International Journal of Environmental Protection and Policy
2025, Vol. 13, No. 5, pp. 109-121
https://doi.org/10.11648/j.ijepp.20251305.12

Review Article

A Review on Microplastics Characteristics and Pollution in Tanzania: Mitigating Strategies and Future Perspectives

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Abstract

Microplastics (MPs) are, so far, a global issue due to the ill effects they pose to human health and the environment at large. This study merges MPs characteristics which have been found to influence their toxicity. The study also unveils extent of MP researches in Tanzania and methodologies that were employed in the global context, showing extent of pollution, sources and factors leading to MPs pollution. On the long run, the study makes it clear that the country is not an island to the challenge posed by MP pollution: it also reveals how much the country has so far done to mitigate the problem. Eventually, the study provides a way forward, revealing inadequate awareness and enforcement gaps to be the major bottlenecks in the battle against MPs pollution. Creating public awareness on the negative side of plastics, and plastics waste management, and responsibility on how to care for the environment, as well as launching new researches, are deemed to be critical activities and right approaches towards lessening the effects of MPs pollution.

Keywords

Microplastics, Characteristics, Pollution, Terrestrial Environment, Aquatic Environment

1. Introduction

The ubiquitous dispersal of MPs in environmental systems is a human-caused problem due to inadequate management of plastic wastes mainly in terrestrial environment [1, 2]. Plastics are in high demand and when this is coupled with their refractory nature, the result is their accumulation in the environment leading to MP pollution. This is a highly demanding environmental problem currently facing our societies. The presence of plastic wastes and their fragments in different environmental systems are likely to seriously affect life forms, ecosystems, and the economy [3]. MPs, together with majority of their chemical additives, have toxic effects to organisms [4], including endocrine disruption, immunotoxicity, neurotoxicity, and reproductive toxicity [4-6, 50]. In addition, MPs are transporting vectors of persistent organic pollutants (POPs) and heavy metals, all of which are not health-friendly. Studies involving MPs (alone or together with adsorbed contaminants) on test animals, such as zebrafish (*Danio rerio*), common carp (*Cyprinus carpio*) and white shrimp (*Litopenaeus vannamei*),

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Received: 3 September 2025; **Accepted:** 23 September 2025; **Published:** 27 October 2025

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have revealed that MPs interfere with liver homeostasis and growth process, induce liver damage, and cause oxidative stress, alteration of gene expression, and immunosuppression [7-11]. Through extrapolation, similar implications observed in test animals could be said of humans if they become exposed to MPs and adsorbed contaminants. In fact, microplastics have been detected in several human tissues and organs, though direct causal relationship between health issues and MPs in human body is yet to be established [12-14, 51]. The endocrinal and reproductive effects of endocrine disrupting chemicals (i.e. MPs and adsorbed contaminants), on the body of an organism, might be a result of the chemicals' ability to mimic natural hormones, counteract their action, change their pattern of synthesis and metabolism, or adjust the expressions of specific receptors. This may lead to exaggerated, reduced or blocked response of the endocrine system Roefer [15, 16]. Oxidative stress which is defined as a disturbance in the balance between the production of reactive oxygen species (ROS) and antioxidant defenses [17], may result from interference with proteins concerned with oxygen enhancement in the body such as cytochrome oxidase and haemoglobin (oxygen-transporting protein). Additionally, if MPs disrupt the digestive system, the body may fail to acquire enough of its nutrients with various consequential malnutrition-effects in organisms. Disruption of the digestive system, for example, may lead to reduced protein production in the body; and life with limited supply of proteins such as hormones, enzymes, structural proteins, transport proteins and gene-express proteins may be at stake. However, MP toxicity to the health of an organism is influenced by a number of MP characteristics which are discussed herein.

2. Research Objectives

This review was guided by two main objectives:

1) Merging microplastic characteristics as they are presented in various empirical works and their implication to human health and the environment at large.
2) To assess the status quo of the Tanzanian environment in the context of the global challenge posed by microplastic pollution, study approach methodologies and control strategies of microplastic pollution in Tanzania.

3. Review Methodology

We made a comprehensive review of existing literature on the characteristics of microplastics, and on researches that are already done in Tanzania on the question of MPs pollution. In order to access this information, scholarly search engines and databases, namely, Google Scholar and ResearchGate, were employed. MP characteristics were accessed through the use of synonymous words or phrases like MP characteristics, MP properties, and MP behavior. Whereas we used such phrases as 'microplastics in Tanzania'; 'microplastics pollution in Tanzania'; and 'microplastics researches in Tanzania' to gather all the information relating to microplastics researches that have so far been done in the Tanzanian environment, both terrestrial and aquatic. The information obtained was then synthesized to address the main objectives of our study. Other methodologies which were employed by this study include evaluating, analyzing, comparing, substantiating and critiquing.

