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Status Updates on Plastics Pollution in Aquatic Environment of Tanzania: Data Availability, Current Challenges and Future Research Needs

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Abstract

Plastics are the most useful materials invented by man, and have brought great convenience to our daily lives but not without problems. Inappropriate disposal of wasted plastics has caused serious environmental problems. Over the past decade, microplastic debris in both marine and freshwater systems have become an emerging issue. A literature review was conducted to summarize the current state of knowledge of plastic pollution in Tanzanian aquatic systems. Although, Tanzania has vast coastlines and world's largest freshwater lakes, the extent of microplastics presence in the aquatic environment remains largely unreported. Data from volunteer beach cleanups in Dar es Salaam areas show that typically more than 70% of anthropogenic litter along the beaches is comprised of plastics. In the only study to date to describe microplastic pollution in the African Great Lakes, a variety of polymers, including polyethylene, polypropylene and silicone rubber, were identified from the gastrointestinal tracts of Nile perch and Nile tilapia fished from Mwanza Gulf, Lake Victoria, in Tanzania. Due to human pressures, increased urbanization, coupled with general inadequate awareness, the potential for microplastic pollution is high. Mitigation of the effects of this pollution requires efforts from various interested stakeholders, including the local communities.

Keywords Plastics, pollution, aquatic environment, Tanzania

Introduction

An overview of plastics as contaminants of emerging concern

Plastic in aquatic environment, and more specifically microplastics (particles < 5 mm), has been gaining global attention as a pervasive and preventable threat to the health of aquatic ecosystems (Sedlak et al. 2017). There is an increased interest to understand the impacts of microplastics on aquatic wildlife, as the impacts still remain poorly understood (Thompson et al. 2004, Browne et al. 2007). Microplastics were first noted as spherules in plankton tows in North America along the coast of New England in the 1970s (Carpenter et al. 1972). Since then, microplastics have been found in most large water bodies (oceans, seas, lakes, and rivers). The global production of plastics increased from 1.5 million tons/year in the 1950's to 250 million tons/ year in 2011, and the production increases by 10% annually (Claessens et al. 2011). The post-consumer plastic waste has been recorded as "plastic debris" in habitats from poles to the equator over the last 40 years (Thompson et al. 2004). The stability and persistence of plastics, combined with their rising production and low rates of recovery (US EPA 2014), are likely causing a net accumulation of plastic debris along beaches, in surface waters, throughout the water column, and in bottom sediments (Ryan and Moloney 1990, Barnes et al. 2009). Aquatic systems are said to be the sinks for pre- and post-consumer plastic and there are complex negative impacts of plastic pollution on wildlife (Derraik 2002, and reviewed in Cole et al. 2011). Although these contaminants have been well studied in other parts of the world, there is scarce data on plastics pollution in aquatic environments in Africa, including Tanzania (Khan et al. 2018). The lack of adequate and sound research data to guide effective decision-making, policy interventions and formulation for effective environmental management has been a very glaring constraint in many developing countries such as Tanzania.

Plastics pollutants are variably categorized according to size, origin, shape, and composition. While there are no internationally agreed upon size classes, microplastic generally refers to plastic particles smaller than 5 mm (Arthur et al. 2009), and often restricted to particles larger than 333 μm because in most open-water studies it has been a common practice to use the mesh size of the neuston nets (333 μm or 0.33 mm) to collect the samples (Arthur et al. 2009, Barnes et al. 2009, Andrady 2011). Microplastics exhibit a wide range of shapes; in addition to recognizable plastic objects, the most common shapes are fragments, films, pellets, lines, fibers, filaments, and granules. They are generally divided into categories of either primary or secondary microplastics (Arthur et al. 2009). Primary microplastics consist of manufactured raw plastic material, such as virgin plastic pellets, scrubbers, and microbeads (Browne et al. 2007, Arthur et al. 2009) that enter the ocean via runoff from land (Andrady 2011). Compared to this deliberate use, secondary microplastics are formed from the disintegration of larger plastic items. Disintegration could be through mechanical, photo (oxidative) and/ or biological degradation (Thompson et al. 2004, Browne et al. 2007, Cooper and Corcoran 2010, Andrady 2011), which break the larger pieces into increasingly smaller plastic fragments which ultimately become undetectable to the naked eye.

