 ± 0.58 mg/L), silver (6.18 ± 0.06 mg/L) and copper (2.61 ± 0.03 mg/L). Compared with regulatory standards, copper, zinc, iron, manganese and chromium exceeded NESREA and/or USEPA permissible limits in both soil and leachate, cobalt in leachate exceeded the WHO guideline value, lead and nickel in soil were at or slightly above regulatory limits, and cadmium was at the permissible limit in soil but undetected in leachate.

Table 1: Heavy Metal Concentrations in Anyigba Dumpsite Soil and Simulated Leachate Compared with NESREA and USEPA Permissible Limits

Parameters	Soil (mg/kg)	Leachate (mg/L)	*NESREA	**USEPA
Boron	0.06 ± 0.00	0.01 ± 0.00	0.05	0.05
Copper	13.39 ± 0.07	2.61 ± 0.03	0.1	0.3
Cadmium	0.01 ± 0.00	BDL	0.01	0.01
Nickel	0.05 ± 0.00	0.01 ± 0.00	0.05	-
Zinc	42.84 ± 0.23	9.36 ± 0.58	3	3
Iron	97.42 ± 0.51	29.22 ± 0.19	3	3
Manganese	66.04 ± 0.35	13.02 ± 0.13	5	5
Chromium	0.09 ± 0.00	0.02 ± 0.00	0.01	0.01
Cobalt	0.43 ± 0.00	0.08 ± 0.00	-	0.005 (WHO)
Arsenic	0.02 ± 0.00	0.00 ± 0.00	-	0.01–0.05
Aluminum	0.01 ± 0.00	0.00 ± 0.00	-	-
Selenium	0.54 ± 0.00	0.11 ± 0.00	-	-
Mercury	0.01 ± 0.00	BDL	-	-
Silver	31.71 ± 0.17	6.18 ± 0.06	-	-
Beryllium	BDL	BDL	-	-
Barium	0.01 ± 0.00	BDL	0.05	0.05

BDL = below detection limit; values are mean ± SEM; NESREA = National Environmental Standards and Regulations Enforcement Agency in Nigeria maximum permissible limits for effluent from wastewater; WHO = World Health Organization; USEPA = United State Environmental Protection Agency.

Assessment of Human Health Risk

Non-Carcinogenic and Carcinogenic Risk

Hazard quotient (HQ) and lifetime cancer risk (LCR) values calculated for the ingestion (HQ_{ing}), inhalation (HQ_{inh}), and dermal contact (HQ_{derm}) pathways, which the ingestion pathway contributed more than 99% of total risk, are presented in Table 2. Children consistently recorded higher HQ_{ing} values than adults. Manganese recorded the highest HQ_{ing} for children (6.73), followed by copper (4.72), iron (3.02), zinc (2.26), chromium (0.48), lead (0.21) and nickel (0.036); the corresponding adult values were manganese (0.98), copper (0.69), iron (0.44), zinc (0.33), chromium (0.071), lead (0.030) and nickel (0.0053). HQ_{ing} values exceeded unity in children for manganese, copper, iron and zinc, whereas no adult ingestion HQ exceeded 1.0. Hazard

quotients via inhalation (10⁻¹⁰–10⁻⁷) and dermal contact (10⁻⁹–10⁻⁵) were several orders of magnitude lower than ingestion values for both age groups, confirming ingestion as the dominant non-carcinogenic exposure route. For carcinogenic risk, chromium showed the highest ingestion related LCR (7.23 × 10⁻⁴ in children; 1.06 × 10⁻⁴ in adults), followed by nickel (6.08 × 10⁻⁵ in children; 8.88 × 10⁻⁶ in adults) and lead (6.15 × 10⁻⁶ in children; 8.98 × 10⁻⁷ in adults); dermal and inhalation cancer risks were negligible (10⁻⁹–10⁻¹⁴ range). Therefore, ingestion was identified as the dominant exposure pathway contributing to both non-carcinogenic and carcinogenic risks, with children being more vulnerable than adults. Chromium and manganese were the major contributors to carcinogenic and non-carcinogenic risks, respectively.