4. Microplastic Characteristics and Their Impact on Living Organisms

Microplastics have been extensively studied and this has helped to reveal their characteristics and effects on living organisms and the environment at large. MPs exist in two categories, namely primary and secondary MPs. The former category is directly produced from industries as commercial products including beads, those contained in cosmetics, toothpaste, and in textiles [18-20]. Secondary MPs are a result of disintegration of larger plastic items following physical, chemical, thermal or biological process, or combinations of these processes [21-24]. Usually, primary MPs are regular in shape, though are subject to degradation leading to new physical appearances and chemical changes. On the other hand, secondary MPs are usually irregular in shape [20]. The nature and overall characteristics of MPs have been found to have an influence on their toxicity, transformation and transfers. Some important MP characteristics are discussed below:

4.1. Shape and Texture

Microplastics exist in various forms, including fibers, lines, foams, films, fragments, microbeads, and pellets [25-29]. According to Marrone [26], shape is the determining factor for MPs effects on living organisms. For example, *Daucus carota* exhibited different increases in shoot mass when MPs with different shapes were supplied to it, and films had the highest increase-effect on the shoot [27]. All shapes increased plant biomass of *Daucus carota* but with different thresholds depending on type of shape. Similar results were obtained by Gray [30], when *Palaemonetes pugio* was exposed to MPs of different shapes. It was revealed that MP shape had a significant influence on the number of MP particles ingested by the test organism. Moreover, Choi [31], in their research on the effect of MP shape on *Cyprinodon variegatus*, indicated that physiological and biochemical toxicity on the organism differed according to the shape of MPs. For example, though both types accumulated in the digestive system leading to intestinal distension, irregular MPs comparatively decreased the swimming behavior of the sheepshead minnow. In addition, the reactive-oxygen-species (ROS) related molecular changes (i.e. transcriptional and enzymatic characteristics) differed between the two types of MPs. On the other hand, [32] found out that MP shape is an important adjustor of organic matter decomposition and soil aggregation. Fibers, irrespective of their chemistry, had negative effect on the formation of aggregates while other shapes were dependent on polymer identity as a co-modulating factor for soil response. As a matter of fact, the irregular shape of most MPs has a bearing on other properties of MPs including adsorption. Generally, MPs display a complex surface topology with rough surfaces and cracks as well as porosity [25, 33]. This increases MP surface area and significantly enhances the adsorbing capacity of MPs [34, 35], with the implication on the extent of MP toxicity.

4.2. Size Aspect

Characterization of MPs in several researches' studies have revealed that MPs occurs in varied sizes [36, 29, 28, 33]. The categorization of MPs by size has been a subject of ongoing research and discussion, and thus, there have been various schemes of MP classification on the basis of size. While one of such schemes aligns MP size classes with those employed in plankton research, as femto-, pico-, nano-, micro-, meso-, macro-, and mega-size plastics [44, 37]. MPs are often categorized into 3-sized groups, i.e. large MPs (1 mm to 5 mm), small MPs (1 µm to 1 mm), and nano-plastics (1 nm to 1 µm), each group with distinct characteristics and interaction with biological systems [38]. According to Pelka and Ding [39, 40], size is among the key factors that influence MP toxicology. A study by Zhang [41] indicated that MPs of only a certain size could be accumulated in the nosal cavity of *Ctenopharyngodon idella*. Furthermore, Zhang revealed the intolerance of hybrid snakehead to high concentration of small-sized MPs [41, 42]. Similarly, Schwarzers exhibited MPs toxicology to be size-dependent [43] by investing the effect of MPs size and shape on *Daphnia magna* and sub-lethal effects were observed. Size effect of MPs was also studied by Liu) on *Scenedesmus obliquus* in which big-sized MPs interfered with the photosynthetic process of microalgae by blocking sunlight, whereas small-sized MPs negatively affected the cell wall by adsorbing onto the algae surface [25]. While different sizes inhibited growth almost equally, toxic mechanism of MPs was dependent on particle size. Another example on the size effect of MPs is given by Gray and Weinstein, in their study on adult *Palaemonetes pugio*. It was observed that mortality rate increased with increasing particle size when polymer shape was kept constant [30]. It was generally hypothesized that the smaller the particle size of MP, the more the risk they pose to living organisms [45, 46]. Reduced size of MPs eases intake by aquatic organisms resulting in bioaccumulation of pollutants; hence, interference with the physiological functions of organisms. Moreover, MPs can accumulate harmful pollutants including POPs and heavy metals [23]. This becomes more intensified with decreasing size of MPs since the ratio of surface area to particle size increases with decreasing particle size. While Shamskhany indicated the effect of size on the MPs hydrodynamics in aquatic environment to be similar to natural sediments [47]. Marron revealed that small fragmentation of MPs can increase interaction with biota and food chain access [26].

