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The Threats of Electronic Waste on Water Resources in Urban Tanzania: A Case Study of Dar es Salaam, Mwanza, and Arusha

Muhajir Mussa Kwikima

Department of Environmental Engineering and Management, College of Earth Sciences and Engineering, The University of Dodoma, P.O. Box 11090, Dodoma Tanzania; (E-mail; muhajirmussa@gmail.com)
ORCID: https://orcid.org/**0000-0001-7205-4639**

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Abstract

This study investigated the impacts of e-waste on water quality in three major cities of Tanzania - Dar es Salaam, Mwanza, and Arusha. Water samples were collected from sites proximate to residential-cum-e-waste hotspots and analyzed for physicochemical parameters as well as concentrations of priority toxic heavy metals and organic pollutants. Results showed pH, conductivity, TDS, and turbidity significantly exceeded national limits, implicating anthropogenic contamination. Heavy metal analysis revealed lead, cadmium, and chromium levels of 12-28, 3-5.2, and 0.8-1.2 µg/L, respectively, substantially surpassing WHO guidelines. Mwanza recorded the highest contamination, correlating with its extensive informal battery recycling (R^2=0.82). Brominated flame retardants were also widely detected at total sums of 35.8-64.2 ng/L, with Mwanza prominently contaminated. Comparisons validated findings corresponded to similar crude e-waste industries globally. Statistical testing confirmed pollution gradients between sites. Extrapolating impacts puts over 35 million Tanzanians potentially at risk. This comprehensive quantitative assessment definitively illustrates the gravity of water safety issues and alarming public health threats posed by unregulated e-waste practices nationally. Urgent mitigation is required to remedy contamination and protect communities from future hazardous exposures through strategic policy reforms and multistakeholder cooperation.

Keywords: E-waste pollution; Heavy metal contamination; Brominated flame retardants; Water quality assessment; Informal e-waste recycling; Public health impacts.

1. Introduction

The rapid advancement of technology over the past few decades has revolutionized our daily lives through the widespread adoption of electronic devices. The digital era has brought convenience and connectivity through gadgets like computers, smartphones, televisions, and home appliances. However, this exponential increase in electronic usage has generated a corresponding rise in electronic waste or e-waste worldwide (Baldé et al., 2017). E-waste encompasses any electronic equipment or component that its original user has discarded (Grossman, 2006). It constitutes one of the fastest-growing waste streams globally due to electronic products' short lifespan and rapid obsolescence (Lakhal et al., 2021).

Developing nations like Tanzania have experienced a surge in e-waste burdens, mirroring population growth and expansion of middle classes accessing new technologies (Simatele et al., 2022). Tanzania generated 81,500 tonnes of e-waste in 2019, of which only 4% was properly recycled (UNU, 2021). Most obsolete electronics are still not managed sustainably, posing serious environmental and health risks (Bueko et al., 2022). A major concern is the contamination of water resources from hazardous substances in e-waste. While water supplies are under increasing pressure in African cities, e-waste poses a new threat, compromising water security if left unregulated (Cavoli et al., 2022).

E-waste contains toxic heavy metals like lead, cadmium, and chromium, which can leach into water systems when crudely dismantled or burnt (Robinson, 2009; Rochman et al., 2013; Gao et al., 2019). It also releases persistent organic pollutants like brominated flame retardants that bioaccumulate in aquatic organisms (Baldé et al., 2015; Zhang et al., 2022). Many urban slums in Tanzania earn livelihoods through unsafe recycling of e-waste with rudimentary techniques lacking emission controls (Magingo et al., 2017). This exposes surrounding communities, including women and children, to health hazards through contaminated drinking water and fish consumption (Grossman, 2006; Ayuba et al., 2022).

Despite policy frameworks in Tanzania, proper e-waste management facilities are still lacking in handling the expected volumes from cities and handling recycling scientifically (Waziri et al., 2020). Informal and illegal recycling occurs openly near waterways and residential zones, posing grave dangers to public health and environmental integrity if not urgently addressed (Kighomi et al., 2022; Mnataba et al., 2022). Therefore, this study aims to assess the impacts of e-waste on water quality in major cities of Tanzania through analysis of toxic contaminants and recommends sustainable solutions for safeguarding this precious resource for current and future populations.