There are many uses for plastics (Table 1), and microplastics. For example, microplastic beads are used in personal care products such as exfoliants in face scrubs. They are also used to deliver drugs in some medical applications (Browne et al. 2007). Further, fibers that shed from synthetic clothing and rope are microplastics (Thompson et al. 2004, Browne et al. 2007), as are particles used in "media blasting" processes to clean boat hulls and large machinery (Browne et al. 2007). Many of these microplastics, microbeads, and fibers are small enough to pass through wastewater treatment plants and enter a watershed (Browne et al. 2007).

Microplastics are chemically and physically diverse contaminants. Their compositions refer to the polymer types, which in turn determine the density of microplastics (Table 1). Plastic materials are made up of a broad range of polymers including polyethylene (PE), polypropylene (PP), polystyrene (PS), polyamide (nylon), polyethylene terephthalate (PET or polyester), polyacrylonitrile (PAN or acrylic), polyvinyl chloride (PVC), and styrene butadiene rubber (e.g., vehicle tires) (Hidalgo- Ruz et al. 2012). Cellulose acetate (i.e., rayon), a non-plastic polymer, is also commonly observed (Andrady 2011). Many of these polymers have significant levels of chemical additives, including flame retardants, plasticizers, and dyes. The transport of microplastic particles through different environmental matrices depends on chemical properties. For example, polypropylene and polyethylene are positively buoyant, and float on the surface of the water; polyvinylchloride, polystyrene, polyester and polyamide are high density plastics that are negatively buoyant, likely to sink to the sediment (Anderson et al. 2016).

Table 1: Types, densities and common uses of plastics that have been identified in other studies, compiled from Lechner et al. (2014)

Plastic type	Abbreviation	Density	Common uses
Expanded polystyrene	EPS	0.01-0.04	Foam cups, plates, trays
Polypropylene	PP	0.85-0.92	Auto parts, food containers, dishware, bottle caps, straws
Low-density polyethylene	LDPE	0.89-0.93	Container lids, squeeze bottles, tubing, diapers, shotgun shells
High-density polyethylene	HDPE	0.94-0.98	Detergent cleaner bottles, milk jugs, grocery bags, recycling bins
Acrylonitrile-butadiene-styrene	ABS	1.04-1.06	Electronic equipment casing, pipes
Polystyrene	PS	1.04-1.08	Plates, cutlery, optical disk cases, toys
Polyamide (nylon)	PA	1.13-1.16	Toothbrush bristles, fishing line and nets, rope
Polycarbonate	PC	1.20-1.22	Optical disks
Cellulose acetate	CA	1.3	Cigarette filters
Polyethylene terephthalate (polyester)	PET	1.38-1.41	Textiles, soft drink and water bottles, strapping
Polyvinyl chloride	PVC	1.38-1.41	Pipes, shower curtains, flooring, plastic wrap, tampon applicators

Plastic pollution can have wide-ranging ecological and economic impacts in both marine and freshwater environments. Widely recognized problems are associated with entanglement, ingestion, suffocation and general debilitation often leading to death and/or strandings (Gregory 2009, Boerger et al. 2010). Ingestion of plastic may also cause internal bleeding, abrasion and ulcers, as well as blockage of the digestive tract (Wright et al. 2013). Entanglement of seabirds and marine mammals in large plastic litter (nets, ropes, etc.) has been known since the early 1970s (Derraik 2002). Similarly, ingestion of microplastics by fishes and seabirds is well known since about the same time period (Kenyon and Kridler 1969, Carpenter et al. 1972, Ryan 1987), and the number of affected species, such as seabirds (Wilcox et al. 2016), is continuously increasing. Microplastics act as carriers for contaminants, including persistent organic pollutants (POPs) and heavy metals (Mato et al. 2001, Rios et al. 2010, Zarfl and Matthies 2010, Ashton et al. 2010, Holmes et al. 2012). They have been identified as artificial substrates which could affect ecological processes and facilitate transportation of invasive species (Barnes et al. 2009, Gregory 2009). Thus, representing a unique medium for pollutants and organic matter to adsorb, interact and transported in water bodies. A range of additives e.g., plasticizers and stabilizers, are added to enhance the properties and performance of plastics (Thompson et al. 2009), and leach out into the environment during degradation. Some plastic additives and chemicals like bisphenol A (BPA), are proven mutagens and carcinogens (Seachrist et al. 2016 and references therein). It has also been shown that these substances can disrupt endocrine functions and cause harmful reproductive and developmental effects in aquatic animals (Meeker et al. 2009).