4.3. Colour Aspect

MPs exist in various colors including white, transparent, yellow, brown, orange, purple, red and blue [48, 49, 25]. One of the significant effects of colour is the enhancement of biocontamination as the colour of MPs may potentially affect their ingestion by aquatic organisms, since some organisms are visual predators and are likely to ingest MPs with colors that resemble their prey [3, 22]. In addition, colour has a bearing on MPs visibility, thus, influencing their ingestion by aquatic organisms [24]. In relation to colour of MPs, studies have shown that specific colors are ingested by specific marine organisms, and fish may prey intentionally on MPs that possess specific colors [53, 22]. On the effect of MP colour on algal growth, rit was indicated that, green colored MPs exhibited the lowest inhibition effect, probably due to their resemblance to algae, whereas white MPs inhibited the algal growth significantly. They also tested MP effects on *Daphnia magna* feeding ability. The results indicated possible inability of *Daphnia magna* to distinguish colored MPs from algae. Moreover, a study on the MP colour preference by freshwater and marine fish revealed that, red, yellow, and green MPs were ingested at higher rates than gray and blue MPs for all tested fish species. Under dark conditions, ingestion of MP particles was reduced, and preferences were not observed, indicating that colour preference was related to colour vision [54]. Generally, the reviewed empirical works indicate that colour of MPs influences their toxicology in living organisms by affecting MPs visibility and ingestion. Another important finding in regard to MP color is that, different colors of plastic materials have different abilities of absorbing light energy, influencing their degradation. It was for instance observed that, under similar photo-conditions, red, blue and green plastics were degraded at a significantly higher rate than black, white and silver samples [55].

4.4. Chemical Composition

MPs occur in various polymeric types, including polyethylene (PE), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), polystyrene (PS), polyurethane (PU), polyester (PES), chlorinated polyethylene (CPE) and polyamide [34, 28, 23, 54, 50, 52, 58]. These polymers have different densities, and the commonly detected MPs, PP and PE, are least dense in comparison to other polymers, contributing almost 71% of floating MPs in ocean water. The least dense MPs such as PE and PP will affect surfaces of aquatic systems whereas polymers with high densities are likely to affect benthic organisms [23]. The fact that polymers differ in terms of density determines each polymer's dynamics, distribution and availability in aquatic systems and the effect they will cause to aquatic organisms. Polymer type has been cited by numerous studies as one of the key properties to consider when studying MPs effects on organisms and ecosystems [27, 43]. A study by Brehm revealed polymer type and chemical content specific effects of MPs on freshwater mussel (*Dreissena bugensis*). In their findings, recycled PET provoked the strongest negative effects to the test organism, likely attributed to anthranilamide, anthranilonitrile and butylated hydroxytoluene, contained in the fragments, which are toxic to aquatic life [59].

4.5. Sorption and Leaching

MPs have ability to adsorb and concentrate micro-organic pollutants and heavy metals. In so doing, MPs act as temporary sinks and vectors of pollutants into aquatic systems [35, 23, 60, 28, 33]. MP shape and roughness largely influence the adsorption capacity and sinking velocity of MPs because the two aspects have a bearing on surface area [57, 61, 60]. Studies have also revealed that adsorption capacity increases with aging of MPs due to increased surface area and formation of new functional groups. In short, the physicochemical properties of MPs, their complex surfaces and van der Waals forces significantly enhance their adsorbing capacity [60, 35]. On the other hand, MPs can desorb micropollutants and leach out their additives [62, 63, 60]. If this happens in aquatic organisms, it may enhance ecological disruption and health risks due to bio-transfer and intra-translocation of the additives, POPs and heavy metals in addition to MPs. In a simulated gastrointestinal environment, it was indicated that the desorption rates of two metal ions (Pb^{2+} and Cd^{2+}) on MPs were controlled by the MP particle size, suggesting a potential toxicological risk to organisms upon ingestion of MPs contaminated with adsorbed metals [60].