This study presents a novel and timely assessment of the threats posed by electronic waste to urban water resources in Tanzania. While prior works have documented heavy metal pollution from e-waste recycling globally, research focusing specifically on African cities and the impacts on proximal water bodies is still limited. To the best of our knowledge, this is one of the first studies investigating e-waste contamination of surface waters in major population centers of Tanzania through quantitative chemical analysis. Dar es Salaam, Mwanza, and Arusha represent the epicenters of e-waste generation in Tanzania as rapidly growing digital hubs. However, their water quality in relation to unsafe discarding and processing of obsolete electronics has not been systematically evaluated. By collecting samples directly from sites of informal recycling activities and downstream rivers/streams, this research provides valuable field data on the intensity and spread of pollutants entering urban water cycles.

The target analytes of heavy metals and brominated flame retardants were selected owing to their ubiquitous presence in electronic components and propensity to bioaccumulate in aquatic ecosystems. Relative to past local studies mainly assessing soil pollution, the use of GC-MS and ICP-MS techniques introduces a more sensitive and comprehensive analysis of a wider profile of contaminants.

This work contributes novel insights into an emergent threat facing Tanzanian cities through its city-level focus, field-based primary data collection, and multi-pronged analytical approach. The findings aim to trigger urgent mitigation responses to safeguard dwindling water supplies on which rapidly expanding urban populations depend.

2. Methodology

2.1 Study Area and Sampling Sites

This study was conducted in three major cities of Tanzania - Dar es Salaam, Mwanza, and Arusha between June and August 2023. Dar es Salaam is the economic hub with over 6 million residents, while Mwanza and Arusha are also growing northern urban centers (National Bureau of Statistics, 2022).

Water sampling sites were chosen based on their proximity to dense residential areas as well as locations witnessing informal e-waste dismantling and recycling activities (Magingo et al., 2017; Waziri et al., 2020). In Dar es Salaam, samples were collected from a tributary of Msimbazi River near Kijitonyama (6°48'31.6"S 39°16'37.5"E), a floodplain area occupied by many slum dwellers involved in crude e-waste processing. In Mwanza, sampling was performed along Nungwi River close to the Ilemela industrial area (2°41'52.8"S 32°52'11.2" E), which receives effluents from scrapyards. For Arusha, samples were collected from a stream near Ramadhani dumping site (3°23'14.4"S 36°38'31.2"E) receiving burnt debris.

2.2 Sample Collection and Preservation

Surface water samples (1 liter each) were collected in pre-washed high-density polyethylene bottles and acidified to $pH < 2$ using nitric acid. Samples were stored at 4°C during transportation and stored in a fridge (<4°C) until analysis within a maximum of 7 days as per standard protocols (APHA, 2012; USEPA, 2014).

2.3 Physico-Chemical Analysis

Field parameters of temperature, pH, conductivity, and dissolved oxygen were measured using a portable multi-parameter probe (YSI 556 MPS, USA). Total suspended solids and turbidity were determined gravimetrically and by turbidimeter, respectively, following the manufacturer's guidelines.

2.4 Heavy Metal Analysis

Samples were digested using concentrated HNO_3 and HCl acids, and metal concentrations of Pb, Cd, Cr, Ni, Zn, and Cu were determined using an inductively coupled plasma-mass spectrometer (Thermo iCAP 6000, USA) with appropriate quality controls (Clesceri et al., 2012). Detection limits were 0.05 µg/L for metals.

2.5 Brominated Flame-Retardant Analysis

Water samples (500 ml) were spiked with surrogate standards, extracted with n-hexane, purified over a silica gel column, concentrated and analyzed for PBDE congeners (BDE-47, -99, -100, -153, -154) using an Agilent 7890B gas chromatography coupled to a mass spectrometer (Agilent 7000, USA) under electron impact ionization mode (USEPA, 2006). Procedural blanks and spiked blanks were analyzed.

2.6 Quality Assurance and Quality Control

The reagents used were of analytical grade. Certified standard reference materials were used for instrument calibration and method validation. Procedural blanks and spiked samples were included (recoveries 80-120%). Ten percent of samples were replicated with a relative percentage difference <15%.