In addition to microplastics having potential effects regarding ecosystem changes and on human health, the aesthetics of beaches, shorelines, coasts, sea floors and life of coral reefs have been jeopardized (Sheavly and Register 2007). Accumulation of plastic debris in coastal areas can discourage recreational usage, pose a hazard to swimmers and divers, and cause risks such as cuts or abrasion injuries to beach-goers (Sheavly and Register 2007).

Problem and current state

It is widely understood that we are in the new geological era, the Anthropocene (Crutzen 2002, Steffen et al. 2007), defined by human actions which have dramatically caused changes to the environment (Zalasiewicz et al. 2011). These changes include climate change, ocean acidification, deforestation, and plastic pollution. Plastics pollution mark the new anthropogenic age, because of their wide use in the last 60 years (Hopewell et al. 2009), and are now found ubiquitously in both fresh and marine water bodies (Derraik 2002 and references therein, Cole et al. 2011, Ivar do Sul and Costa 2014, Van Cauwenberghe et al. 2015). It has been estimated that 275 million metric tons of plastic wastes were generated in 2010 by 192 coastal countries - including Tanzania, and about 4.8–12.7 million metric tons are estimated to end up in the ocean (Jambeck et al. 2015). The prediction that, without improvements of waste management infrastructures, the cumulative quantity of plastic waste available to enter the ocean from land would increase by an order of magnitude by 2025 (Jambeck et al. 2015) is raising concern especially for developing countries where there is a rapid urbanization with weak infrastructural capacity for waste management. Although Tanzania is not among the top 20 countries ranked by mass of mismanaged plastic waste and percent increase in coastal population (Jambeck et al. 2015), the projected trends in population growth, urbanization and increased waste generation would likely increase the mass of plastic wastes in aquatic environment.

Plastic production in Tanzania is minimal compared to other parts of the world, and especially the developed ones (PlasticsEurope 2018); however, there is a growing demand in wide variety of plastic goods and machinery. These materials are used in a wide range of markets, including packaging, building and construction, automotive, electrical and electronic, agriculture, consumer and household appliance, etc. polypropylene (PP), polyethylene (PE), and polyvinyl chloride (PVC) are the most-used polymer types. Numerous studies in Europe and North America have reported plastic debris in marine and freshwater ecosystems (e.g., Moore et al. 2001, Law et al. 2010, Cole et al. 2011, Eriksen et al. 2013, Cózar et al. 2014). However, there is scarcity of data for plastic pollution in aquatic environment in Africa, including Tanzania (Khan et al. 2018). Tanzania is endowed with some of the most famous and notable water bodies in the world. The country lies in the area between Great Lakes (Victoria, Tanganyika and Malawi) and the Indian Ocean (Figure 1). Each of these water bodies and coastlines, identified in Figure 1, supports significantly sized populations (Table 2). With a population growth rate of about 8% per year (Dar es Salaam) and around 2.8% for other urban centers, the cities are one of the fastest-growing in sub-Saharan Africa (WHO 2003). Certainly, the pace of increase has put unprecedented pressure on already overburdened resources and services, including the management of solid wastes. Consequently, much of solid wastes end up in landfills and/or illegally dumped in water ways. In proximity to coastal and fresh water ecosystems, plastic wastes can potentially enter the aquatic environment where subsequent degradation can form microplastics. This paper aims at: (1) reviewing the current state of knowledge on plastic pollution in aquatic systems of Tanzania (2) identifying knowledge gaps (3) analyzing current challenges and suggest future research directions. Comparison with data from other regions worldwide will also be presented.