Table 2: Hazard Quotient (HQ) and Total Lifetime Cancer Risk (TLCR) for Children and Adults Exposed to Anyigba Dumpsite Leachate

Metals	HQ _{ing}		HQ _{inh}		HQ _{derm}		LCR _{ing}		LCR _{inh}		LCR _{derm}	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Pb	2.07×10 ⁻¹	3.02×10 ⁻¹	1.49×10 ⁻⁹	3.19×10 ⁻⁹	5.04×10 ⁻¹¹	5.76×10 ⁻¹¹	6.15×10 ⁻⁶	8.98×10 ⁻⁷	-	-	1.11×10 ⁻¹²	1.27×10 ⁻¹²
Cu	4.72×10 ⁻¹	6.90×10 ⁻¹	3.14×10 ⁻⁹	6.73×10 ⁻⁹	5.76×10 ⁻¹¹	6.57×10 ⁻¹¹	-	-	-	-	-	-
Ni	3.62×10 ⁻¹	5.28×10 ⁻¹	2.35×10 ⁻⁹	5.03×10 ⁻⁹	4.90×10 ⁻¹¹	5.60×10 ⁻¹¹	6.08×10 ⁻⁵	8.88×10 ⁻⁶	4.06×10 ⁻¹³	8.70×10 ⁻¹³	2.22×10 ⁻¹²	2.54×10 ⁻¹²
Zn	2.26×10 ⁻¹	3.30×10 ⁻¹	1.51×10 ⁻⁹	3.23×10 ⁻⁹	4.13×10 ⁻¹¹	4.71×10 ⁻¹¹	-	-	-	-	-	-
Fe	3.02×10 ⁻¹	4.41×10 ⁻¹	2.02×10 ⁻⁹	4.32×10 ⁻⁹	5.52×10 ⁻¹¹	6.31×10 ⁻¹¹	-	-	-	-	-	-
Mn	6.73×10 ⁻¹	9.83×10 ⁻¹	4.50×10 ⁻⁹	9.64×10 ⁻⁹	1.91×10 ⁻¹¹	2.19×10 ⁻¹¹	-	-	-	-	-	-
Cr	4.82×10 ⁻¹	7.05×10 ⁻¹	3.38×10 ⁻⁹	7.24×10 ⁻⁹	8.82×10 ⁻¹¹	1.01×10 ⁻¹¹	7.23×10 ⁻⁴	1.06×10 ⁻⁴	-	-	2.17×10 ⁻⁹	2.48×10 ⁻⁹

Hazard Index and Total Lifetime Cancer Risk

The cumulative hazard index (HI) and total lifetime cancer risk (TLCR) values are presented in Table 3. The results indicate clear age related differences in overall risk patterns. For children, HI values exceeded unity indicating significant non-carcinogenic risk for manganese (6.73), copper (4.72), iron (3.02) and zinc (2.26), whereas lead, nickel and chromium recorded HI values below unity. All adult HI values were below 1.0, indicating no significant non-

carcinogenic risk across all assessed metals with manganese again the highest contributor (9.83 × 10⁻¹), followed by copper (6.90 × 10⁻¹), iron (4.41 × 10⁻¹), zinc (3.30 × 10⁻¹), chromium (7.05 × 10⁻²), lead (3.02 × 10⁻²), and nickel (5.28 × 10⁻³). The cumulative HI across all assessed metals exceeded 20 for children, reflecting extremely high aggregate non-carcinogenic risk. Regarding carcinogenic risk, TLCR values showed that chromium exceeded the USEPA acceptable threshold (10⁻⁴) for both children (7.23 × 10⁻⁴) and

adults (1.06×10^{-4}), posed a carcinogenic risk for both children and adults while nickel and lead fell within the acceptable range for children, and nickel remained acceptable for adults; lead posed no appreciable carcinogenic risk in adults. TLCR values were not computed for copper, zinc, iron, manganese or arsenic owing to the absence of USEPA

cancer slope factors. Children exhibited higher cumulative non-carcinogenic and carcinogenic risks compared to adults. Manganese, copper, iron, and zinc were the principal contributors to non-carcinogenic risk in children, while chromium was the primary contributor to carcinogenic risk in both age groups.

Table 3: Hazard Index (HI) and Total Lifetime Cancer Risk (TLCR) Values from Anyigba Dumpsite Leachate for Adults and Children

Metal	HI Children	Interpretation	TLCR	Interpretation	HI Adults	Interpretation	TLCR	Interpretation
Pb	2.07×10^{-1}	No significant risk	6.15×10^{-6}	Acceptable risk	3.02×10^{-2}	No significant risk	8.98×10^{-7}	No carcinogenic risk
Cu	4.72×10^{-0}	Significant risk	–	–	6.90×10^{-1}	No significant risk	–	–
Ni	3.62×10^{-2}	No significant risk	6.08×10^{-5}	Acceptable risk	5.28×10^{-3}	No significant risk	8.88×10^{-6}	Acceptable risk
Zn	2.26×10^{-0}	Significant risk	–	–	3.30×10^{-1}	No significant risk	–	–
Fe	3.02×10^{-0}	Significant risk	–	–	4.41×10^{-1}	No significant risk	–	–
Mn	6.73×10^{-0}	Significant risk	–	–	9.83×10^{-1}	No significant risk	–	–
Cr	4.82×10^{-1}	No significant risk	7.23×10^{-4}	Carcinogenic risk	7.05×10^{-2}	No significant risk	1.06×10^{-4}	Carcinogenic risk

Metals below Detection Limit (Cd, Hg, Be, Ba) and as concentrations at/near 0.00 mg/L are excluded from calculations. Co, Al, Se, Ag as no RfD/CSF values and are also excluded.