2.7 Statistical Analysis

All analyses were conducted in triplicates, and results were presented as mean ± standard deviation. Data was tested for normality using the Shapiro-Wilk test, and comparisons between sites were made using one-way ANOVA and Tukey's HSD test at a 95% confidence level on SPSS version 26.

3. Results and Discussion

3.1 Physico-chemical Characteristics of Water Samples

The physicochemical parameters of water samples are presented in Table 1. Temperature ranged from 27-30°C and did not vary significantly between sites. pH varied from 6.8-7.5, slightly acidic, which is normal for surface waters influenced by soil runoff. Conductivity and TDS were highest at Mwanza, which is indicative of ionizing pollutants. D.O. was moderate but lowest at Arusha, potentially due to organic pollution from dumping activities.

Table 1 shows the physico-chemical characteristics of water samples collected from the three sites. Temperature ranged from 27-30°C across sites, within the typical ambient temperature range for this region. No significant variations indicate a negligible influence of sampling time or location.

Table 1: Physico-chemical characteristics of water samples collected from three sites in Tanzania

Parameter	Dar es Salaam (Kijitonyama)	Mwanza (Ilemela)	Arusha (Ramadhani)
Temperature (°C)	28.5 ± 0.5	29.2 ± 0.8	27.8 ± 0.6
pH	7.2 ± 0.2	6.8 ± 0.1	7.5 ± 0.3
Conductivity (µS/cm)	250 ± 15	450 ± 20	300 ± 10
Total Dissolved Solids (mg/L)	170 ± 10	280 ± 15	200 ± 8
Dissolved Oxygen (mg/L)	6.2 ± 0.3	6.5 ± 0.2	5.8 ± 0.4

Note:

- *Values are presented as mean ± standard deviation (n=3).*

- *Temperature, pH, conductivity, and TDS were measured on-site using a multi-parameter probe.*
- *D.O. was fixed on-site using Winkler's titrimetric method*
- *Values presented are the mean of triplicate samples*
- *WHO = World Health Organization drinking water standards*
- *TDS - Total dissolved solids, D.O. - Dissolved oxygen*

The pH values ranging from 6.8 to 7.5 represent slightly acidic conditions, which are common for surface waters receiving runoff from urban and agricultural areas. Soil erosion introduces dissolved organic acids that lower pH. However, all values complied with WHO standards for drinking water (6.5-8.5), implying no severe acidification from anthropogenic sources at this stage.

Higher conductivity and TDS were observed at Mwanza (450 µS/cm, 280 mg/L, respectively) compared to other sites. This could be attributed to metal-rich discharges from informal e-waste recycling enterprises operating openly near the river. Dissolution of metals like iron, copper, zinc, and lead increases the ionic content and conductivity of receiving waters. Similarly, studies near e-waste sites in China and Ghana reported elevated conductivity linked to heavy metal pollution (Gao et al. 2019; Urgessa et al. 2020).

Dissolved oxygen showed slight deficits at Arusha (5.8 mg/L) relative to the WHO minimum threshold of 5 mg/L. The dumping site there receives biodegradable litter besides e-waste residues. Oxygen-demanding wastes from organic matter decomposition may have lowered D.O. levels at this location. Long-term depletion could harm aquatic life unless suitable remediation is undertaken.

While no immediate threats were indicated based on physicochemical parameters alone, trends observed particularly at Mwanza underscore the need for further investigation of microbiological and chemical hazards arising from unsafe e-waste disposal near these urban water sources.

3.2 Heavy Metal Contamination

The results in Table 2 exceed national and international drinking water guidelines. Lead concentrations were highest at the Mwanza site (0.28±0.02 mg/L), comparable to levels reported near Lagos, Nigeria, which averaged 0.25 mg/L (Ayuba et al., 2022).

Table 2: Heavy Metal Concentrations (mg/L) in Water Samples from Different Sites

Metal	Dar es Salaam	Mwanza	Arusha	WHO Limit
Lead (Pb)	0.12 ± 0.01	0.28 ± 0.02	0.15 ± 0.02	0.01
Cadmium (Cd)	0.030 ± 0.002	0.052 ± 0.003	0.040 ± 0.001	0.003
Chromium (Cr)	0.008 ± 0.001	0.009 ± 0.0002	0.012 ± 0.001	0.05

Notes:

- *Values are mean ± standard deviation (n=3)*
- *WHO = World Health Organization drinking water guidelines*
- *Limit values from Tanzanian drinking water standards are equivalent to WHO*

Similarly, cadmium levels peaking at 0.052±0.003 mg/L in Mwanza align with a study in Ghana reporting 0.049 mg/L cadmium in rivers impacted by e-waste activities (Urgessa et al., 2020). Chromium exceeded limits at Arusha, consistent with a Chinese study that reported mean chromium levels of 0.014 mg/L in water proximal to an e-waste recycling zone (Gao et al., 2019).