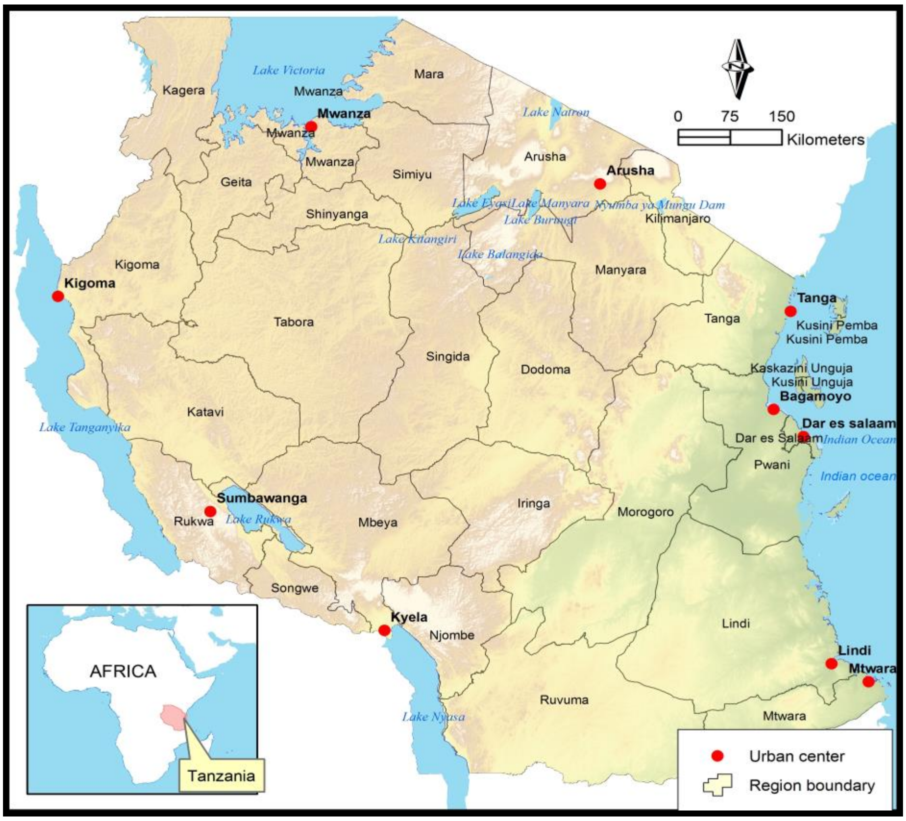

Figure 1: The map of Tanzania. Red dots indicate urban centers (with population > 0.2 million, except Kyela) in proximity to water bodies.

Table 2: Tanzania major water bodies and coastal lines and their neighboring urban centers with estimated populations

S/N	Water body/Coastline	Urban centers	Estimated Population size (million)
1	Dar es Salaam coastline	Dar es Salaam city	4.5
2	Tanga coastline	Tanga City	2.5
3	Pwani coastline[a]	Rufiji	0.22
		Mkuranga	0.25
		Bagamoyo	0.35
4	Lindi coastline[a]	Lindi Urban	0.47
5	Mtwara coastline[a]	Mtwara Urban	0.36
6	Lake Victoria[b]	Mwanza	1.12
7	Lake Tanganyika[b]	Kigoma - Ujiji	0.37
8	Lake Nyasa[b]	No urban center with > 0.2 population	

[a] Source: World Bank–Africa Region, Coastal Profile for Tanzania (2014)

[b] Source: United Nations, Department of Economic and Social Affairs, Population Division (2015)

Methods

A state-of-the-art review was conducted on published articles, reports, and other materials on plastic pollution in Tanzania, which were searched on databases of scientific research and the general internet using a combination of keywords: Plastics and Tanzania, microplastics and Tanzania, microplastics and aquatic environment and Tanzania, plastic pollution and Tanzania. Search results were thoroughly read and analyzed. Studies that included plastic pollution in fresh and marine water bodies in Tanzania were identified and systematically reviewed to obtain key information. Databases of scientific research included Science Direct, Springer Link, and Google Scholar. A broad search on general internet was included because it is a common practice for industries not to publish their studies and findings in scientific journals. Furthermore, several academic and research staff at the Institute of Marine Sciences and the Department of Aquatic Sciences and Fisheries Technology (University of Dar es Salaam) were contacted to find out if they have done any research or study on the subject matter. Dar es Salaam-based environmental NGOs were also consulted to gain insights on their collaborative activities and level of engagement on plastic pollution management. The visits aimed at gathering information on availability of any written reports and personal communications. Information related to education or training activities and networking were also gathered and reviewed.