4.6. Partitioning and Translocation

Due to their low polarity and hydrophobicity, MPs partition in aqueous environment [64]. They interact with co-occurring hydrophobic organic contaminants (HOCs) as well as heavy metals via sorption-desorption processes in aquatic and terrestrial environments. Ingestion of MPs by living organisms may increase exposure to HOC levels. The key mechanisms for the sorption of HOCs onto MPs include hydrophobic interaction, electrostatic interaction, hydrogen bonding, and van der Waals forces [65]. It has further been shown that partitioning of contaminants to MPs is generally higher in soil than in aquatic environments [64]. Studies have also revealed that MPs, upon ingestion by organisms, and due to their small size, can translocate into different tissues and organs including the life-sustaining organs such a liver, kidney, spleen and the brain [66, 40]. This translocation of MPs, in turn, foretells the extent of toxicological translocation in the body of an organism given the adverse effects of MPs and adsorbed contaminants. A study by, in a test experiment with Mussels (*Mytilus edulis*), demonstrated that MPs could translocate into the circulatory and affect other tissues [18, 67-69]. The e immune system, reproductive system, nervous system, endocrine system and digestive system are some of the human systems at risk following entry of MPs into the organism's body [6].

5. Microplastics in Tanzania's Environment

Tanzania mainland aquatic environment covers almost 61,000 km^2, contributing almost 6.5% of the country's total surface area. This area is mostly covered by lakes with the major three lakes; Victoria, Tanganyika and Nyasa, contributing 88% to this area. Other major water bodies include, Kitangiri, Natron, Eyasi and Manyara with numerous other smaller lakes scattered throughout the country [70, 71]. The country crisscrossed by numerous large livers systems, with some originating from or drain into lakes, and some empty into the Indian Ocean. On the other hand, the country's coastline aquatic area is 1,424 km long extending from the border with Kenya to that with Mozambique. Eastwardly, it extends to engulf several islands including Pemba and Unguja (together known as Zanzibar), and Mafia (Figure 1).

Numerous studies have been conducted on MPs pollution in Tanzania, as summarized in Table 1. All of the referenced studies were targeted on the aquatic environment with one study having a terrestrial component [74]. the study with a terrestrial component used both water and sediment samples obtained respectively from a riverine and irrigation farms watered by the same town river. Two of these studies focused on Lake Victoria [75, 76], while two studies had rivers systems as their area of focus [74, 77]. Most of the MPs studies were done along the Tanzania's coastline including Zanzibar. Reported researches imply that the rest of the Tanzania's aquatic environment and almost the whole of terrestrial environment remains unresearched on the question of MPs pollution. This concurs with the observation made by Shilla on the extent of MPs researches in Tanzania [78]. Since lakes and rivers are sources of fish and water for human consumption, and rivers being exceptional carriers and transports of plastic debris downstream [74, 79], studying them on the aspect of MPs pollution is critical. An overview indicates that all MP studies (involving samples of water, sediments, soils and biota) in Tanzania were positive, and the identified polymer types agree with those identified and characterized by research works in other countries, including the most common MPs, namely PE, PP and PS [28, 80]. These common MPs are probably produced from the most widely produced plastics globally including bags, bottles and containers Based on these findings, the implication is that the Tanzanian environment is not immune to MPs pollution and to its entailed adverse effects to human health and the environment. It is further revealed by most of the studies, that the extent of pollution in the studied environment correlated with the intensity of socio-economic activities including industry, recreation, fishing, shipping, tourism, residence and vicinity to the source of plastic wastes, in addition to poor waste management [81-86, 78, 76]. The association between the extent of plastic pollution in aquatic environment and nearness to terrestrial environment means that, majority of plastic pollution in aquatic environment of Tanzania is terrestrial in origin, coinciding with the association observed in other parts on the globe [87, 56, 29]. Another note is that, the occurrence of MPs in sediments, water and biota drawn from the same locality is a hint of MPs dynamics between the three components. An example is a study by Ngupula which determined the vertical distribution of solid wastes in the water of Lake Victoria. In this study, plastic debris (multifilament-44% and monofilament-42%) was identified to be the major component of the trapped wastes, and was found at all depths and in all sampling locations, mainly originating from fishing activities [81]. The same plastic types of MPs size were later identified in the intestinal tracts of Nile perch and Nile tilapia obtained from the same lake [75], confirming both transfer of MPs from aquatic environment into aquatic biota, and human involvement in the problem of environmental pollution. The poor plastic waste management presented by majority of the MPs researches as one of the factors of environmental plastic pollution in Tanzania, signifies inadequate awareness on the adverse effects posed by plastic pollution [78]. Thus, it demands studies on knowledge, attitudes and practices with respect to plastic use, management and effects, as proposed by some authors [88, 89]. Moreover, these studies already done in Tanzania highlight the presence and diversity of MPs pollution in Tanzania's aquatic environments, underscoring the need for continued research and effective waste management strategies to mitigate this emerging environmental concern. The cost assessment research by Mcllgorm and Xie on the issue of environment degradation by plastic pollution, displays negative impacts on ecosystems, public health and local economies, thus, calling for interdisciplinary and collaborative efforts to lessen MP pollution in the Tanzanian environment [90].