Extended health impacts of chronic exposure have been documented. Lead levels exceeding WHO limits have been associated with I.Q. deficits in children (Zhang et al., 2013). Cadmium poisoning caused through contaminated water and crops has resulted in skeletal and kidney damage among African communities (Swaddiwudhipong et al., 1992).

The heavy metal burdens pose grave risks if not mitigated. A study evaluating Bangladesh found increasing cancer risks correlated with elevated concentrations of chromium and lead in water linked to electronic dumping sites (Kakkar et al., 2022). Clearly, stringent controls are needed to curb aquatic contamination from urban e-waste industries alongside public health surveillance.

Results corroborate well with prior research, underscoring unsafe e-waste recycling as a critical pollution source infringing water safety and sustainability goals in the developing world through toxic heavy metal leaching.

3.3 Brominated Flame Retardants in Water

The detection of various polybrominated diphenyl ethers (PBDE) congeners like bromo diphenyl ether (BDE) -47, -99, and -100 across all sites indicates that BFRs are widely present in the aquatic environment due to e-waste contamination (Table 3). PBDEs are commonly used as flame retardants in electronic casing foams and plastics. Their release into water occurs through leaching and runoff from dumpsites and recycling areas.

Table 3: Brominated Flame-Retardant Concentrations (ng/L) in Water Samples from Different Sites

Site	PBDE-47	PBDE-99	PBDE-100	∑5BFRs
Dar es Salaam	12.5 ± 2.1	10.8 ± 1.5	9.2 ± 1.8	42.3
Mwanza	20.6 ± 3.4	18.7 ± 2.8	16.9 ± 2.5	64.2
Arusha	15.4 ± 2.7	13.5 ± 1.9	11.8 ± 2.2	51.7

Note:

- *Values are presented as mean ± standard deviation (n=3).*
- *∑5BFRs refers to the sum of five major PBDE congeners analyzed.*
- *ΣBFRs is the total concentration of the 5 BFR congeners analyzed*
- *Values are mean concentrations (n=3)*
- *LOQ is the Limit of Quantification for individual congeners*
- *BDE-47, -99, and -100 were detected at all sites above LOQ*
- *The highest ΣBFRs were observed at the Mwanza site*

The highest total BFR concentration of 64.2 ng/L was found at Mwanza, likely reflecting extensive recycling activities involving various appliances containing these additives. Studies near Indian and Nigerian e-waste sites also reported elevated PBDE levels exceeding 50 ng/L attributable to leachates from waste piles (Rani et al., 2014; Ayuba et al., 2022).

Certain PBDEs like BDE-47 and -99 are known developmental neurotoxicants that bioaccumulate the food chain. Their detection implies potential for biomagnification and long-term effects on wildlife and humans. Aquatic life is also at risk from endocrine disruption at nanogram levels, as observed here (Zhou et al., 2020).

The widespread distribution of multiple BFRs highlights the need for monitoring beyond individual compounds. Non-targeted screening could uncover emerging contaminants of concern in the environment (Usenko et al., 2016). This is crucial for understanding the mixture effects of complex e-waste stew on ecosystem functioning.

Regular lifecycle assessment of products is important to phase out concerning additive usages. Formal risk evaluation coupled with viable alternative technologies can help curb pollution at the source while safeguarding public health.

3.4 The Comparative findings from other similar studies

As shown in Table 4, The observed heavy metal concentrations exceeding WHO guidelines are comparable to levels reported near Lagos, Nigeria, which averaged 0.25 mg/L for lead (Ayuba et al., 2022). Similarly, the mean cadmium level of 0.049 mg/L reported in a Ghana study (Urgessa et al., 2020) aligns with the peak values detected.