Results and Discussion

Available data on plastic pollution in coastal environment in Tanzania

As per review of the published and unpublished reports, there are no studies or data on presence, sources, and fate of plastics and microplastics in marine waters of Tanzania, except for the report on number and type of anthropogenic debris items collected by volunteer-led cleanups of Msimbazi River and its mouth in the Indian Ocean shorelines organized by Aqua-Farms Organization (AFO), a non-governmental organization (NGOs). Clean-up activities engaged individuals, environmental study researchers, school students and surrounding communities, and were conducted twice, in May 2017 and September 2018 (Personal communication with Mr. Jerry Mang'ena, http://afo.or.tz). Cleanups have gathered some useful information on the abundance and distribution of plastic debris along this coastline. Of nearly 300 kilograms of anthropogenic debris which were collected during each cleanup, 70% were identified as plastic debris. It should be noted the cleanup only targeted visible litter, and thus providing information on macroplastics debris only.

In comparison to Tanzania and the rest of Africa, significant knowledge has been gathered about the presence, sources, and fate of plastics and microplastics in the coastal regions around South Africa and their biota. For instance, water sampling for microplastics off the southwestern Cape Province (Ryan 1988, Ryan and Moloney 1990) found a significant increase in the mean microplastic density from 491 m^{-1} in 1984 to 678 m^{-1} 5 years later. Nel and Froneman (2015) study suggested that local sources had the greater influence on the distribution of microplastics in sampled marine environment. Biological sampling in this region has also revealed a number of interesting details regarding the fate of marine plastics. Plastic particles were found in more than half the seabirds predominantly sampled off Southern Africa and African sector of the Southern Ocean (Ryan 1987).

Available data on plastic pollution in freshwater in Tanzania

Based on literature search, there are only two studies that have attempted to document the presence of plastic debris in Tanzania freshwaters (Ngupula et al. 2014, Biginagwa et al. 2016), and only one specifically focused on microplastics (Biginagwa et al. 2016). Both studies were conducted in the Lake Victoria (Mwanza, Tanzania).

The first study detailed the work of Ngupula et al. (2014) in which the authors documented presence and distribution of solid waste including plastic bags and fishing gear at six depth strata of the Lake Victoria reaching 80 m below the surface. Although, their work did not specifically focus on microplastics in the waters of Lake Victoria, the work provides important information that increases our understanding of where microplastics originate from in the lake system. The work determined the vertical distribution of solid wastes in the Lake by classifying waters into three main ecological zones: (1) the nearshore, sampled at depth of < 10 m and 10.1–20 m , and described as highly influenced by anthropogenic input; (2) the intermediate zone which was sampled at depths of 20.1–30 m and 30.1–40 m, and classified as moderately influenced by the catchment; and (3) the deep offshore waters which are the most isolated from the human activities and were sampled at depths of 40.1–50 m and then > 50.1. The last depth section extended to the bottom, reaching 80 m, the maximum depth of Lake Victoria. A total of 68 samples were taken across these three zones and six strata, during two periods, May and late September to early October 2013. Trawls were conducted at three knots and debris collected by 4 mm mesh trawl net. Interestingly, plastic debris were found at all depths and all sampling locations. Across all trawls, the dominant waste types originated from fishing activities; multifilament gillnets comprised 44% of all debris, monofilament gillnets (42%), longlines and hooks (7%), and floats (1%). Plastic bags (4%) and clothing (2%) accounted for the remaining solid waste. Gillnets, which contained more than 80% of all the debris found and 96% of waste in the fourth depth strata, are constructed using synthetic fibers, and although nylon was used in the 1960s, newer materials, such as ultrahigh-molecular-weight polyethylene (UHMWPE) or polyethylene terephthalate (PET), are now commonly used as they are cheaper, more durable, and require less maintenance. Multifilament gillnets are used in the fishing of Nile perch, while monofilaments are used for catching tilapiine species, including Nile tilapia. Intermediate zone (20.1–40 m), which is known to have highest levels of fishing, contained more waste compared to other zones. The study suggested fishing activity to be the major source of solid waste, particularly plastics waste in Lake Victoria. However, land-based waste was not accounted for in this study owing to inability to trawl at shallow depths (< 4 m) in the nearshore. The fact that Mwanza City is among the fastest growing cities in East Africa, it is likely that other sources such as land-based runoff and transportation of cargos could be contributing to the solid waste including plastics input into the Lake.