Cytogenotoxic Effect and Root Growth Inhibition of the Leachate on *Allium Cepa*

The effect of Anyigba dumpsite leachate on root growth and cell division in *Allium cepa* is summarised in Table 4 and Plate 1 and 2. The negative control recorded a mean root length of 4.40 cm (0% inhibition), whereas exposure to 20, 40 and 60% leachate significantly reduced mean root length to 0.87, 0.52 and 0.32 cm respectively ($p < 0.05$), corresponding to root growth inhibition of 80.23, 88.18 and 92.73%. The number of dividing cells fell from 235 in the control to 123, 84 and 45 at 20, 40 and 60% leachate, respectively, and mitotic index (MI) declined correspondingly from 11.75% in the control to 6.15, 4.20 and 2.25% (mitotic inhibition of

47.66, 64.23 and 80.85%). Phase index analysis showed an overall decline or irregular fluctuation in cell division phases with increasing concentration, indicating disruption of normal mitotic progression; the prophase and telophase stages occur more frequently than the rest phases probably due to the toxicants inhibition of cell cycle. Furthermore, exposure to different leachate samples significantly and dependently caused irregularities of dividing cell cycles as well as aberrant cells chromosome behaviours consistent with clastogenic and aneugenic activity. *A. cepa* bulbs grown in the leachate showed changes in root colouration and swollen roots compared to the negative control roots.

Table 4: Root Growth Inhibition and Mitotic Index in *Allium Cepa* Exposed to Anyigba Dumpsite Leachate (Mean $\pm$ SEM; 2000 Cells Scored per Concentration)

Conc. (%)	Mean Root Length (cm)	Root Growth relative to control (%)	Root Growth Inhibition (%)	Number of Dividing Cells	Mitotic Index (%)	Mitotic inhibition (%)
NC	4.40 ± 0.29	100	0.00	235	11.75	0.00
20	$0.87 \pm 0.13^*$	19.77*	80.23*	123	6.15*	47.66*
40	$0.52 \pm 0.19^*$	11.82*	88.18*	84	4.2*	64.23*
60	$0.32 \pm 0.01^*$	7.27*	92.73*	45	2.25*	80.85*

Total cells scored per concentration = 2000. * indicates significant difference from the negative control ($p < 0.05$). Values are expressed as Mean $\pm$ SEM.



(a)



(b)



(c)



(d)

Plate 1: Root growth observed in controlled samples (A); leachate treated samples (B); scanty root growth observed in leachate treated sample (C); root length measurement (D)

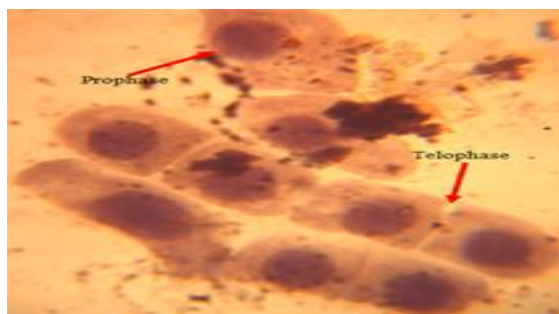
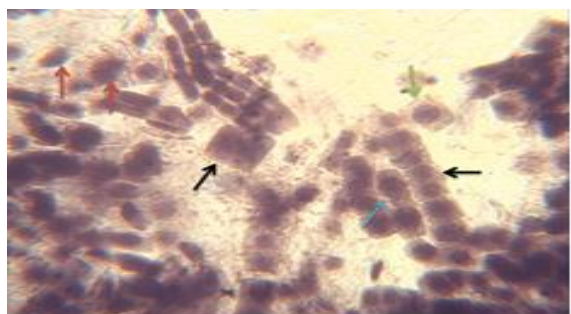


Plate 2: Representative Photomicrographs of *Allium cepa* root tip cells of showing normal cells prophase (green arrow), metaphase (Red arrow), anaphase (blue arrow), telophase with sign of cell plate formation (magnification x1000)

Discussion

Dumpsite toxin exposure is increasing, particularly in developing countries, due to a lack of resources to execute appropriate waste management processes. Globally waste generation and management constitute a significant concern but more acute in poor nations (Sale Junior *et al.*, 2024). As the number and size of dumpsites expanded, so did the volume of waste generated; as a result, the variety of waste increased. Public and private local garbage collectors deposit a range of wastes at Anyigba Dumpsite, a typical MSW dumpsite in Dekina, LGA, Kogi State, Nigeria. Because there is no provision for a subsurface drainage system to collect leachate, the dumpsite's leachate ends up in the nearby aquifers, posing health and environmental dangers to the nearby residents.

