Indicators of Microplastic Poisoning in the Catchment of Nyumba-ya-Mungu Water Reservoir - Tanzania

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Abstract

Microplastic (MP) pollution has emerged as a significant global issue, primarily due to the potential adverse health effects associated with the entry of microplastics into the human body, mainly by ingestion and inhalation. This study explored the relationship between microplastic pollution at Nyumba-ya-Mungu water reservoir (NWR) in Kilimanjaro, Tanzania and public health issues in the catchment area. The study employed a cross-sectional study design that combined questionnaire, document analysis, microscopy, and spectroscopy methods for data collection. A total of 401 community respondents from the study area, 19 medical doctors in 4 hospitals from the catchment, 22 fish samples, and 30 surface water samples (each sampled in triplet) from NWR. The study's findings indicate that some risky practices and behaviors can directly affect human health due to microplastic pollution, including plastic burning (76.6%), serving hot foods in plastic containers (87.5%), and drink polluted water (71.5%) and eat fish (93.5%) in the study area. Fish and water samples contained MP with a mean concentration of 2.80 ± 3.13679 MP fish^{-1} and $2.30 \pm$

2.55231 MP L^{-1}, respectively. Various health issues in the catchment area of NWR can be associated with microplastic pollution, including cardiovascular disease, diabetes, intestinal, reproductive, and respiratory diseases. The co-existence of the risky practices and the implied health issues suggests an associative relationship. The study recommends creating public awareness on proper plastic handling and management and support research studies that focus on public health issues.

Keywords: Microplastics, Pollution, Water Reservoir, Public Health, Catchment Area

1. Introduction

Microplastic (MP) pollution has emerged as an ubiquitous environmental pollutant, particularly in aquatic ecosystems (Ashrafy et al., 2023). MPs are defined as plastic particles which are less than 5 mm in diameter. They originate from both primary and secondary sources, such as industrial abrasives and cosmetic microbeads, and secondary MPs result from the degradation of larger plastic debris (Varsha & Singh, 2025). These particles are increasingly detected in freshwater bodies, where they pose risks to biodiversity, water quality, and potentially human health (Bexeitova et al., 2024; Witczak et al., 2024). MP pollution is increasingly recognized as a significant contributor to various unresolved public health challenges worldwide due to MPs widespread presence in food, water, and air (2024 wright & Kelly, 2017). Humans are primarily exposed to MPs through ingestion and inhalation. Recent studies estimate that an adult may ingest up to 5 grams of microplastics weekly, the equivalent of a credit card through contaminated food and beverages (Smith et al., 2018). Furthermore, airborne microplastics contribute to exposure, with indoor concentrations ranging from 1 to over 1,500 particles per cubic meter (Prata, 2018). In the body, MPs can cross biological barriers, enter the bloodstream, and accumulate in organs such as the lungs, liver, brain, and even the placenta (Pulusu et al., 2025; Wright & Kelly, 2017). The health implications are significant. MPs have been linked to inflammation, oxidative stress, and DNA damage, which are risk factors for cancer (Yong et al., 2020). Observational studies suggest associations with cardiovascular disease, stroke, and neurodegenerative disorders, including dementia (Leslie et al., 2022). Additionally, plastic additives such as phthalates act as endocrine disruptors, affecting hormonal balance and fertility (EMA, 2014; Talsness et al., 2009).

The global plastic production is projected to increase by 70% by 2040. The detection of microplastics even in remote ecosystems warrants urgent mitigation strategies and standardized risk assessments to safeguard public health (UNEP, 2021). Recently, studies have demonstrated that microplastics can accumulate in sediments and be ingested by aquatic organisms, leading to reduced feeding efficiency, growth inhibition, and reproductive toxicity (J. Liu & Li, 2025). Moreover, microplastics act as vectors for toxic chemicals, including heavy metals and persistent organic pollutants (POPs) (Achoukhi et al., 2024), which can bioaccumulate and bio-magnify through the food chain, raising serious concerns for human exposure (Bhardwaj et al., 2024). In addition, the widespread mismanagement of plastic wastes, including practices like open burning and using plastic containers for hot food increase the chance of human exposure to toxic chemicals released from plastics, contributing

to health problems (Kibria et al., 2023; Pathak et al., 2023, ; Velis & Cook, 2021).

In public health, emerging evidence suggests that microplastics may disrupt gut microbiota, induce oxidative stress, and contribute to conditions such as colorectal cancer (Mishra et al., 2025), depression, and respiratory illnesses (Bora et al., 2024; Gosavi et al., 2025). Recently, MPs have been detected in human tissues, including lungs, liver, placenta, and even bone marrow, indicating systemic exposure and potential long-term health effects (Amato-Lourenço et al., 2021; Sutkar et al., 2025). Consequently, causal research serves as critical bridges between observed associations and established causation (Drakvik et al., 2022). Glass et al. (2013 : Aronow & Samii (2017). Furthermore, causal research can elucidate underlying mechanisms and inform effective prevention strategies (Pulusu et al., 2025; Thornton Hampton et al., 2022).

In Kilimanjaro, Tanzania, the NWR has been the subject of ecological and hydrological studies because of the declining fish productivity and water quality. For example, Mangi et al. (2023) reported a 95% decline in fish productivity between 1972 and 2018, associated with increased turbidity, nutrient loading, and algal blooms. Gobry et al. (2023) confirmed the presence of harmful algal blooms (HAB) and microcystins in the dam, which pose direct risks to aquatic life and human health through waterborne exposure as well as food chain routes. Despite these findings, the role of microplastics in the ecological dynamics and public health outcomes in the NWR catchment remained underexplored. Given the global evidence of microplastics environmental persistence and their related health risks, there is a need to investigate their presence and potential impacts in this region. Additionally, the growing burden of public health challenges such as gastrointestinal, cancer-related, and respiratory disorders, necessitates the investigation of factors contributing to these conditions.

There are evidence of MPs persistence and capacity to absorb toxic substances, that potential determinant of adverse health outcomes (Boccia et al., 2024; Y. Li et al., 2023; Xiong et al., 2024). However, establishing causal links between environmental pollutants and population health remains constrained by several challenges. These include limited funding for causal inference research (Crane et al., 2018; Jones et al., 2025) and substantial data gaps in population health metrics, particularly in low- and middle-income countries (LMICs), which hinder the evaluation of interventions and the conduct of robust public health studies (Adebisi & Lucero-Prisno, 2022). Nevertheless, foundational researches that raise awareness and inform protective measures for communities at risk is important. Therefore, the objectives of this study were : (i) to assess microplastics pollution in the NWR catchment area, ii) to determine the factors linked to public health issues in the catchment area, and (iii) to establish an associative relationship between MP pollution and public health issues in the catchment area. The findings contribute to public health action in resource-limited settings and support global efforts toward achieving sustainable ecosystems.

2. Materials and Methods

2.1 Description of Study Area

The study was carried out at NWR catchment area. NWR is an artificial lake located within

the upper Pangani River Basin, situated between 3º49'33.0" S and 37º28'9.6" E, in Kilimanjaro Region, Northern-East Tanzania (Figure 1). The reservoir is fed by two main rivers, the Kikuletwa River, which originates from Mount Meru to the northwest, and the Ruvu River, which flows from Lake Jipe to the northeast. The reservoir is drained by the Pangani River into the Indian Ocean (IBA, 2001; Ikingura & Akagi, 2003). NWR is an important fishing area in the region, and the entire shoreline is utilized by fishermen with permanent settlements several meters from the reservoir's edge. It is the main source of fish for the Kilimanjaro Region and its water serves the public in the catchment for domestic and agricultural use (IUCN, 2003). The reservoir is bordered by three wards namely Kirya and Lang'ata (Mwanga District), and Mikocheni (Moshi District) that were the study area.

2.2 Study Design

This study employed a cross-sectional research design to investigate associative relationship between microplastic pollution in the NWR and public health outcomes in the surrounding catchment area as well as studying MP in the NWR. This design was chosen due to its effectiveness in capturing data from a population at a single point in time, allowing the concurrent assessment of the environmental and health variables. Specifically, our study employed a combination of questionnaires, document analysis, spectroscopic, and stereoscopic techniques for data collection.