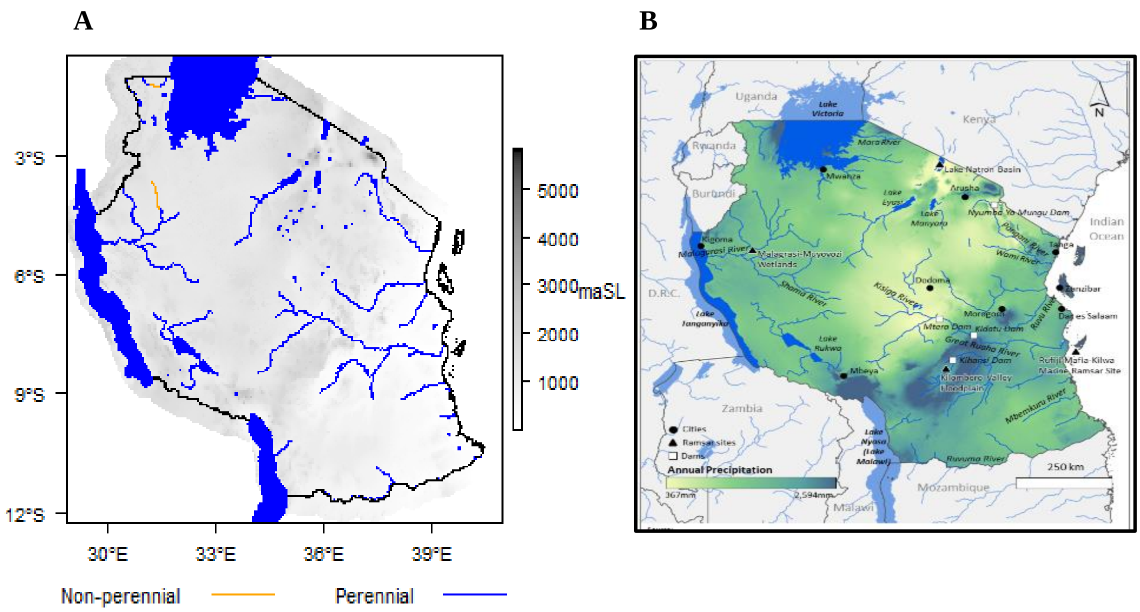

Figure 1. *Map of Tanzania showing; (A) Country's hydrology and (B) Country's water resources profile [72, 73].*

Table 1. *Microplastic researches, results and possible sources of pollution in Tanzania.*

S/N	Study area	Study main focus	Study main finding	Source of pollution	Reference
1	Lake Victoria	Vertical distribution of solid wastes in water	Plastic debris in all samples	Fishing activities	[75]
2	Lake Victoria	MPs in Fish	MPs in some sample fish (PE, PE-PP copolymer, polyester	Urban wastes and consumer use	[75]
3	Coast of Zanzibar	MPs along coast of Zanzibar	MPs in samples, fragments and fibers were dominant	Local waste disposal practices, Local social economic activities; shipping and form other countries,	[82]