The detectable transfer of metals into simulated leachate, the significant enrichment of iron, manganese, zinc, silver, and copper in the dumpsite soil is consistent with contamination patterns reported for some Nigerian municipal dumpsites. At an abandoned dumpsite in Enugu, Ekere *et al.* (2020) found similar enrichment of iron, manganese, and zinc, but higher levels of lead and cadmium due to increased disposal of lead acid batteries and electronic wastes. Nwadiobie and Atuanya (2018) observed excessive metal concentrations in Benin City, where high Pb levels were connected to indiscriminate battery and paint disposal. Ibor *et al.* (2020) reported elevated levels of heavy metals in the Lemna solid waste dumpsite in Calabar, Southern Nigeria. Oshode *et al.* (2008), Alimba and Bakare (2016), and Fagbenro *et al.* (2024) reported comparable findings from the Aba-Eku landfill in Oyo State and the Abule Egba and Olusosun landfill in Lagos State in Southwestern Nigeria. Metal sorption onto soil particles, precipitation as insoluble compounds, and complexation with organic matter are likely the reasons for the partial mobilization during leaching indicated by the generally high metal concentrations in soil compared to leachate found in this study. The amount of metal enrichment found in this study suggests a similarly high level of contamination burden in Anyigba.

The results showed that in both matrices, the levels of some of the examined metals, including copper, zinc, iron, manganese, and chromium, were higher than the standard permissible limits. These metals are known to have neurotoxic, genotoxic, mutagenic, and endocrine disruptive properties. Due to the potential for these metals to pollute the environment and interfere with organisms' biomolecules, which may result in cancer induction and genetic changes in living cells, the presence of some toxic metals at high concentrations portends a public and environmental health concern (Alabi *et al.*, 2013; 2025). Mshelia *et al.* (2024) reported potential health risks associated with heavy-metal contamination of borehole water near a dumpsite in Giwo, Bauchi State, particularly due to lead, chromium, and arsenic. The findings underscore the importance of assessing metal contamination and estimating human exposure risks in communities surrounding waste disposal sites. Because according to reports, arsenic (As) damages skin, causes circulation problems, and has neurotoxic effects that affect speech, vision, and cognitive function. Cadmium (Cd) damages the respiratory system and encourages neurological diseases like Parkinson's and Alzheimer's, whereas chromium (Cr) is carcinogenic and causes allergic dermatitis. In addition to harming the kidney, cadmium buildup in the renal cortex promotes bone demineralization, diabetes, hypertension, and cancer. Visual perception, memory, and cognitive abilities are all affected by lead (Pb) poisoning. In addition, it causes anemia, hemolysis, renal damage, decreased libido and vigor, and decreased sperm production. Female miscarriages and stillbirths have also been linked to lead exposure (Amadi *et al.*, 2017; Bakare *et al.*, 2025).

The metals found in this study have significant toxicological significance. The primary non-carcinogenic risk factor, manganese ($HQ_{ing} = 6.73$ in children), is neurotoxic at high exposure levels and can cause manganism, a Parkinsonian syndrome characterized by tremor, rigidity, and cognitive impairment. Children are especially susceptible due to higher relative absorption and developing nervous systems (USEPA, 2009). When exposed in excess, copper ($HQ_{ing} = 4.72$ in

children) can disrupt zinc and iron homeostasis and produce reactive oxygen species through Fenton-type chemistry. It can also cause gastrointestinal, hepatic, and renal consequences as well as hemolytic anemia. Despite being necessary micronutrients, iron ($HQ_{ing} = 3.02$) and zinc ($HQ_{ing} = 2.26$) are similarly linked to organ toxicity at the increased amounts found in this study (haemochromatosis, hepatic and cardiac consequences for iron; copper insufficiency and immunological dysfunction for zinc). These hazard quotients exceed those reported by Ekere et al., 2020; Mama et al., 2021, where manganese HQ range of 1.2–2.8 and copper HQ range of 2.1–3.5 for children near Enugu dumpsites studies, suggesting relatively elevated metal exposure risk at Anyigba.