2.3 Samples and Sampling Design

The study used both purposive and random sampling. Purposive sampling was involved in setting criteria for participant's inclusion in the study. Thereafter, random sampling was used to select participants from among those who met the criteria. Our study involved 401 community respondents, 19 medical doctors from 4 hospitals, 20 fish samples and 30 surface water samples. Community respondents were randomly sampled from the catchment of study area using Smith's formula (Smith, 2013) which is employed when the population is too large or unknown. The formula stands as follows $n=Z^2X(1-SD)/Sx^2$, where n= sample size, Z= z-score (=1.96), SD= standard deviation (=0.5), Sx= standard error (=0.05), at 95% confidence level. The sample size amounts to 386 participants as the minimum. Inclusion criteria included being either a resident in the catchment area, ability to read and write, above the age of attending primary education, and willingness to participate in the study. The four (4) hospitals were selected from a compiled a list of all health facilities that met the inclusion criteria. From this list, representative hospitals were randomly selected. Sample hospitals were required to be located within the catchment area to ensure relevance to the study. In addition, the hospitals had to possess a well-established reputation for high patient volume and diversity, thereby ensuring a broad representation of public health conditions. Finally, the selected hospitals were required to possess adequate medical records to allow retrospective analysis and to have medical professionals willing to participate in the research questionnaire. Sampling of medical doctors was purposive, with each hospital providing five practitioners who had a minimum of four years of experience in their respective hospitals. With respect to fish sampling, 22 specimens were randomly selected from a haul obtained from NWR and purchased directly from local fishermen. The fish size reflected the type most commonly sold

and preferred for household consumption. Additionally, 30 surface near-shore water samples, (each sample collected in triplet) were purposively collected from 10 sites: 5 from areas with high human interaction, and 5 from sites with relatively low human interaction for comparison purposes. Furthermore, near-shore water was used because this is the commonly drawn water for domestic use including cooking and drinking. Both fish and water samples were transported to the laboratory at the Nelson Mandela African Institute of Science and Technology (NM-AIST) for MPs extraction and analysis.

2.4 Data Collection Procedure

A mixed methods approach, which employed structured questionnaires, a document analysis guide, and laboratory work (including MPs extraction, and characterization by using microscopy, and spectroscopy,) were used.

2.4.1 Questionnaire method

To assess the potential associations between microplastic pollution and public health issues within the study area, data were collected from 401 community respondents using structured questionnaires. The surveys focused on identifying risky practices such as plastic waste disposal methods, food handling behaviors, and, fish and water usage habits that could contribute to health risks associated with MPs exposure. Questionnaire for community participants, the questionnaire was in the form of questions whereby the respondent was required to respond with either a YES/NO/NOT SURE. Additionally, another questionnaire was administered to 19 medical doctors from selected hospitals namely St. Joseph Hospital, Kibosho Hospital, Kilema Hospital, and Marangu Lutheran Hospital located within the catchment area. This questionnaire focused on gathering expert insights on the prevalence and nature of public health issues that may be associated with MP pollution. The medical professionals were required to assess the prevalence rate of each given health issue associated with microplastic poisoning based on their professional experience of not less than four years in their respective hospital, to gather information from them, the Likert scale with the options, frequent (i.e. encountered almost every week)/ occasional (i.e. encountered almost every month)/ rare (i.e. encountered after some months)/never (i.e. was not encountered at all) was used. The community-level data and clinical perspectives were purposely combined to get a comprehensive understanding of the potential health impacts linked to MP contamination in the study area.

2.4.2 Document Analysis

Health records analysis from the sample hospitals around NWR was also employed. This aimed at identifying the most common public health issues reported in the study area and to triangulate these data with those obtained from medical doctors through structured questionnaires in order to strengthen the validity of the findings with respect to possible association between microplastic pollution and public health outcomes. In fact, the document analysis guide that was given to the sample hospitals was the questionnaire that was administered to medical doctors to further strengthen validity of findings (Denzin, 2017). In each sample hospital, the medical records for three consecutive years, i.e. 2021, 2022 and

2023 was analyzed to assess the prevalence or ocurring rate of each of the given health issues at the hospital based on health records, to get information from hospitals. The Likert scale with the options, frequent (i.e. among the 10 top common diseases each year)/ occasional (i.e. among the top 10 common diseases for at least 2 years) rare (i.e. among top 10 common diseases for at least 1 year)/never (i.e. not among the top 10 common diseases for all 3 years) was employed.

2.4.3 Microplastics Extraction

To extract MPs from water and fish samples, extraction procedures as described by Rocha-Santos et al. (2015) were used.

- Extraction of microplastics from water samples

The process of extracting microplastics started with sieving (< 5 mm) the water samples through a series of meshes to separate plastic and non-plastic materials. The sieved organic matter was then chemically digested using a 30% hydrogen peroxide (H_2O_2) solution at 60°C for approximately 24 hours. The resulting mixture underwent density separation using a zinc chloride ($ZnCl_2$) solution with a density of 1.75 g/cm³ to isolate the lighter plastic particles. The separated fraction containing MPs was filtered through a 0.45 µm membrane filter, rinsed with distilled water to remove any residual salts, and then dried for subsequent microscopy and spectroscopy analysis.

- Extraction of microplastics from fish sample

The fish samples intestines were chemically digested using a 10% potassium hydroxide (KOH) solution at 50°C for about three days to dissolve organic material. The digested mixture was subjected to density separation using a $ZnCl_2$ solution of 1.75 g/cm³, followed by filtration through a 0.45 µm membrane filter. The filters were rinsed with distilled water to eliminate salts and dried before microscopy and spectroscopy analysis to identify and characterize the isolated MP.

2.4.4 Spectroscopy and Stereoscopy Analysis

The extracted samples were analyzed using stereoscopy, which facilitated the counting of microplastic particles in each sample and enabled the determination of MPs concentrations. Fourier Transform Infrared Spectroscopy (FTIR) identified the polymer type extracted samples, following the procedure recommended by Rocha-Santos et al. (2015). Polymer classification was performed through spectral matching with established reference libraries (Käppler et al., 2016). The identified polymer types were subsequently analyzed in relation to their potential health risks and compared with the common health issues observed within the study area's catchment, which are often associated with microplastic contamination.

2.5 Ethical Considerations

Ethical research standards were observed, ensuring informed consent from all participants and confidentiality of personal data. Laboratory procedures followed established safety protocols

for handling environmental samples (WHO, 2021). Furthermore, permits for conducting research were obtained from respective authorities at national, regional and district level.

2.6 Data Analysis

Qualitative data from the questionnaires, document analysis guide and laboratory were processed using IBM SPSS Statistics software (IBM Corp., 2022). Descriptive statistics, including frequencies and percentages, were generated to summarize raw data for interpretation and discussion.t-test was run to compare means of microplastics concentrations between locations that differed in human interaction to find out if there was significant statistical difference. On the other hand, multiple comparison test was employed to compare means from different sampling points to find out if there were points that statistically differed significantly.

3. Results

3.1 Possible sources of direct MPs- pollution relating to public health issues in the study area

The survey results revealed notable patterns in participation to practices which can be potentially harmful with regards to MPs exposure as indicated in Figure 1. Majority of the participants (87.5%) reported serving hot foods in plastic containers and the rest did not (question a). Similarly, 93.5% of respondents consumed fish from the NWR and 6.5% were not used to (, question b). Regarding water usage, 75.1% acknowledged that water of NWR was used for drinking and cooking, whereas 6.7% negated usage, and 18.2% were uncertain (question c). Concerning waste management practices, 76.6% considered burning plastics waste to be a proper method for managing them while the rest disagreed (question d). Also, our analysis on environmental samples indicated notable differences in microplastic contamination between fish and water sources. Out of 22 fish samples examined, majority of them (54%) were found polluted, with mean Concentrations of 3.05 ±3.13679 MP per fish. with respect to water samples, all of them (100%) were contaminated with microplastics. water Samples from locations with high human interaction had mean concentration of 7.1320 ±3.29661 MP per sample, while those samples from locations with low human interaction had mean concentration of 4.3300 ±1.80801MP per sample. Thus, average concentration of microplastics per water sample was 5.731 ±2.55231 MP (Table 1). Since fish and water of NWR were being consumed by majority of the participants, this could be another possible source of direct poisoning to the public and might be associated with to related public health issues in the catchment of the reservoir, that are usually linked with MP pollution.

3.2 Human interaction with the reservoir

Though the independent samples t-test for the means of the two groups with respect to water samples, one from location with high human interaction and the other from location with low human interaction (Table 1) gave (t (28) = 1.610, p = 0.119, with a mean difference of 2.8 MP, at 95% confidence level. Since the p-value is greater than 0.05, the difference between the two groups was generally not statistically significant. Although water samples from areas with high human activities (Group One) had, on average, 2.8 more microplastic particles than samples from areas with low human activities (Group Two), but this difference was not strong

enough to conclude a measurable effect of human activity on water microplastic concentrations. However, when multiple comparison test of all means of sampling points was run, at two sampling points of contrasting sampling points (i.e. one from area with high human interaction, and the other from an area with minimal human interaction) differed significantly (p=0.047) indicating that to some extent human interaction with NWR contributed to the reservoir's contamination with MP.