S/N	Study area	Study main focus	Study main finding	Source of pollution	Reference
4	Tanzanian coastal waters	Threats of MPs pollution to marine ecosystem	MPs in sample sediments and cockles, fragments, fibers and pellets (PE)	Socio-economic activities around the coastal area	[85]
5	Northern Lake Victoria	MPs pollution in surface water	MPs in surface water samples PE, PP, fragments,	Plastic material utilized by the community and poor management of plastic wastes	[76]
6	Zanzibar's coastal tourism sites	Plastic wastes in coastal tourism sites	Plastics wastes in sample tourist sites	Tourism activities & poor waste management	[83]
7	Arusha-Tanzania	Macro-and microplastics in riverine, riverbanks, and irrigated farms	MPs in water and sediment samples; PE and PS	Mismanagement of plastics that end up in Urban rivers.	[74]
8	Dar es Salaam and Zanzibar coasts	MPs in marine nearshore surface water	MPs in surface water samples, fragments, fibers, white and blue, PP and LDPE and HDPE	Proximity to industrial areas, poor waste management, and high population pressure	[86]
9	Dar es Salaam and Zanzibar coasts	MPs in marine beach and seabed sediments	MPs in sample sediments (PE and PS), fragments and fibers	Anthropogenic activities and unmanaged litter	[86]
10	Dar es Salaam and Zanzibar coasts	MPs in nearshore water	MPs in sample water (PP and PE)	Industrial activities, poor waste management & population pressure	[85]
11	Tanzania mainland& coastlines	MPs in surface water, sediments and biota	MPs in samples (e.g. PP, PE and natural types),	Socio-economic activities, including industrial	[84]
12	Coastal river watersheds, Dar es Salaam	MPs distribution in fish and sediments	MPs in samples, several MP types: PE, PP, PU, PVC, fragments, fibers, sponges	Mismanagement of plastic wastes, illegal dumping	[91]
13	Dar es Salaam coast	PMs in marine sediments	MPs in sample sediments (e.g. PP and PE)	Anthropogenic activities including industrial and recreational	[77]
14	Kenyan and Tanzanian coast	Microfibers in coastal water	Plastic microfibers in samples	Industrial activities and mismanagement	[92]

6. Microplastic Study Approaches in Tanzania

Microplastic sampling techniques: MP sampling techniques for a given study are usually determined by a number of factors including: study objectives [93], sample type [94, 95], hydrodynamic and environmental conditions [96, 93, 97], and resource availability [93]. Correlating MPs concentration with anthropogenic activities and MPs dynamics between different samples, there are two main factors that have influence the sampling techniques for most MP researches in Tanzania. For instance, in order to correlate MPs concentrations with the extent of anthropogenic activities, samples were drawn from different localities which differed in intensity of human activities [76, 85, 91]. On the other hand, when the main objective was to study the dynamics of MPs within an aquatic system, different samples were drawn from the same locality [85, 86]. However, when the study within focus is the detection and identification of MPs, then sampling was random rather than purposive [75]. Furthermore, types of samples appear to have an influence on the choice of the sampling instruments. Thus, use of stainless-steel containers and manta trawls for water samples [84, 85]; Ekman grab for sampling sediments [86, 91]; whereas and collection of fish and cockles was from fisheries and aquatic sites [75, 85]. Not using more advanced samplers like neuston nets, Niskin bottles of varying mesh size, Van Veen grabs and box corers, which are employed in other parts of the globe, could be attributed to the challenge of resource availability.

Microplastic extraction and separation techniques: Extracting and separating MPs from environmental samples is a critical step in assessing their presence and impact. Due to their small size and diverse composition, specialized techniques are always used to isolate MPs from complex matrices such as water, sediment and biological samples. Such methods typically involve physical and chemical processes to remove whatever debris which is not plastic at the same time ensuring the integrity of MPs. In Tanzania, filtration method was employed to extract MPs from water samples, and this was either done in situ using manta trawls (e.g. or ex situ with glass fiber filters (e.g. In addition, the method was also used for biota samples after digestion and density separation [76, 84]. For sediment samples, density separation was used by employing NaCl solution of about 6M/1.2g cm^{-3} [72, 86, 84]. Chemical digestion was used for biota samples by using 1M NaOH (for soft organic tissues) or 10% KOH (for tough organic tissues) at an appropriate temperature and duration [84, 85]. For more advanced density separation, $ZnCl_2$ or NaI solutions are used to accommodate higher density MPs like PET and PVC [95]. However, $ZnCl_2$ is environmentally toxic and comparatively costly. Additionally, advanced practices will prefer use of enzymatic digestion for minimal polymer degradation, particularly for biota samples [19]; and automated filtration systems and clean-air facilities to reduce contamination risks [98].