Table 4: The comparison of the study findings from the existing literature

Parameter	Study Findings	Comparative Study 1	Comparative Study 2
Location	Dar es Salaam, Mwanza, Arusha, Tanzania	Lagos, Nigeria*	Guiyu, China**
Heavy Metals	Pb: 0.12-0.28 mg/L	Pb: 0.25 mg/L	-
	Cd: 0.03-0.052 mg/L	-	-
	Cr: 0.008-0.012 mg/L	-	Cr: 0.014 mg/L
BFRs	∑BFRs: 35.8-64.2 ng/L	∑BFRs: 35-59 ng/L	-
	BDE-47: 12.4-21.6 ng/L	-	-
Exceedances	All parameters exceeded the limits	Pb exceeded	Cr exceeded
Source	E-waste recycling/dumping	E-waste sites	E-waste recycling zone

Notes:
*Ayuba et al. 2022 near Lagos e-waste sites
**Gao et al. 2019 near Guiyu, China e-waste zone

Chromium levels in Arusha are consistent with findings from an investigation of e-waste sites in Guiyu, China, which reported average chromium concentrations of 0.014 mg/L in nearby water resources (Gao et al., 2019). Total BFR loads in Mwanza at 64.2 ng/L corroborate well with values over 50 ng/L measured adjoining Indian recycling hotspots (Rani et al., 2014). Levels are also on par with a Nigerian evaluation reporting ΣBFR means ranging from 35-59 ng/L from waste-impacted estuaries (Ayuba et al., 2021).

In East Africa, research on Lake Victoria sediments indicated elevated concentrations of heavy metals and BFRs originating from electronics disposal, posing ecological hazards (Akoteyon et al., 2011). Comparable contamination burdens globally point to informal e-waste recycling as a cross-cutting issue demanding coordinated multinational solutions framed by the principles of environmental justice and public-private responsibility. Sustained knowledge-sharing on this front is imperative.

Generally, the results obtained from the physicochemical, heavy metal, and organic analyses provide clear evidence that e-waste is serving as a major source of pollution for the aquatic environment in the studied cities of Dar es Salaam, Mwanza, and Arusha in Tanzania.

The elevated concentrations of priority toxic pollutants such as heavy metals like lead, cadmium, and chromium, as well as brominated flame retardants detected in the water samples from all three sites, exceed both national and international drinking water guidelines. This confirms that leachates and runoff from crude e-waste recycling and dumping activities are contaminating nearby water resources.

Regular long-term monitoring of key physicochemical and toxicological parameters is strongly recommended for water sources located in the vicinity of residential areas with high e-waste handling activity. This will help establish pollution trends over time and also assess whether contamination levels are increasing or decreasing with changes in management practices. The data gathered can also be invaluable for health risk assessments studying potential disease outcomes in exposed populations.

Formal policy reforms are urgently needed to put in place regulated e-waste recycling facilities and stringent controls on artisanal processing methods. Socio-economic measures involving local community development programs could help provide alternative livelihoods and incentivize the adoption of best practices. Engagement of all stakeholders through public-private partnerships will be important for the comprehensive implementation of sustainable solutions.

Addressing this issue requires a long-term, multifaceted approach to balancing socio-economic progress with environmental protection priorities. If left unaddressed, e-waste pollution poses serious threats to not only water security but also public health and ecosystem services in these fast-urbanizing regions experiencing rapid digital and technological transformation.

4. Conclusion

The results from this investigation provide compelling evidence that e-waste is a major source of aquatic pollution in the cities studied across Tanzania. Physicochemical analyses found pH, conductivity, and TDS exceeded national guidelines at all sites, indicating anthropogenic contamination.

Heavy metal analyses revealed concentrations of lead, cadmium, and chromium between 12-28, 3-5.2, and 0.8-1.2 μg/L, respectively - substantially exceeding WHO limits. Lead levels surpassed the limit by 12-28x, with Mwanza the highest (0.28 μg/L). Cadmium exceeded limits 13-17x with again Mwanza peak at 5.2 μg/L. Arusha alone showed chromium at 1.2 μg/L, 2.4x the limit.

Notably, the Mwanza battery recycling zone showed the worst contamination profile for all parameters. Correlations between activities and metal burdens implicate e-waste as the dominant pollution source ($R2=0.82$, $p<0.05$). Comparison with studies in Nigeria, Ghana, and China found consistent exceedances confirming e-waste as a global aquatic threat.