3.3 Polymer abundance in samples and dynamics

The identified polymers in samples of fish and water and their abundances are shown in Figure 2. Abundance in fish was based on 61 MP that were extracted from fish samples for water based on 100 MP extracted from water that were analyzed by FTIR, respectively. The results show that several types of MP polymers were identified in samples of water and fish, including low density polyethylene (LDPE), high density polyethylene (HDPE) which were comparatively the most abundant in the two types of samples. Others were polystyrene (PS), Polypropylene (PP), Poly vinyl chloride (PVC), polyester (PST). Their average abundances in samples (samples considered together) was respectively 54.6%, 21.6%, 9.8%, 9.1%, 2.1%, and 3.0%. Note that low density polymers (LDPE, PP and PS) were more dominant in water than were high density polymers (PVC and PST). Drawing from these results, it means that the identified polymers were ingested together with fish and water by majority of the community participants as it was observed in Figure 1. It further means that people who were used to consuming water and fish of NWR were at risk of incurring the implicated health issues posed by the identified polymers once ingested. It is noted that almost all types of polymers were found in both types of samples with the exception of PST. This is a hint to the dynamics of MP between water and biota and may eventually get into human body through the food chain.
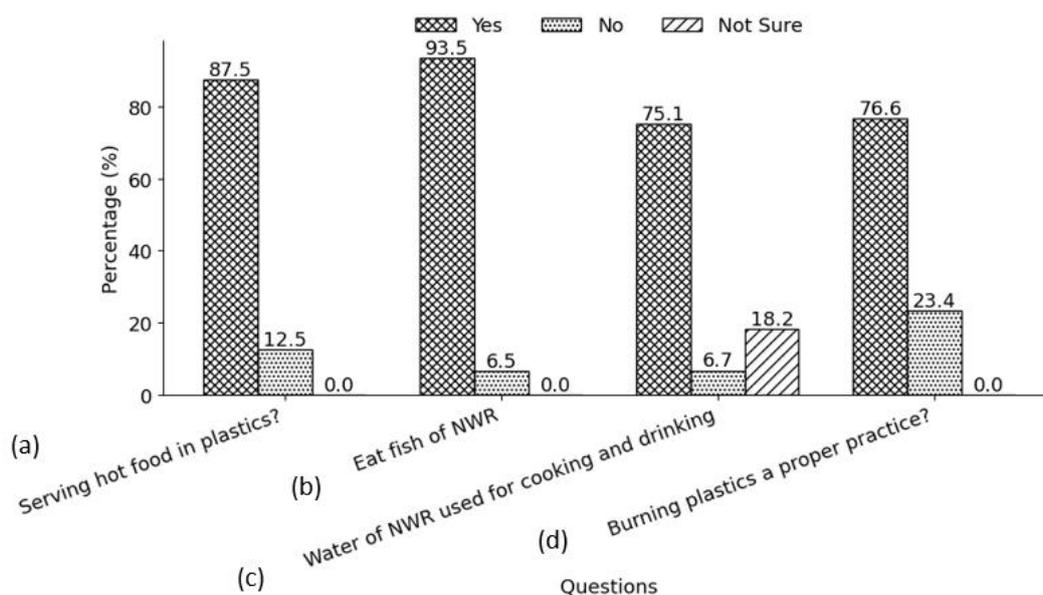

Figure 1. Public Responses to Questions relating to risky practices that can negatively and directly impact human health due to MPs poisoning

3.4 Public health issues in the catchment of Nyumba-ya-MunguWater Reservoir

Health records from sample hospitals in the NWR catchment area over three consecutive years (2021, 2022 and 2023) revealed varying frequencies of public health issues potentially associated with microplastic exposure as summarized in Table 2. Intestinal disorders were reported most frequently in 75% of cases, with occasional occurrence in 25% and rare occurrence in another 25%. Carcinogenic conditions appeared frequently in 50% of cases and occasionally in another 50%, with rare occurrence in 25%. These results provide evidence of increasing cancer cases reported in the catchment probably because of life style changes associated with MP pollution. Neural disorders were less common, with frequent and occasional occurrences, each accounting for 25%, while 50% were classified as rare. Respiratory issues demonstrated a relatively high prevalence, occurring frequently in 50% of cases and occasionally in another 50%, with no reports of rare or absent cases. Reproductive health problems were never reported as frequent but appeared occasionally in 50% of cases, while rare occurrences accounted for the remaining 50% (Table 4). Notably, diabetes and cardiac conditions were consistently reported as frequent in 100% of cases.

Furthermore, the prevalence of public health issues as reported by medical doctors in hospitals within the catchment area varied considerably (Table 3). Intestinal and respiratory conditions were reported most frequently, each by 57.9% of respondents, while diabetes mellitus showed the highest occurrence overall, with 89.5% reporting it as frequent. Cardiac conditions were also common, reported as frequent by majority of doctors (78.9%). whereas carcinogenic issues were predominantly occasional (68.4%), neural disorders were largely occasional (42.1%), and reproductive health issues were less frequent, with nearly half (47.4%) reporting it occasional in occurrence. These findings suggest a predominance of chronic conditions such as diabetes and cardiac diseases compared to other health issues linked to MP exposure. Note that cardiac and diabetes health issues were consistently frequent in the catchment area according to both health records and medical experts.
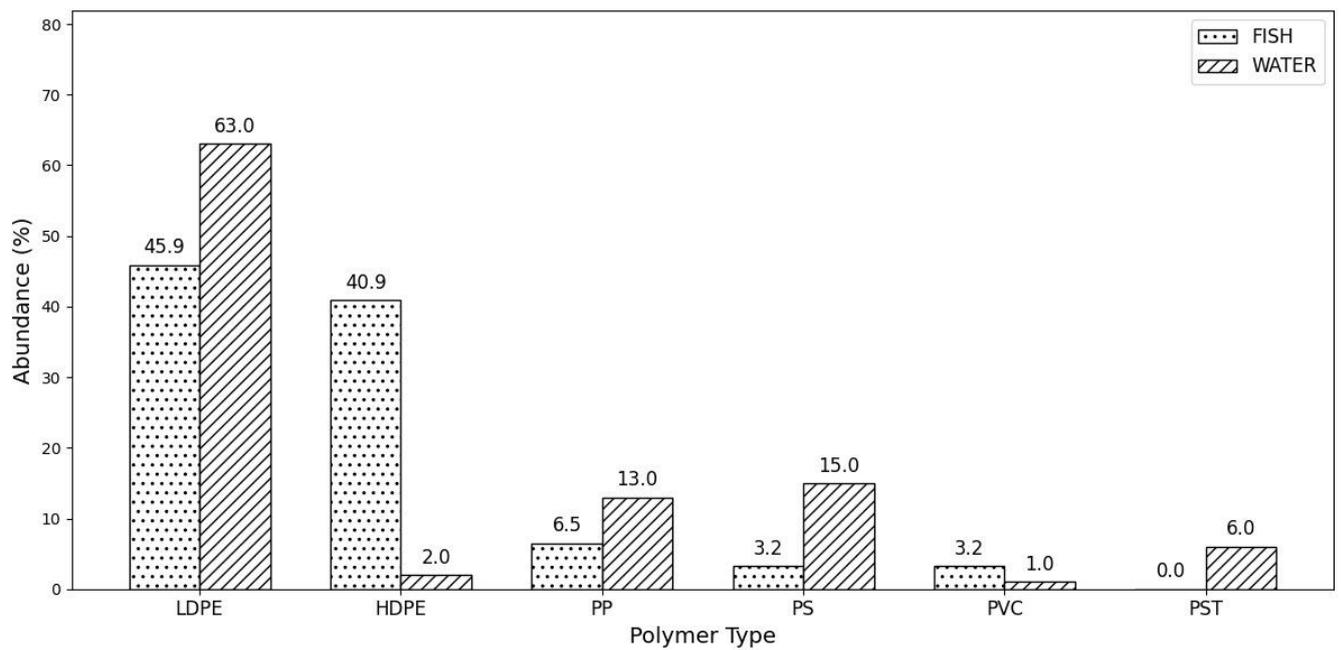
Figure 2. Polymers identified in samples of fish and water and their abundance (%) in based on the number of microplastics analyzed by FTIR per sample type

Table 1. Sample types, extent of pollution means and Standard deviations, and sampling points of water and fish samples of NWR

Sample type	Sampling point type	N	Pollution extent (%)	Mean Concentration of MP per sample	Std. Deviation
	1. High human interaction	15	100	7.1320	3.29661
Water	2. Low human interaction	15	100	4.3300	1.80801
Fish	Random	22	54	3.0500	3.13679

Table 2. Prevalence of public health issues linked to MP pollution in the catchment area from the 4 sample hospitals based on health records for three consecutive years (2021, 2022 and 2023).

Health issue	Rate of occurrence of health issue (frequency (percentage)			
	Frequent	Occasional	Rare	Never
Intestinal	3 (75%)	1(25%)	1 (25%)	0 (0%)
Carcinogenic	2 (50%)	2 (50%)	1 (25%)	0 (0%)
Neural	1(25%)	1 (25%)	2(50%)	0 (0%)
Respiratory	2 (50%)	2 (50%)	0 (0%)	0 (0%)
Reproductive	0 (0%)	2 (50%)	2 (0%)	0 (0%)
Diabetes	4 (100%)	0 (0%)	0 (0%)	0 (0%)
Cardiac	4(100%)	0 (0%)	0 (0%)	0 (0%)

Table 3. Prevalence of public health issues as reported by sample medical doctors from sample hospitals in the catchment of NWR, based on experience of not less than four years at respective hospitals (frequency and (percentage).