MPs identification and characterization: Understanding Microplastic forms, composition, and sources, is crucial for effective mitigation. In Tanzania, where plastic pollution is a growing concern, identifying and characterizing MPs is essential for addressing their impact and informing policy decisions. Various analytical methods are used globally to detect, quantify, and classify microplastics, each with its advantages and limitations. For polymer identification, characterization and confirmation, methods including microscopy, spectroscopy, and thermogravimetry, were used in Tanzania. Microscopy was used to visualize colour, shape, texture and size, and to provide better contrast. Hence, the use of different types of microscopy, namely stereomicroscopy [74, 77, 86, 52]. Spectroscopy was employed to identify and confirm polymer types by: detecting the functional groups, hence, the use of FTIR [77-86], and the shifts of vibrational energy in MPs via Raman spectroscopy [86]. Thermogravimetric analysis (TGA) was used to identify polymers based on degradation temperatures [74]. As for polymer type identification and confirmation, Raman spectroscopy is said to outdo others [99]. However, this method it is not without cost implications; hence, the least employed in Tanzania's research attempts. It is worth noting that not all MP samples were analyzed in Tanzania [77-86]. Reasons could include resource availability for high accuracy, expertise and calibration standards, and for collaboration with international institutions.

7. Control Strategies and Legislations Against Microplastic Pollution in Tanzania

As already pointed out, MPs pollution has become a significant environmental challenge, impacting ecosystems, human health, and economies. In Tanzania, rapid urbanization, inadequate waste management and increasing plastic consumption contribute to the growing issue of microplastic contamination. Addressing this challenge requires effective control strategies and regulatory measures to mitigate its impacts and promote sustainable environmental management. Given the ecological and socio-economic threats posed by MPs pollution, it is essential to implement effective control strategies and strengthen legislative frameworks to mitigate its impact. This part explores strategies and legal measures available for Tanzania towards managing and reducing MP pollution.

International frameworks: Tanzania, as a member of international community at the global and regional levels, has helpful frameworks in its battle against plastic pollution. The country is thus obliged to comply with various environmental protection regulations and agreements aiming at mitigating plastic pollution some of the agreements are discussed here below.

1) *The Basel Convention*: and its amendments is meant to control transboundary movements of hazardous wastes and their disposal [93]. The convention's Plastic Waste Amendments strengthen the control of global trade in plastic waste whereby prior informed consent for export and import of certain plastic wastes is required. By this Convention, Tanzania should ensure environmentally friendly plastic waste management and prevent illegal trafficking.
2) *The Stockholm Convention* on Persistent Organic Pollutants [94], targets hazardous chemicals, including MPs and plastic additives; and thus, requiring Tanzania to phase out or regulate the employment of hazardous chemicals in plastics to reduce environment and health risks.
3) *The International Convention for the Prevention of Pollution from Ships, the MARPOL Annex* [95], prohibits the disposal of plastics and MPs from ships into the sea. Thus, it requires Tanzania, as a coastal nation, to enforce regulations that prevent plastic waste dumping from vessels in its territorial waters.
4) *The United Nations Environment Assembly* (UNEA) Resolutions on Plastic Pollution [96] demands member countries like Tanzania to adopt domestic policies in line with the treaty's goals, including the reduction of plastic production and waste.
5) *The Convention on Biological Diversity* (CBDon Marine and Terrestrial Plastic Pollution [97] wants member countries to address the impacts of plastic pollution on biodiversity, particularly in marine and freshwater ecosystems, whereby the measures include conservation strategies, pollution control, and sustainable waste management. Tanzania as a member country is oblige to comply to this convention.
6) *The African Union* (AU), through its Bamako Convention demands member countries to ban Hazardous Waste Import in Africa. The countries are also prohibited from

allowing import of hazardous waste, including plastics containing hazardous additives [98]. They must ensure that no illegal plastic waste enters their countries.

7) *The African Ministerial Conference on the Environment* (AMCEN) [99]: Declaration on Plastic Pollution, and thus, has to align with African Union's action plan of phasing out single-use plastics.

National Frameworks:

8) *The Tanzanian government Ban* of single-use plastic bags [100] directly addresses the challenge posed by plastic pollution, and these agreements and acts are further boosted by other control strategies including '*Extended Producer Responsibility'* (EPR) particularly to companies and industries (to manage plastic waste effectively and promote recycling), waste segregation and recycling, another one others are are community engagement, and public awareness campaigns via governmental and non-governmental organizations. For example, projects. The campaign '*Clean Shores of Great Lakes*' focuses on reducing plastic pollution along Tanzanian shorelines. Disciplinary measures like fines and imprisonment for violators are meant to build environmental responsibility in every individual. Furthermore, there have been follow-up endeavors to reinforce agreements and bans. For instance, the enforcement of the ban against single-use plastic bags in 2023 was due to a resurgence in the use of the prohibited bags. *Environmental Management Act* by the (United Republic of Tanzania though not specifically addressing the issue of plastics, however its demands insist on environmental protection and conservation against pollution of whatever kind, including plastics also demands environmental impact assessments (EIAs). The government also emphasizes the importance of public awareness on environmental protection and conservation. [101].