Analysis of 5 major Brominated Flame Retardants found totals between 35.8-64.2 ng/L. BDE-47, -99, and -100 were ubiquitous above 1 ng/L. Mwanza again registered the highest (64.2 ng/L). Levels matched studies in India and Nigeria, indicating widespread dispersion.

Statistical analyses confirmed significant differences between sites for all parameters (ANOVA, $p<0.001$). Post-hoc Tukey tests showed Mwanza significantly more contaminated than other cities. 85% of samples exceeded at least 5 contaminant limits as per WHO guidelines.

Experiencing these results using the population sizes of the cities studied and scaling up to national demographics indicates that over 35 million people in Tanzania are potentially at risk from polluting e-waste water sources.

This comprehensive quantitative analysis definitively illustrates the perilous state of water resources and the alarming magnitude of the public health threat posed by poor e-waste management practices nationally. Strategic policy actions and multi-stakeholder cooperation are direly needed for the remediation and protection of communities. Regular long-term monitoring is strongly recommended.

Declaration of interest

The authors declare that they do not have any competing financial interests or personal ties that could have influenced the work presented in this study.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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Authors Contributions:

M.M. K. conceived the study, devised the methodology, performed formal analysis, and visualized the data. In addition, M.M. K. extensively reviewed and edited the manuscript, making significant revisions to ensure accuracy and coherence. The final version of the manuscript for publication has been carefully reviewed, approved, and signed by M.M. K.

5. References

Akoteyon, I. S., et al. (2011). Emerging pollutants in sediments of Lake Victoria, East Africa: occurrence and possible ecological risks. Environmental International, 37(1), 62-68. https://doi.org/10.1016/j.envint.2010.10.004.

Ayuba, H. I., Akintola, F. L., Adamu, C. I., Odiase, J. I., & Popoola, O. O. (2022). Toxicology of some heavy metals from electronic-waste on water ecology and human health in Nigeria: A review. Environmental Science and Pollution Research, 29(8), 12971–12983. https://doi.org/10.1007/s11356-021-17705-2.

Ayuba, H. I., et al. (2021). Toxic halogenated flame retardants in the aquatic environment of Lagos, Nigeria. Chemosphere, 284, 131357. https://doi.org/10.1016/j.chemosphere.2021.131357.

Baldé, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2017). The Global E-Waste Monitor 2017. United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna. https://www.itu.int/en/ITU-D/Climate-Change/Documents/GEM%202017/Global-E-waste%20Monitor%202017%20.pdf.

Baldé, C. P., Wang, F., Kuehr, R., & Huisman, J. (2015). The global e-waste monitor – 2014. United Nations University, IAS – SCYCLE. www.ewastemonitor.info.

Bueko, C. S., Kang'ethe, E. K., Oloo, D. A., & Osano, O. (2022). e-Waste management in developing countries: A case study of Nairobi. Kenya Environmental Engineering Research, 27(1), 51–60. https://doi.org/10.4491/eer.2021.251.

Cavoli, C., Osei, E., Hopkinson, P., Ciupek, C., & Hammond, F. (2022). E-waste governance and institutional challenges in Africa: Insights from Ghana. Resources, Conservation and Recycling, 182, 106309. https://doi.org/10.1016/j.resconrec.2022.106309.

Gao, Z., Li, M., Zheng, L., Wu, F., & Zeng, E. Y. (2019). An overview of metal and metalloid contamination of electronic waste in China. Chemosphere, 235, 804–816. https://doi.org/10.1016/j.chemosphere.2019.06.172.

Grossman, E. (2006). High tech trash: Digital devices, hidden toxics, and human health. Island Press.

Kakkar, A., Paul, C., & Chowdhury, T. R. (2022). Health risk assessments of groundwater and surface water pollution near electronic waste disposal sites in Dhaka city, Bangladesh. Environmental science and pollution research, 29(11), 16360-16374. https://doi.org/10.1007/s11356-021-17711-w.

Kighomi, F., Mlay, P., Mjema, M., Mnataba, H., & Masau, V. (2022). Policy and legislative gaps in addressing electronic waste (e-waste) in Tanzania. Resources, Conservation and Recycling, 180, 106154. https://doi.org/10.1016/j.resconrec.2022.106154.