Chromium was the dominant carcinogenic risk contributor, with TCR values of 7.23×10^{-4} in children and 1.06×10^{-4} in adults exceeding the USEPA acceptable risk ceiling. This finding is comparable to chromium related cancer risk values of 5.2×10^{-4} to 8.9×10^{-4} reported for Niger Delta communities (Onyegeme-Okerenta et al., 2023) and 6.8×10^{-4} reported for southeastern Nigerian dumpsites (Edet et al., 2025), suggesting that chromium contamination from stainless steel, leather tanning and chromate containing waste is a widespread feature of Nigerian municipal dumpsites. Nickel and lead, while classified as posing acceptable cancer risk within the USEPA range, remain of concern given nickel's association with allergic dermatitis, pulmonary fibrosis and respiratory cancers, and lead's well documented neurotoxicity and skeletal accumulation with a biological half-life of 20–30 years.

Children showed significantly higher cumulative non-carcinogenic and carcinogenic risk than adults, according to the exposure parameter assumptions. This was due to higher rates of soil and water ingestion relative to body weight, hand to mouth behavior, immature detoxification capacity, and a longer remaining lifespan over which chronic disease may manifest (USEPA, 2009). The cumulative hazard index exceeding 20 for children in this study is significantly higher than the HI ranges of 1.2–4.5 reported by Ekere et al., (2020); Onyegeme-Okerenta et al., (2023); Mama et al., (2025). This suggests that the Anyigba site has a particularly high level of contamination or exposure potential, which is likely related to its location within the market complex, high waste density, and total lack of leachate containment infrastructure. Thus, ingestion route dominated overall risk contributing more than 99% of total HQ and LCR, consistent with the low volatility and limited dermal bioavailability of most heavy metals in aqueous matrices reported in USEPA guidance.

The results of the *Allium cepa* bioassay offer independent biological validation of the chemical risk assessment. Strong, concentration-dependent cytotoxicity and genotoxicity are indicated by root growth inhibition of up to 92.73% and mitotic index depression from 11.75% to 2.25% at higher leachate concentrations. These findings are consistent with oxidative damage to membranes, proteins, and DNA, disruption of microtubule assembly and spindle fiber formation, and competitive interference with essential cation uptake by the heavy metals identified chemically in this study. The observed chromosomal misbehavior or abnormal cells, along with the erratic oscillations in cell cycle indices, are indicative of clastogenic and aneugenic activity resulting from metal-DNA interactions and disruption of the spindle mechanism.

These findings are comparable to, and in places more severe than, those reported for other Nigerian dumpsite leachates: Bakare et al. (2025) study of Lapite dumpsite leachate reported root growth inhibition of 67.80–11.96% and mitotic

indices of 8.33–1.25%. Ogunyemi et al. (2019) reported concentration-dependent inhibition of root growth and mitotic activity in *Allium cepa* exposed to landfill solid leachate from a dumpsite in Lagos State, Nigeria, accompanied by chromosomal aberrations, demonstrating the cytotoxic and genotoxic potential of the leachate. Studies using the *Allium cepa* assay have demonstrated that landfill leachates can suppress root growth and mitotic activity and induce chromosomal abnormalities, providing evidence of their cytotoxic and genotoxic potential (Ogunyemi et al., 2019). The convergence of elevated hazard quotients for manganese, copper, iron and zinc, elevated cancer risk for chromium, and pronounced cytogenotoxicity in the *Allium cepa* assay provides multiple, mutually reinforcing lines of evidence that Anyigba dumpsite leachate poses a genuine environmental and public health hazard.

Conclusion

This study shows that the Anyigba municipal dumpsite is a major source of heavy metal contamination with soil and simulated leachate containing several metals at amounts above national (NESREA) and international (USEPA, WHO) regulatory limits. The predominant metals in both matrices were iron, manganese, zinc, silver, and copper; however, because to their carcinogenic and non-carcinogenic characteristics, chromium, lead, and nickel were of higher toxicological concern despite being present at relatively lower quantities. According to human health risk assessment, children who consume excessive amounts of manganese, copper, iron, and zinc are at non-carcinogenic risk, whereas both adults and children are at unacceptable carcinogenic risk from chromium. The *Allium cepa* bioassay corroborated these chemical findings, confirming strong, concentration dependent cytotoxic and genotoxic activity of the leachate. These findings indicate that the Anyigba dumpsite constitutes a public health hazard warranting urgent remediation and strengthened waste management practice.

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