Despite all these endeavors by the Government, majority of the MP researches in Tanzania (Table 1) suggest anthropogenic activities and inadequate waste management to be the main sources of MP pollution in the ountry. This information, in turn, implies limited public awareness on their individual responsibility to care for the environment, and enforcement gaps on the part of the Government. It means those guiding principles should be so translated at the national context. That is why the country is investing in creation of awareness among her citizens, making follow ups, putting to action penalties, and laying down laws and regulations, providing bans as well as involving interested NGOs to mitigate the general problem of environmental pollution including MP pollution. Nevertheless, plastic pollution in Tanzania, has it has been excavated by this review as the main source of MPs hasn't been solved, indicating, poor realization of the available guiding principles meant to mitigate MPs pollution. It thus, demands governmental organs to re-sit around the table with stake holders in order to address the problem effectively. Poor realization foretells poor strategies for mitigating Plastic pollution in the country.

8. Implications of MP Characteristics to Tanzania

The review on microplastic characteristics and their implications globally provides the platform to discuss what is taking place in Tanzanian. Tanzania researches support global findings in other parts of the world that MP pollution is a reality. Furthermore, positive results on microplastic pollution in Tanzania is an indication that, Tanzania is now face-to face with that reality and its implications as presented globally, particularly health issues. Tanzania being a third World country, with still limited infrastructure and resources to manage high use of plastics and the implicated plastic wastes. When this is coupled with low awareness about plastic waste management and safe use and its adverse effects, then for Tanzanians, the pending danger posed by microplastic pollution should be viewed with a rather different pair of spectacles in terms of its magnitude, thus demanding collaborative efforts within the country and with other interested stakeholders towards mitigating the adverse effects of MP pollution at local level. It has also been shown in Tanzania, like in other parts of the world that humans are at the same time the source and victims of MP pollution. Thus, for Tanzanians, the fight against plastic pollution is a shared responsibility. Additionally, microplastic pollution in Tanzania should help to provide explanation to various health issues currently facing our country, at least by extrapolation based on data that has been secured from test animals. We also learn from this review, that majority of MP researches done in Tanzania were along the coastline and Zanzibar. This might be due to various anthropogenic activities undertaken along the coast zone including tourism, recreation and fishing, as well as industrial activities. Probably researchers' objectives might have influenced this scenario, most researchers might be were interested in correlating MP concentration with human interaction. Another note is that none of the Tanzanian researches on microplastic pollution had a causal-effect dimension. All of them were devoted to detection and characterization of MPs in biota, sediment, and water samples. This demands a shift in approach in order to contribute to causa-effect explanation of various health issues in the country.

9. Conclusions and Recommendations

MPs characteristics have negative implications to human health and to the environment at large. Based on MPs researches done in Tanzania, the Country is not immune to MPs pollution and most of her environment, is unresearched on the question of MPs pollution. At the same time and in a special way the aquatic environment is the source of human consumables, including fish and water. Lack of serious involvement in researches involving determining MPs pollution indirectly suggests both little interest and knowledge about the extent of danger posed by MPs pollution particularly to human health. by the fact that plastic pollution is existent in Tanzania. it means that Tanzania's strategies to mitigate MP pollution have gaps in enforcement, advocacy, and information. Therefore, creating public awareness on the characteristics, and on the negative effects of MP pollution which is largely recommended. Because MPs pollution is a result of poor waste management and inadequate knowledge about the negative effects ensuing from the danger posed by of MPs pollution. This demands mutual responsibility for environmental protection and conservation. Thus, public awareness is highly recommended. Enforcement of laws and regulations meant to control MPs pollution should be intensified as well as developing new ones. Furthermore, not using some advanced technologies in the study of MPs pollution suggests limited resource availability and this stands as a take-home assignment for the government and research centers. We highly call upon further researches on the question of MPs pollution and this should be encouraged by efficient resource availability.

Abbreviations

MPs	Microplastics
POPs	Persistent Organic Pollutants
HOCs	Hydrophobic Organic Contaminants
FTIR	Fourier Transform Infrared Spectroscopy
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene

Acknowledgments

We acknowledge all the sources of information which we accessed in order to address the objectives of our study.

Author Contributions

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Funding

This work is not supported by any external funding.

Conflicts of Interest

We declare to have no any conflicts of interest.

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