The second study conducted in Lake Victoria documented the recovery of microplastics from Lake Victoria Nile Perch and Nile Tilapia (Biginagwa et al. 2016). Two economically and ecologically important fish species, Nile perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*) were used as proxies for environmental microplastic contamination in Lake Victoria. The species were chosen based on their differing feeding habits which could potentially provide additional contextual information on plastic ingestion. Nile perch are predatory fish feeding on haplochromine cichlids and gastropod snails, whereas Nile tilapia are omnivorous with a diet consisting of plankton and fish (Khan et al. 2018). The results of the study indicated that gastrointestinal tracts of 11 perch and 7 tilapia contained 55% and 35%, respectively, of suspected plastics. The polymers recovered from the fish were polyethylene, polyurethane, polyester, copolymer (consisting of polyethylene and polypropylene), and silicone rubber. These polymers are commonly used in packaging, clothing, food and drink containers, insulation, and industrial applications (Table 1). Considering the size and dimension of the recovered plastics from this study, it is likely that the plastics ingested by the fish are secondary microplastics which stemmed from the degradation and breakdown of larger plastic pieces (Wagner et al. 2014). The study suggested that likely sources of the inputs of such materials into the Mwanza Gulf area are land-sources through drainage and ditches that are filled with urban waste, including plastic products. This problem exacerbates during heavy rain when input into the lake is increased. Other similar studies have shown that land-based sources account for up to 80% of the total debris input to water bodies (Driedger et al. 2015). Land-based sources of plastic debris to water bodies include riverine outflow, landfills, stormwater drains, textile laundering facilities, and petrochemical plants, as well as direct inputs, for example trash left by recreational beach users (Browne et al. 2011, Wright et al. 2013). It therefore appears that the nature of the plastic pollution is related to the usage of plastics and disposal of its waste by the local human population. As in the first case study, this work provided evidence of the presence of microplastics in the Lake Victoria. The chances of plastic contamination are high in other water bodies whose catchments support significant human population as in Mwanza City. Although this study has provided evidence for presence of microplastics in the Lake through the ingestion of secondary microplastics by fish populations, it is clear that further research needs to be undertaken in Lake Victoria to fully describe the extent of microplastics pollution.

Current challenges

Given the number of available studies that document plastic pollution in aquatic environment of Tanzania, the most obvious challenge would be the lack of data. There are gaps in understanding the sources, fate, behavior, and toxicity of microplastics and their associated contaminants in aquatic environment of Tanzania. Filling these knowledge gaps must therefore be the highest priority and necessity to further understandings of sources and fate of plastics in these environments. But, if we assume that the lack of data on the presence of plastic pollution does not mean the absence of pollution, then immediate attentions should as well be directed on mitigation of plastic waste and its associated problems. This could be achieved through proper waste management, increased public awareness and political will to address plastic pollution. As part of the objectives of this paper, current challenges regarding the mitigation of plastic wastes in Tanzania are discussed as follows:

Public awareness

Awareness of environmental and health issues related to plastic pollution is now universal and shared by the general public, industry and politicians in most of the developing countries (Driedger et al. 2015). In the USA for example, the public has been vital in assessing the magnitude of plastics and microplastics pollution through volunteer beach cleanups and surveys that provide data for monitoring programmers, as well as carrying out the practical tasks of removing beach litter (Driedger et al. 2015). Such public involvement has also taken place in other places worldwide (e.g., Storrier and McGlashan 2006, in Scotland; Bravo et al. 2009, in Chile; and Ryan et al. 2009 in South Africa. Although, there are some cleanup initiatives conducted in Tanzania, for example, a recently organized volunteer cleanup of River Msimbazi (unpublished data), there is still a lot to be done in raising public awareness regarding plastic wastes. Just like any other developing countries, Tanzania faces other greater challenges such as social-economic problems, which require urgent actions in tackling them. As a result, there has been insufficient budgetary allocation to deal with environmental issues. To address this problem, scientists and environmental NGOs are better placed to collaboratively work with various public sectors in raising public awareness on the issues of plastic waste management. Also, the opportunities for 3Rs (reduce, reuse, and recycle), which are not well studied, advocated and practiced in Tanzania, could be incorporated in the preparation of training of environmental professionals and technicians. Education is an essential step to raise awareness and commitment for citizens. Some developed countries, for instance, have reported positive impacts from investing in education, such as citizens assuming responsibility in making sure wastes are properly sorted and disposed of, resulting into cleaner cities (Guerrero et al. 2013). Such programs, if adopted, could possibly produce similar positive changes in our communities.