Health issue	Rate of occurrence of health issue (frequency (percentage)			
	Frequent	Occasional	Rare	Never
Intestinal	11 (57.9)	7 (36.8)	1 (5.3)	0 (0.0)
Carcinogenic	2 (10.5)	13 (68.4)	3 (15.8)	1 (5.3)
Neural	5 (26.3)	8 (42.1)	5 (26.3)	1 (5.3)
Respiratory	11 (57.9)	7 (36.8)	1 (5.3)	0 (0.0)
Reproductive	1 (5.3)	9 (47.4)	7 (36.8)	2 (10.5)
Diabetes mellitus	17 (89.5)	1 (5.3)	0 (0.0)	1 (5.3)
Cardiac	15 (78.9)	2 (10.5)	2 (10.5)	0 (0.0)

4. Discussion

4.1 Risky practices that put health of the study population at risk of microplastics poisoning

Our findings indicate that most participants in the study area considered direct burning of plastic waste as an acceptable and proper disposal method. The observations may be driven by convenience, lack of infrastructure, and awareness. However, the practice poses severe environmental and health risks. Burning plastics releases hazardous pollutants, including bisphenols and phthalates, which disrupt endocrine, neural, and reproductive functions.

Additionally, combustion produces carcinogenic compounds such as dioxins and furans, which can be inhaled and absorbed into the body (Sarkingobir et al., 2021; Velis & Cook, 2021). These risks are not unique to the study area; similar findings reported that in low- and middle-income countries where open burning remains the common practice because of inadequate waste management systems (UNEP, 2025; Ramadan et al., 2023). Globally, the World Health Organization has warned that exposure to dioxins from plastic burning contributes to long-term health problems, including cancer and developmental disorders (Baca et al., 2023).

Another risky practice observed was serving hot food in plastic containers. Heat accelerates polymer degradation, releasing microplastics and toxic additives into food (Babayemi et al., 2019; Chen et al., 2020; G. Liu et al., 2022). This aligns with studies from Asia and Africa, where food-contact plastics are widely used despite evidence linking them to chemical leaching and chronic diseases (Banerjee & Khan, 2020; Hussain et al., 2023; Hyman et al., 2025; Muncke et al., 2025; Obuzor & Onyedikachi, 2023; Sheriff et al., 2025). In high-income countries, regulatory frameworks such as the European Union (EU) REACH and FDA guidelines restrict certain additives, yet enforcement gaps persist globally, especially in informal markets (Amore & Smaoui, 2025; Mubarak et al., 2024). The persistence of these practices in our study area suggests a significant gap in public awareness, a trend corroborated by research in Nigeria, India, and Brazil, where knowledge deficits fuel unsafe plastic use (Chilote & Dhakal, 2025; Khanam et al., 2019; Ojonuba et al., 2025; Soares et al., 2021).

Collectively, these findings highlight the need to integrate interventions, strengthening public education, enforcing food safety regulations, and promoting sustainable waste management alternatives. Lessons can be drawn from successful initiatives in countries like Rwanda, which implemented strict plastic bans (Danielsson, 2017), and the EU, which adopted circular economy strategies to reduce plastic pollution (European Commission, 2018). Without such measures, the health and ecological risks associated with plastics will continue to escalate globally. On the aspect of policy makers, our findings underscore the urgent need for integrated policy interventions. Public education campaigns should target behavioral change regarding plastic use and disposal, while regulatory frameworks must enforce safer alternatives for food packaging and prohibit open burning. Investments in waste management infrastructure, such as community recycling programs and extended producer responsibility schemes, are critical. These actions align with Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), and SDG 14 (Life Below Water) (United Nations, 2024). Addressing plastic pollution through these measures will not only protect human health but also safeguard aquatic ecosystems and promote sustainable resource use.

4.2 Fish and water resources of Nyumba-ya-Mungu Water Reservoir are contaminated with different polymers

The findings of this study have indicated that a significant proportion of the population in the catchment of NWR consumes fish and water sourced from the reservoir. Further analysis revealed that these resources were contaminated with multiple MP polymers, which have

several implicated health issues. Once ingested, these substances can interfere with critical physiological systems, contributing to respiratory, cardiovascular, endocrine, reproductive, and carcinogenic health complications, as previously highlighted by Wright & Kelly (2017). Specific health issues associated with each type of polymer are highlighted herein. Notably, most of the health problems associated with the identified polymers were reported within the catchment area by medical experts and sample hospitals. This concurrence suggests an associative relationship between MP pollution and public health outcomes in the catchment. The link may be reinforced by risky practices observed including open-air burning of plastics, serving hot food in plastics, and consumption of contaminated fish and water.. High-density polyethylene (HDPE) and low-density polyethylene (LDPE) have been linked to respiratory disorders, carcinogenic effects, and endocrine disruption (Krasucka et al., 2022). Polypropylene (PP) is associated with respiratory and reproductive toxicity, as well as carcinogenic health complications(Mishra et al., 2025; Woo et al., 2023)). Polyvinyl chloride (PVC) presents several risks, including carcinogenicity, reproductive harm, and endocrine disruption (Campisi et al., 2025; Dhaka et al., 2022). Furthermore, Polystyrene (PS) is implicated in carcinogenic, cardiac, and reproductive health issues (Hwang et al., 2020). Additionally, polyester (PST) is linked to respiratory complications, endocrine disruption, and carcinogenicity (Singh & Bhalla, 2017;)). It was also noted that almost all types of he identified polymers were found in both fish water samples signifying possibility of transfer of microplastics from water into fish. This observation concurs with that of Biginagwa et al. (2016) who found out that polymers of MP size that were identified in sample fish collected from Lake Victoria were of polymeric type of the nets usually used to catch fish in Lake Victoria. This implies that MPs are dynamics and potentially bio accumulate in the food chain and cost human health. In this study the most dominant polymer was PE in its two forms (low and high density). The major sources are the single use plastic bags, packages materials and house hold items and fishing gear (Richardson et al., 2019; Jambeck et al., 2015;). This dominance concurs with other researches in Tanzania (Kundu et al., 2021; Nchimbi et al., 2022) and globally (Zahari, et al., 2022)

4.3 Concentrations of Microplastics in fish and water samples should not be underestimated

So far, there are no globally set safe levels of MPs in human consumables. The discovered concentrations may apparently appear low. However, it should be noted that the identified polymers contain additives. Moreover, one of the special characteristics of MPs is the ability to adsorb and concentrate contaminants like POPs and heavy metals (Mushumbusi et al., 2025). Additionally, long-term ingestion of MP leads to bioaccumulate (Dzierzynski, et al., 2025; Roslan et al., 2024) and amplifying their negative effects to human health.

4.4 Human interaction with Nyumba-ya-Mungu Water Reservoir contributes to its pollution with microplastics.

The fact that there was significant statistical difference between the means of two sampling points that differed in human interaction is a proof that anthropogenic activities around NWR to some extent contribute to the reservoirs' contamination with MP. This finding is in line with most of the studies in Tanzania on MP pollution which found out that MP pollution is a

human-based problem (Mushumbusi et al., 2025). Thus, incorporating the study of the human-dimension with respect to environmental sustainability in the battle towards mitigating the global problem of MP pollution, is indispensable (Pahl, & Wyles, 2017; Deng et al.,2022).

4.5 The prevalence of Microplastic-related public health issues in the catchment of NWR is noteworthy

The analysis of hospital records and expert opinions from the NWR catchment area highlights a notable prevalence of health conditions that may be linked to MP pollution. Intestinal and respiratory disorders emerged as the most common, while chronic diseases such as diabetes and cardiac conditions were consistently reported as frequent. Although carcinogenic, neural, and reproductive disorders appeared less frequently, their presence cannot be overlooked given the documented toxicological properties of plastic-derived chemicals. These findings are consistent with global evidence indicating that MPs and associated additives can disrupt gastrointestinal integrity, impair respiratory function, and contribute to systemic inflammation (Chartres et al., 2024; Kumar et al., 2025; Ravindra et al., 2025). Inhalation of airborne microplastics has been associated with pulmonary inflammation and fibrosis (Bora et al., 2024; Mtega et al., 2023; Prata, 2018; Prata et al., 2020), while ingestion through contaminated food and water can alter gut microbiota and increase cancer risk (Abbas et al., 2025; Al Mamun, 2025; Prata et al., 2020). Endocrine-disrupting chemicals such as bisphenols and phthalates, commonly found in plastics, have been linked to metabolic disorders, reproductive dysfunction, and cardiovascular disease (Hwang et al., 2020; Lucas et al., 2022; Ohore & Zhang, 2019). The high prevalence of diabetes and cardiac conditions in the study area may reflect these mechanisms, although causality needs to be established.