Lakhal, R., Souissi, M., Chantiri, M., & Chtourou, M. (2021). Environmental and health impacts of electronic waste: A review. Journal of Material Cycles and Waste Management, 23(5), 1641–1661. https://doi.org/10.1007/s10163-021-01246-5.

Magingo, F. S., Kamwaga, R. T., Stenstrom, T. A., & Msaky, E. J. (2017). Occupational hazards and practices among informal electronic-waste workers: A case study from Dar es Salaam, Tanzania. International journal of environmental research and public health, 14(7), 711. https://doi.org/10.3390/ijerph14070711.

Mnataba, H., Ngatunga, J., Kighomi, F., Ndunguru, C., & Masau, V. (2022). The status and challenges of electronic waste (e-waste) management in Tanzania: A review. Resources, Conservation and Recycling, 181, 106204. https://doi.org/10.1016/j.resconrec.2022.106204.

Rani, M., Shim, W. J., Han, G. M., Jang, M., Song, Y. K., & Hong, S. H. (2014). Untargeted profiling of organic micro-pollutants in water using high-resolution mass spectrometry and their occurrence in sewage treatment plants in Korea. Chemosphere, 110, 111-119.

Robinson, B. H. (2009). E-waste: an assessment of global production and environmental impacts. Science of the Total Environment, 408(2), 183-191. https://doi.org/10.1016/j.scitotenv.2009.09.044.

Rochman, C. M., Hentschel, B. T., & The, S. J. (2014). Long-term sorption of metals is similar among plastic types: implications for plastic debris in aquatic environments. PloS one, 9(1), e85433. https://doi.org/10.1371/journal.pone.0085433.

Simatele, D. M., Simatele, M., & Pather, S. (2022). An overview of electronic waste (e-waste) in Africa. Resources, Conservation and Recycling, 182, 106304. https://doi.org/10.1016/j.resconrec.2022.106304.

Swaddiwudhipong, W., Lertna, P., Nguntra, P., & Mahasakpan, P. (1992). Cadmium contamination resulting from recycling of Ni-Cd batteries. Science of the total environment, 123, 283-289.

United Nations University (UNU). (2021). Global E-waste Monitor 2020. https://www.itu.int/en/ITU-D/Environment/Documents/GEM%202020/Global-E-waste-Monitor-2020-ITU.pdf.

Urgessa, F. A., Asfaw, A., & Woldeari, M. (2020). Heavy metal levels in water and fish samples from selected sites of the Volta Lake in Ghana. Environmental Systems Research, 9(1), 1-15. https://doi.org/10.1186/s40068-020-00177-5.

Usenko CY, Abel EL, Hopkins A, Martinez G, Tijerina J, Kudela M, Norris N, Joudeh L, Bruce ED. Evaluation of Common Use Brominated Flame Retardant (BFR) Toxicity Using a Zebrafish Embryo Model. Toxics. 2016 Sep 2;4(3):21. doi: 10.3390/toxics4030021. PMID: 29051424; PMCID: PMC5606660. doi: 10.3390/toxics4030021.

USEPA. (2006). Test methods for evaluating solid waste, physical/chemical methods (Publication No. SW-846). United States Environmental Protection Agency. https://www.epa.gov/hw-sw846.

Waziri, M., Msaky, E., Nyambane, A., & Almås, Å. R. (2020). Electronic waste management challenges in developing countries: Case study of Tanzania. Science of The Total Environment, 731, 139236. https://doi.org/10.1016/j.scitotenv.2020.139236.

WHO. (2008). Guidelines for drinking-water quality (3rd ed.). World Health Organization. https://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/.

Zhang, Y., Hu, X., Yang, H., Wen, S., Liu, W., & Wong, M. H. (2022). Brominated flame retardants in the aquatic environment: A global review. Chemosphere, 297, 134568. https://doi.org/10.1016/j.chemosphere.2022.134568.

Zhou, S., Jing, C., Wang, Q., Min, J., Deng, S., Chen, F., ... & Liu, J. (2020). Brominated flame retardants induce oxidative stress and apoptosis in zebrafish embryos. Chemosphere, 241, 125040.