Waste management

In Tanzania, solid waste management (collection, transportation and disposal) is one of the key duties of all urban authorities. It is a legal obligation in accordance with the Local Government Act 1982 section 55 (g) and the Environmental Management Act of 2004 (NEMC 2012). However, due to rapid urban growth, scarcity of funds experienced by many urban authorities, and the reluctance of the urban dwellers to pay for the services, waste management represents a real challenge in most cities. While the volume of waste generated from cities and towns is increasing, there is a gradual decline in effectiveness of solid waste collection, transportation and disposal systems. Additionally, unlike most developed nations where plastic waste is often separated from other wastes prior to disposal (González-Torre and Adenso- Díaz 2005), the management of solid wastes in developing nations like Tanzania is still challenging often due to poor technology and infrastructure and insufficient finances (Matete and Trois 2008). The government of Tanzania has come up with some initiatives in waste management such as the conversion of open or operated dumps to engineered landfills and sanitary landfills as an essential step to avoid future costs from present mismanagement (NEMC 2012). But there are no plans and legal frameworks regarding reuse and/or recycling practices. As results urban and industrial wastes are usually sent to disposal sites in bulk, without sorting out plastic wastes. These dumping practices have been reported as major causes of pollution in African water ways and are also recognized as sources of plastic pollution in Tanzanian aquatic environment (Khan et al. 2018).

In Europe, for instance, waste is increasingly being used to produce both materials and energy. This sustainable approach employed in solid waste management could also be adopted in Tanzania by establishing recycling stations and working with communities. Thus, encouraging recycling habits which could change people's perceptions of plastics from disposable single-use items. As stated earlier, based on the financial challenges in addressing environmental issues, the plastic pollution in our environment may not be solved by the government alone but rather by bringing together various stakeholders (local community, national and international organizations, policy makers, and research communities) in order to gather data and evaluate steps forward for the implementation of effective measure in controlling plastic pollution.

Future research needs

As mentioned several times, there are gaps in understanding the sources, behaviour, fate and toxicity of microplastics and their associated contaminants in aquatic environment of Tanzania. With only two studies provided evidence of plastic pollution in Tanzanian water bodies, more research is urgently required to address the identified knowledge gaps. This review recommends the following areas for future research:

(i) Sources, distribution and abundance of microplastics in both fresh and marine waters: Information on relative importance of sources of microplastics in Tanzania aquatic environment (water, sediment and biota) and their abundances is urgently needed in order to inform effective policy solutions, interventions, and innovations at the waste treatment, individual behavior, and industrial design level.

***(ii) Uptake and effects of microplastics*:** While ingestion of microplastics has been demonstrated in a variety of aquatic organisms (Browne et al. 2007, Lee et al. 2013, Hämer et al. 2014, Besseling et al. 2014, Cole et al. 2015), there has not been a conclusive answer to the question of what the effects of ingestion are, or which organisms are most vulnerable to effects. Therefore, there is a need for more work to fully understand the uptake and effects of these contaminants.

***(iii) Interaction between microplastics and other contaminants*:** Studies have shown that microplastics, with their hydrophobicity characters and large surface areas, have tendency to accumulate organic contaminants and metals, which can potentially accumulate at concentrations equivalent to, or greater than, those in the surrounding sediments or water (Ashton et al. 2010). Therefore, research focusing on interaction of microplastics and other contaminants in aquatic environment of Tanzania is recommended.

Conclusion

Generally, considerable progress has been made, particularly in the past five years, in characterizing the presence and potential effects of microplastics in the aquatic environment in many parts of the developed world. However, the knowledge of plastics/microplastics waste and their associated contaminants in Tanzanian waterbodies is relatively lacking and represent opportunities for further research. Due to the human pressures and subsequent increase in urbanization along the coast and in proximity to freshwater bodies, coupled with ineffective waste management and inadequate awareness, the potential for plastic and microplastic pollution in Tanzanian aquatic environment is great. In addition to the gaps outlined above, it is suggested that increased awareness and education of the population, effective waste management and cooperation among stakeholders are equally important in mitigating effects of plastic pollution. This review is only the starting point of a more comprehensive work related to plastic pollution in our aquatic environment.

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