Globally, similar patterns have been observed in regions with high plastic pollution. Studies in Asia and North America report elevated rates of cardiometabolic diseases and gastrointestinal disorders in populations exposed to microplastics through seafood and drinking water (Pal, 2005; Gosavi et al., 2025; Makwana et al., 2025; Yuan et al., 2022). Given that the majority of the public in the catchment consume fish and water of NWR, bioaccumulation of microplastics in aquatic ecosystems represents a critical exposure pathway, mirroring trends documented elsewhere (Ghosh, 2025; X. Li et al., 2023; Sharma et al., 2021).

These health risks underscore the broader sustainability challenge posed by plastic pollution. MP contamination threatens multiple Sustainable Development Goals, including SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), and SDG 14 (Life Below Water). UNEP projects report that without decisive action, plastic leakage into aquatic systems could increase by 50% by 2040, amplifying health and ecological impacts (UNEP, 2025; UNEP, 2024). Addressing these risks requires integrated strategies: strengthening regulatory frameworks on food-contact plastics, promoting circular economy models, and implementing public awareness campaigns to reduce plastic dependency and exposure.

4.6 The implications on public health status for NWR its catchment and Kilimanjaro Region

The implications for public health in the catchment of NWR and the whole of Kilimanjaro Region need special attention. Communities in this area rely heavily on local water sources and

fish from NWR ecosystems vulnerable to MP contamination. For Kilimanjaro, where tourism (Kilungu, 2023) and agriculture are key economic drivers, plastic pollution could also undermine food safety and water quality, posing broader socio-economic challenges. These findings underscore the urgent need for integrated interventions. Public health strategies should prioritize awareness campaigns on the dangers of burning plastics and using plastic containers for hot food, as these practices accelerate chemical leaching and microplastic formation. Regulatory measures must enforce safer alternatives for food packaging and improve waste management systems to reduce open burning. Furthermore, monitoring programs should be established to assess microplastic levels in water, fish, and human tissues, coupled with longitudinal studies to clarify causal links between exposure and chronic diseases.

5. Conclusions

Our study identified several practices in the NWR catchment area that may directly contribute to MP pollution, including open-air burning of plastics, serving hot foods in plastic containers, and consumption of fish and water contaminated with MPs. Health records and expert reports revealed a range of conditions potentially associated with such exposure, notably cardiac, endocrine, respiratory, and carcinogenic disorders. The coexistence of risky plastic-handling behaviors, environmental MP contamination, and corresponding health issues suggests a plausible associative link between microplastic exposure and adverse health outcomes that were evident in the catchment. Polymers that were identified in samples collected from NWR have serious health implications, and their concentrations should not be underestimated. Last but not least, human interaction with Nyuma-ya-Mungu Water Reservoir contributes to its contamination.

Acknowledgments

Authors contributions

Cornelius benedict Mushumbusi was responsible for Study idea, conceptualization, study design, investigation, data collection and coding, revision, formatting, editing and correspondence; Leticia Joseph Kalumbilo was responsible for paper improvement, ethical language, revision, editing and graphs production, Dr. Emmanuel Mogusu Onyanka, was responsible for supervision, revision and proof reading and editing; Prof. Robert Arsen Max was responsible for supervision, conceptualization revision, editing and proof reading and formatting. All authors read and approved the final manuscript.

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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References

Abbas, G., Ahmed, U., & Ahmad, M. A. (2025). Impact of Microplastics on Human Health: Risks, Diseases, and Affected Body Systems. *Microplastics*, *4*(2), 1–21. https://doi.org/10.3390/microplastics4020023..

Achoukhi, I., El Hammoudani, Y., Haboubi, K., Benaabidate, L., Bourjila, A., El Boudammoussi, M., Moudou, M., Faiz, H., Touzani, A., & Dimane, F. (2024). Impact of microplastics on human health and aquatic species. *E3S Web of Conferences*, *527*, 1–12. https://doi.org/10.1051/e3sconf/202452702001..

Adebisi, Y. A., & Lucero-Prisno, D. E. 3rd. (2022). Fixing Data Gaps for Population Health in Africa: An Urgent Need. *International Journal of Public Health*, *67*, 1605418.

https://doi.org/10.3389/ijph.2022.1605418..

Al Mamun, A. (2025). Microplastics in Air, Drinking Water and Food: Impacts on Human Health BT - Microplastics Pollution: A Threat to Biosphere (V. Kumar, P. Singh, S. Kumar, & A. Kumar Singh (eds.); pp. 33–66). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-99774-7_2..

Amato-Lourenço, L., Carvalho-Oliveira, R., Júnior, G., Galvão, L., Ando, R., & Mauad, T. (2021). Presence of airborne microplastics in human lung tissue. *Journal of Hazardous Materials*, *416*, 126124. https://doi.org/10.1016/j.jhazmat.2021.126124

Aronow, P. M., & Samii, C. (2017). Interference , With Application To a Social Network Experiment. *The Annals of Applied Statistics*, *11*(4), 1912–1947.

Aronow, P. M., & Samii, C. (2017). Interference , With Application To a Social

Ashrafy, A., Liza, A. A., Islam, M. N., Billah, M. M., Arafat, S. T., Rahman, M. M., & Rahman, S. M. (2023). Microplastics Pollution: A Brief Review of Its Source and Abundance in Different Aquatic Ecosystems. *Journal of Hazardous Materials Advances*, *9*, 100215. https://doi.org/https://doi.org/10.1016/j.hazadv.2022.100215

Babayemi, J. O., Nnorom, I. C., Osibanjo, O., & Weber, R. (2019). Ensuring sustainability in plastics use in Africa: consumption, waste generation, and projections. *Environmental Sciences Europe*, *31*(1), 60. https://doi.org/10.1186/s12302-019-0254-5..

Baca, D., Monroy, R., Castillo, M., Elkhazraji, A., Farooq, A., & Ahmad, R. (2023). Dioxins and plastic waste: A scientometric analysis and systematic literature review of the detection methods. *Environmental Advances*, *13*, 100439. https://doi.org/https://doi.org/10.1016/j.envadv.2023.100439..

Banerjee, S., & Khan, D. (2020). *Food for life or miasma-a study on hot food in plastic container*. *2*, 1173–1177.

Bexeitova, K., Baimenov, A., Varol, E. A., Kudaibergenov, K., Zhantikeyev, U., Sailaukhanuly, Y., Toshtay, K., Tauanov, Z., Azat, S., & Berndtsson, R. (2024). Microplastics in freshwater systems: A review of classification, sources, and environmental impacts. *Chemical Engineering Journal Advances*, *20*, 100649. https://doi.org/https://doi.org/10.1016/j.ceja.2024.100649..

Bhardwaj, L. K., Rath, P., Yadav, P., & Gupta, U. (2024). Microplastic contamination, an emerging threat to the freshwater environment: a systematic review. *Environmental Systems Research*, *13*(1). https://doi.org/10.1186/s40068-024-00338-7..

Biginagwa, F., Mayoma, B., Shashoua, Y., Syberg, K., & Khan, F. (2015). First evidence of microplastics in the African Great Lakes: Recovery from Lake Victoria Nile perch and Nile tilapia. Journal of Great Lakes Research. https://doi.org/10.1016/j.jglr.2015.10.012,,

Boccia, P., Mondellini, S., Mauro, S., Zanellato, M., Parolini, M., & Sturchio, E. (2024). Potential Effects of Environmental and Occupational Exposure to Microplastics: An

Overview of Air Contamination. *Toxics*, *12*(5). https://doi.org/10.3390/toxics12050320..

Bora, S. S., Gogoi, R., Sharma, M. R., Anshu, Borah, M. P., Deka, P., Bora, J., Naorem, R. S., Das, J., & Teli, A. B. (2024). Microplastics and human health: unveiling the gut microbiome disruption and chronic disease risks. Frontiers in Cellular and Infection Microbiology, 14, 1492759. https://doi.org/10.3389/fcimb.2024.1492759..

Campisi, L., La Motta, C., & Napierska, D. (2025). Polyvinyl chloride (PVC), its additives, microplastic and human health: Unresolved and emerging issues. The Science of the Total Environment, 960, 178276. https://doi.org/10.1016/j.scitotenv.2024.178276..

Chartres, N., Cooper, C. B., Bland, G., Pelch, K. E., Gandhi, S. A., BakenRa, A., & Woodruff, T. J. (2024). Effects of Microplastic Exposure on Human Digestive, Reproductive, and Respiratory Health: A Rapid Systematic Review. Environmental Science & Technology, 58(52), 22843–22864. https://doi.org/10.1021/acs.est.3c09524..

Chen, C.-C., Dai, L., Ma, L., & Guo, R.-T. (2020). Enzymatic degradation of plant biomass and synthetic polymers. Nature Reviews. Chemistry, 4(3), 114–126. https://doi.org/10.1038/s41570-020-0163-6..

Chilote, M. O., & Dhakal, H. N. (2025). Plastic Pollution and Framework Towards Sustainable Plastic Waste Management in Nigeria: Case Study. Environments - MDPI, 12(6). https://doi.org/10.3390/environments12060209..

Comission, July, 24. https://doi.org/10.1021/acs.est.7b02368

Corp., I. B. M. (2022). *IBM SPSS Statistics (Version 29.0)*. https://www.ibm.com/products/spss-statistics

Crane, J. T., Andia Biraro, I., Fouad, T. M., Boum, Y. 2nd, & R Bangsberg, D. (2018). The "indirect costs" of underfunding foreign partners in global health research: A case study. *Global Public Health*, *13*(10), 1422–1429. https://doi.org/10.1080/17441692.2017.1372504

D'Amore, T., Smaoui, S., & Varzakas, T. (2025). Chemical Food Safety in Europe Under the Spotlight: Principles, Regulatory Framework and Roadmap for Future Directions. *Foods*, *14*(9), 1–33. https://doi.org/10.3390/foods14091628

Danielsson, M. (2017). *The plastic bag ban in Rwanda: Local procedures and successful outcomes.* *Thesis*. *January*. http://www.diva-portal.org/smash/get/diva2:1067480/FULLTEXT01.pdf

Danielsson, M. (2017). The plastic bag ban in Rwanda: Local procedures and successful outcomes. Thesis. January. http://www.diva-portal.org/smash/get/diva2:1067480/FULLTEXT01.pdf

Deng, L., Li, G., Peng, S., Wu, J., & Che, Y. (2022). Microplastics in personal care products: Exploring public intention of usage by extending the theory of planned behaviour. The Science of the Total Environment, 848, 157782. https://doi.org/10.1016/j.scitotenv.2022.157782

Denzin, N. K. (2017). *The research act: A theoretical introduction to sociological methods*. Routledge. https://doi.org/10.4324/9781315134543..

Dhaka, V., Singh, S., Anil, A. G., Sunil Kumar Naik, T. S., Garg, S., Samuel, J., Kumar, M., Ramamurthy, P. C., & Singh, J. (2022). Occurrence, toxicity and remediation of polyethylene terephthalate plastics. A review. *Environmental Chemistry Letters*, *20*(3), 1777–1800. https://doi.org/10.1007/s10311-021-01384-8

Drakvik, E., Kogevinas, M., Bergman, Å., Devouge, A., Barouki, R., Kogevinas, M., Devouge, A., Sarigiannis, D., Destoumieux-Garzón, D., Matthies-Wiesler, F., Peters, A., Zalko, D., Villanueva, C., Tonne, C., Cardis, E., Diago-Navarro, E., Antó, J. M., Foraster, M., Nieuwenhuijsen, M., … Garric, J. (2022). Priorities for research on environment, climate and health, a European perspective. *Environmental Health: A Global Access Science Source*, *21*(1). https://doi.org/10.1186/s12940-022-00848-w

Dzierżyński, E., Blicharz-Grabias, E., Komaniecka, I., Panek, R., Forma, A., Gawlik, P. J., ... & Flieger, J. (2025). Post-mortem evidence of microplastic bioaccumulation in human organs: insights from advanced imaging and spectroscopic analysis. *Archives of Toxicology*, 1-16. https://doi.org/10.1007/s00204-025-04092-2..

EMA. (2014). *Guideline on the use of phthalates as excipients in human medicinal products*. *3*(November 2014), 1–13.

European Commission. (2018). A European Strategy for Plastics. *European Comission*, *July*, 24. https://doi.org/10.1021/acs.est.7b02368

Ghosh, T. (2025). Microplastics bioaccumulation in fish: Its potential toxic effects on hematology, immune response, neurotoxicity, oxidative stress, growth, and reproductive dysfunction. *Toxicology Reports*, *14*, 101854. https://doi.org/10.1016/j.toxrep.2024.101854

Glass, T. A., Goodman, S. N., Hernán, M. A., & Samet, J. M. (2013). Causal inference in public health. Annual Review of Public Health, 34, 61–75. https://doi.org/10.1146/annurev-publhealth-031811-124606

Gobry, J. J., Bachwenkizi, H. S., Kimambo, O. N., Ngassapa, F. N., & Kilulya, K. F. (2023). Occurrence of Harmful Algal Blooms in Freshwater Sources of Mindu and Nyumba ya Mungu Dams , Tanzania. 2023. https://doi.org/10.1155/2023/5532962

Gosavi, R., Fong, K., Yap, R., Bell, S., Ooi, G., & Narasimhan, V. (2025). Microplastics and the Rising Tide of Early-Onset Colorectal Cancer: Exploring the Environmental Gut Connection. ANZ Journal of Surgery. https://doi.org/10.1111/ans.70156

Hussain, K. A., Romanova, S., Okur, I., Zhang, D., Kuebler, J., Huang, X., Wang, B., Fernandez-Ballester, L., Lu, Y., Schubert, M., & Li, Y. (2023). Assessing the Release of Microplastics and Nanoplastics from Plastic Containers and Reusable Food Pouches: Implications for Human Health. Environmental Science & Technology, 57(26), 9782–9792. https://doi.org/10.1021/acs.est.3c01942

Hwang, J., Choi, D., Han, S., Jung, S. Y., Choi, J., & Hong, J. (2020). Potential toxicity of polystyrene microplastic particles. Scientific Reports, 10(1), 7391. https://doi.org/10.1038/s41598-020-64464-9

Hyman, S., Acevedo, J., Giannarelli, C., & Trasande, L. (2025). Phthalate exposure from plastics and cardiovascular disease: global estimates of attributable mortality and years life lost. EBioMedicine, 117. https://doi.org/10.1016/j.ebiom.2025.105730

IBA. (2001). Nyumba ya Mungu Reservoir. http://datazone.birdlife.org/site/factsheet/nyumba-ya-mungu-reservoir-iba-tanzania (Accessed 14 April 2023).

Ikingura, J.R.,& Akagi, H. (2003). Total mecury and mehylmercury levels in fish from hydroelectric reservoirs in Tanzania. Science of the Total Environment, 304, 355-368.

iong, X., Wang, J., Liu, J., & Xiao, T. (2024). Microplastics and potentially toxic elements: A review of interactions, fate and bioavailability in the environment. Environmental Pollution, 340, 122754. https://doi.org/https://doi.org/10.1016/j.envpol.2023.122754

Islam, M. R., Welker, J., Salam, A., & Stone, E. A. (2022). Plastic Burning Impacts on Atmospheric Fine Particulate Matter at Urban and Rural Sites in the USA and Bangladesh. *ACS Environmental Au*, *2*(5), 409–417. https://doi.org/10.1021/acsenvironau.1c00054

Issac, M. N., & Kandasubramanian, B. (2021). Effect of microplastics in water and aquatic systems. *Environmental Science and Pollution Research*, *28*(16), 19544–19562. https://doi.org/10.1007/s11356-021-13184-2

IUCN (2003). Pangani Basin: A Situation Analysis. IUCN (international union of conser

Jaafar, N., Azfaralariff, A., Musa, S. M., Mohamed, M., Yusoff, A. H., & Lazim, A. M. (2021). Occurrence, distribution and characteristics of microplastics in gastrointestinal   tract and gills of commercial marine fish from Malaysia. The Science of the Total Environment, 799, 149457. https://doi.org/10.1016/j.scitotenv.2021.149457..

Jones, J., Karim, S. A., Faden, R., Esmonde, K., Hutler, B., Johns, M., & Barnhill, A. (2025). Under-Funded and Under-Pressure: State Epidemiologists During the COVID-19   Response. Disaster Medicine and Public Health Preparedness, 19, e110. https://doi.org/10.1017/dmp.2025.110

Käppler, A., Fischer, D., Oberbeckmann, S., Schernewski, G., Labrenz, M., Eichhorn, K.-J., & Voit, B. (2016). Analysis of environmental microplastics by vibrational microspectroscopy: FTIR, Raman or both? Analytical and Bioanalytical Chemistry, 408(29), 8377–8391. https://doi.org/10.1007/s00216-016-9956-3

Khanam, N., Wagh, V., Gaidhane, A., & Quazi, S. (2019). Knowledge, attitude and practice on uses of plastic products, their disposal and environmental pollution: A study among school-going adolescents. Journal of Datta Meghe Institute of Medical Sciences University, 14, 57. https://doi.org/10.4103/jdmimsu.jdmimsu_27_19

Kibria, M. G., Masuk, N. I., Safayet, R., Nguyen, H. Q., & Mourshed, M. (2023). Plastic Waste: Challenges and Opportunities to Mitigate Pollution and Effective Management. International Journal of Environmental Research, 17(1), 20. https://doi.org/10.1007/s41742-023-00507-z..

Kilungu, H. (2023). Not only Adventurous but also Leisure: Re-defining Tourism in Tanzanian Mount Kilimanjaro National Park. *Pan-African Journal of Business Management*, *7*(1), 91-106 https://www.ajol.info/index.php/pajbm/article/view/..

Krasucka, P., Bogusz, A., Baranowska-Wójcik, E., Czech, B., Szwajgier, D., Rek, M., Ok, Y. S., & Oleszczuk, P. (2022). Digestion of plastics using in vitro human gastrointestinal tract and their potential to adsorb emerging organic pollutants. *The Science of the Total Environment*, *843*, 157108. https://doi.org/10.1016/j.scitotenv.2022.157108..

Kumar, S. B., Pachiyappan, J. K., Chandrasekar, S., Karri, V. V. S. R., Krishnamurthy, P. T., Natarajan, J., Palaniami, T., & Kuppusamy, G. (2025). Microplastics and health hazards: gastrointestinal risk assessment across a multi-species perspective. Asian Journal of Atmospheric Environment, 19(1). https://doi.org/10.1007/s44273-025-00068-x

Kundu et al. (2021). Analysis of macro-and microplastics in riverine, riverbanks, and irrigated farms in Arusha. https://doi.org/10.1007/s00244-021-00897-1..

Lee, Y., Cho, J., Sohn, J., & Kim, C. (2023). Health Effects of Microplastic Exposures: Current Issues and Perspectives in South Korea. *Yonsei Medical Journal*, *64*(5), 301–308. https://doi.org/10.3349/ymj.2023.0048..

Leslie, H. A., van Velzen, M. J. M., Brandsma, S. H., Vethaak, A. D., Garcia-Vallejo, J. J., & Lamoree, M. H. (2022). Discovery and quantification of plastic particle pollution in human blood. Environment International, 163(December 2021), 107199. https://doi.org/10.1016/j.envint.2022.107199..

Li, W., Zu, B., Yang, Q., Huang, Y., & Li, J. (2022). Adsorption of lead and cadmium by microplastics and their desorption behavior as vectors in the gastrointestinal environment. Journal of Environmental Chemical Engineering, 10, 107379. https://doi.org/10.1016/j.jece.2022.107379..

Li, X., Bao, L., Wei, Y., Zhao, W., Wang, F., Liu, X., Su, H., & Zhang, R. (2023). Occurrence, Bioaccumulation, and Risk Assessment of Microplastics in the Aquatic Environment: A Review. *Water*, *15*, 1768. https://doi.org/10.3390/w15091768..

Li, Y., Tao, L., Wang, Q., Wang, F., Li, G., & Song, M. (2023). Potential Health Impact of Microplastics: A Review of Environmental Distribution, Human Exposure, and Toxic Effects. Environment & Health, 1(4), 249–257. https://doi.org/10.1021/envhealth.3c00052..

Liu, G., Wang, J., Wang, M., Ying, R., Li, X., Hu, Z., & Zhang, Y. (2022). Disposable plastic materials release microplastics and harmful substances in hot water. *The Science of the Total Environment*, *818*, 151685. https://doi.org/10.1016/j.scitotenv.2021.151685..

Liu, J., & Li, C. (2025). Impact of Microplastics on Aquatic Ecosystems. *Water (Switzerland)*,

17(14), 2–5. https://doi.org/10.3390/w17142124..

Lucas, A., Herrmann, S., & Lucas, M. (2022). The role of endocrine-disrupting phthalates and bisphenols in cardiometabolic   disease: the evidence is mounting. *Current Opinion in Endocrinology, Diabetes, and Obesity*, *29*(2), 87–94. https://doi.org/10.1097/MED.0000000000000712

Maione, C. (2021). Quantifying plastics waste accumulations on coastal tourism sites in Zanzibar, Tanzania. *Marine Pollution Bulletin*, *168*, 112418. https://doi.org/10.1016/j.marpolbul.2021.112418..

Makwana, B., Khadke, S., Kumar, A., Nasir, K., Wadhera, R., Shah, R., Sheth, S., Kong, Y., Navas-Acien, A., Adamkiewicz, G., Rajagopalan, S., Al-Kindi, S., Dani, S. S., Moffatt-Bruce, S., & Ganatra, S. (2025). Marine Microplastic Levels and the Prevalence of Cardiometabolic Diseases in US   Coastline Counties. Journal of the American Heart Association, 14(13), e039891. https://doi.org/10.1161/JAHA.124.039891..

Mangi, H. O., Onywere, S. M., & Kitur, E. C. (2023). *Fish Productivity Response to Water Quality Variations : A Case Study of Nyumba ya Mungu Dam , in Pangani Water Basin , Tanzania*. *2023*. https://doi.org/10.1155/2023/7353898..

Mayoma, B. S., Sørensen, C., Shashoua, Y., & Khan, F. R. (2020). Microplastics in beach sediments and cockles (Anadara antiquata) along the   Tanzanian coastline. *Bulletin of Environmental Contamination and Toxicology*, *105*(4), 513–521. https://doi.org/10.1007/s00128-020-02991-x..

Mbwilo, E., & Mahenge, F. (2022). Municipal Solid Waste Collection Services in Rapidly Growing Cities of Tanzania. *Journal of the Geographical Association of Tanzania*, *42*(1), 83–105. https://doi.org/10.56279/jgat.v42i1.219

Mcilgorm, A., & Xie, J. (2023). *The Costs of Environmental Degradation from Plastic Pollution in Selected Coastal Areas in the United Republic of Tanzania: Technical Report*. https://doi.org/10.1596/39547..

Mishra, S. K., Sanyal, T., Kundu, P., Kumar, R., Ghosh, D., Chakrabarti, G., Sikdar, N., Bhattacharya, S., Paul, S., & Das, A. (2025). Microplastics as emerging carcinogens: from environmental pollutants to oncogenic drivers. Molecular Cancer, 24(1), 248. https://doi.org/10.1186/s12943-025-02409-4..

Mtega, M., Matobola, M. J., & Kiluvya, K. F. (2023). Abundance and Distribution of Microplastics in Fish and Sediments from Coastal River Watersheds of Dar es Salaam, Tanzania Abbas, N., Hashmi, F. K., Shahbaz, H., & Bukhari, N. I. (2024). Industrial prospects on regulatory gaps and barriers in pharmaceutical exports and their counteraction: Local experiential with global implication. PLOS ONE, 19(7), e0305989. https://doi.org/10.1371/journal.pone.0305989..

Mubarak, Z., Abbas, N., Hashmi, F. K., Shahbaz, H., & Bukhari, N. I. (2024). Industrial prospects on regulatory gaps and barriers in pharmaceutical exports and their counteraction:

Local experiential with global implication. PLOS ONE, 19(7), e0305989. https://doi.org/10.1371/journal.pone.0305989..

Muncke, J., Touvier, M., Trasande, L., & Scheringer, M. (2025). Health impacts of exposure to synthetic chemicals in food. Nature Medicine, 31(5), 1431–1443. https://doi.org/10.1038/s41591-025-03697-5

Mushumbusi, C. B., Mogusu, E. O., Max, R. A. (2025). A Review on Microplastics Characteristics and Pollution in Tanzania: Mitigating Strategies and Future Perspectives. International Journal of Environmental Protection and Policy, 13(5), 109-121. https://doi.org/10.11648/j.ijepp.20251305.12..

Nations, U. (2024). The Sustainable Development Goals Report. *United Nations*, 26–27. https://unstats.un.org/sdgs/report/2021/

Nchimbi, A. A., Kosore, C. M., Oduor, N., Shilla, D. J., Shashoua, Y., Khan, F. R., & Shilla, D. A. (2022). Microplastics in marine nearshore surface waters of Dar es Salaam and Zanzibar, East Africa. Bulletin of Environmental Contamination and Toxicology, 109(6), 1037-1042. https://doi.org/10.1007/s00128-022-03620-5

Obuzor, G., & Onyedikachi, U. (2023). Chemical Leaching into Food and the Environment Poses Health Hazards (pp. 129–148). https://doi.org/10.1007/978-3-031-34963-8_14

Ohore, O. E., & Zhang, S. (2019). Endocrine disrupting effects of bisphenol A exposure and recent advances on its removal by water treatment systems. A review. Scientific African, 5, e00135. https://doi.org/https://doi.org/10.1016/j.sciaf.2019.e00135

Ojonuba, A., Ahmed, M., & Abubakar, M. (2025). Assessment of Public Awareness, Knowledge, Attitude and Perception on Microplastics Pollution in Kaduna Metropolis, Kaduna. Ghana Journal of Geography, 17, 7–14. https://doi.org/10.4314/gjg.v17i1.2..

Pahl, S., Wyles, K. J.(2017). The human dimension: how social and behavioural research methods can help address microplastics in the environment. *Analytical Methods*. 2017, 9(9), 1404-1411. http://dx.doi.org/10.1039/C6AY02647H

Pal, M. (2005). Random forest classifier for remote sensing classification. *International Journal of Remote Sensing*, *26*(1), 217–222. https://doi.org/10.1080/01431160412331269698..

Pathak, G., Nichter, M., Hardon, A., & Moyer, E. (2024). The Open Burning of Plastic Wastes is an Urgent Global Health Issue. Annals of Global Health, 90(1), 1–5. https://doi.org/10.5334/aogh.4232

Pathak, G., Nichter, M., Hardon, A., Moyer, E., Latkar, A., Simbaya, J., Pakasi, D., Taqueban, E., & Love, J. (2023). Plastic pollution and the open burning of plastic wastes. *Global Environmental Change*, *80*, 102648. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2023.102648

Prata, J. C. (2018). Airborne microplastics: Consequences to human health? *Environmental Pollution*, *234*, 115–126. https://doi.org/10.1016/j.envpol.2017.11.043

Prata, J. C., da Costa, J. P., Lopes, I., Duarte, A. C., & Rocha-Santos, T. (2020). Environmental exposure to microplastics: An overview on possible human health effects. *The Science of the Total Environment*, *702*, 134455. https://doi.org/10.1016/j.scitotenv.2019.134455

Pulusu, V. S., Chilamula, S., Holkunde, A., Gunturi, R., Vidiyala, P., & Bashetty, S. R. (2025). Microplastics and Nanoplastics: Environmental Pathways, Ecological Impacts, and Regulatory Perspectives. In *OALib* (Vol. 12, Issue 07). https://doi.org/10.4236/oalib.1113696..

Ramadan, B., Rosmalina, R., Syafrudin, s, Munawir, M., Khair, H., Rachman, I., & Matsumoto, T. (2023). Potential Risks of Open Waste Burning at the Household Level: A Case Study of Semarang, Indonesia. *Aerosol and Air Quality Research*, *23*, 1–17. https://doi.org/10.4209/aaqr.220412..

Ravindra, K., Kaur, M., & Mor, S. (2025). Impacts of microplastics on gut health: Current status and future directions. Indian Journal of Gastroenterology : Official Journal of the Indian Society of Gastroenterology. https://doi.org/10.1007/s12664-025-01744-0

Rocha-Santos, T., & Duarte, A. C. (2015). A critical overview of the analytical approaches to the occurrence, the fate and the behaviour of microplastics in the environment. *TrAC Trends in analytical chemistry*, *65*, 47-53. https://doi.org/10.1016/j.trac.2014.10.011..

Roslan, N. S., Lee, Y. Y., Ibrahim, Y. S., Anuar, S. T., Yusof, K. M. K. K., Lai, L. A., & Brentnall, T. (2024). Detection of microplastics in human tissues and organs: A scoping review. *Journal of Global Health*, *14*, 04179.https://doi.org/10.7189/jogh.14.04179..

Sarkingobir, Y., Bello, M., & Yabo, H. (2021). Harmful effects of plastics on air quality. Academia Letters. https://doi.org/10.20935/AL2967

Sharma, P., Bhagat, P., Mandal, M. B., & Singh, T. B. (2021). Assessment of Awareness Regarding Health Hazards of Plastic Chemicals and their Warning Label among a Sample Population of Varanasi City: A Cross-sectional Study. Journal of Pharmacy & Bioallied Sciences, 13(Suppl 2), S1428–S1433. https://doi.org/10.4103/jpbs.jpbs_240_21

Sheriff, S. S., Yusuf, A. A., Akiyode, O. O., Hallie, E. F., Odoma, S., Yambasu, R. A., Thompson-Williams, K., Asumana, C., Gono, S. Z., & Kamara, M. A. (2025). A comprehensive review on exposure to toxins and health risks from plastic waste: Challenges, mitigation measures, and policy interventions. Waste Management Bulletin, 3(3), 100204. https://doi.org/https://doi.org/10.1016/j.wmb.2025.100204

Shilla, D. J. (2019). Status Updates on Plastics Pollution in Aquatic Environment of Tanzania : Data Availability , Current Challenges and Future Research Needs. 45(1), 101–113.

Singh, Z., & Bhalla, S. (2017). Toxicity of Synthetic Fibres and Human Health (OPEN ACCESS). *Advance Research in Textile Engineering*, *2*, 1012–1015. https://doi.org/10.26420/advrestexteng.2017.1012

Smith, M., Love, D. C., Rochman, C. M., & Neff, R. A. (2018). Microplastics in Seafood and the Implications for Human Health. Current Environmental Health Reports, 5(3), 375–386. https://doi.org/10.1007/s40572-018-0206-z

Smith, S. (2013). Determining sample size: How to ensure you get the correct sample size. Qualtrics Online Sample. https://www.qualtrics.com/blog/determining-sample-size/

Soares, J., Miguel, I., Venâncio, C., Lopes, I., & Oliveira, M. (2021). Public views on plastic pollution: Knowledge, perceived impacts, and pro-environmental behaviours. Journal of Hazardous Materials, 412, 125227. https://doi.org/10.1016/j.jhazmat.2021.125227

Sutkar, P., Dhulap, V., Girigosavi, S., Deshmukh, S., Desai, M., & Sutkar. (2025). Microplastics in the Human Body: A Comprehensive Review of Exposure, Detection, and Health Risks. 2025. https://doi.org/10.6084/m9.figshare.28845923

Talsness, C. E., Andrade, A. J. M., Kuriyama, S. N., Taylor, J. A., & Saal, F. S. V. (2009). Components of plastic: Experimental studies in animals and relevance for human health. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 2079–2096. https://doi.org/10.1098/rstb.2008.0281..

Thornton Hampton, L. M., Bouwmeester, H., Brander, S. M., Coffin, S., Cole, M., Hermabessiere, L., Mehinto, A. C., Miller, E., Rochman, C. M., & Weisberg, S. B. (2022). Research recommendations to better understand the potential health impacts of microplastics to humans and aquatic ecosystems. Microplastics and Nanoplastics, 2(1). https://doi.org/10.1186/s43591-022-00038-y..

UNEP. (2021). From Pollution to Solution: A global assessment of marine litter and plastic pollution. United Nations Environment Programme. https://www.unep.org..

UNEP. (2025). *Plastic pollution*. https://www.unep.org/topics/chemicals-and-pollution-action/plastic-pollution

V & Singh, S. K. (2025). Microplastics in Freshwater Ecosystems: Sources, Transport and Ecotoxicological Impacts on Aquatic Life and Human Health. *Environment and Ecology*, *43*(1A), 289–295. https://doi.org/10.60151/envec/devo7788

V & Singh, S. K. (2025). Microplastics in Freshwater Ecosystems: Sources, Transport and Ecotoxicological Impacts on Aquatic Life and Human Health. Environment and Ecology, 43(1A), 289–295. https://doi.org/10.60151/envec/devo7788

Velis, C., & Cook, E. (2021). Mismanagement of Plastic Waste through Open Burning with Emphasis on the Global South: A Systematic Review of Risks to Occupational and Public Health. Environmental Science & Technology, 55. https://doi.org/10.1021/acs.est.0c08536..

WHO. (2021). Laboratory Biosafety Manual Fourth Edition and Associated Monograph. In Manual de Biossegurança Laboratorial. Quarta Edição. https://doi.org/10.37774/9789275724170..

Witczak, A., Przedpełska, L., Pokorska-Niewiada, K., & Cybulski, J. (2024). Microplastics as a Threat to Aquatic Ecosystems and Human Health. Toxics, 12. https://doi.org/10.3390/toxics12080571..

Woo, J.-H., Seo, H. J., Lee, J.-Y., Lee, I., Jeon, K., Kim, B., & Lee, K. (2023). Polypropylene nanoplastic exposure leads to lung inflammation through p38-mediated NF-κB pathway due to mitochondrial damage. Particle and Fibre Toxicology, 20(1), 2. https://doi.org/10.1186/s12989-022-00512-8..

Wright, S. L., & Kelly, F. J. (2017a). Plastic and Human Health: A Micro Issue? Environmental Science and Technology, 51(12), 6634–6647. https://doi.org/10.1021/acs.est.7b00423

Xiong, X., Wang, J., Liu, J., & Xiao, T. (2024). Microplastics and potentially toxic elements: A review of interactions, fate and bioavailability in the environment. *Environmental Pollution*, *340*, 122754. https://doi.org/https://doi.org/10.1016/j.envpol.2023.122754

https://econpapers.repec.org/RePEc:gam:jijerp:v:17:y:2020:i:5:p:1509-:d:325426

Yong, C. Q. Y., Valiyaveettil, S., & Tang, B. L. (2020). Toxicity of Microplastics and Nanoplastics in Mammalian Systems. IJERPH, 17(5), 1–24. https://econpapers.repec.org/RePEc:gam:jijerp:v:17:y:2020:i:5:p:1509-:d:325426

Yuan, Z., Nag, R., & Cummins, E. (2022). Human health concerns regarding microplastics in the aquatic environment - From marine to food systems. Science of The Total Environment, 823, 153730. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.153730..

Zahari, N. Z., Tuah, P. M., Junaidi, M. R., & Mohd Ali, S. A. (2022). Identification, abundance, and chemical characterization of macro-, meso-, and microplastics in the intertidal zone sediments of two selected beaches in Sabah, Malaysia. *Water*, *14*(10), 1600. https://doi.org/10.3390/w14101600

Zhou, G., Wang, Q., Zhang, J., Li, Q., Wang, Y., Wang, M., & Huang, X. (2020). Distribution and characteristics of microplastics in urban waters of seven cities in the Tuojiang River basin, China. *Environmental Research*, *189*, 109893. https://doi.org/10.1016/j.envres.2020.109893