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Vertical distribution of microplastics in urban farmland soils. A case of Mabibo Bonde la Mchicha farm, Dar es Salaam, Tanzania

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ABSTRACT

The rise of microplastics (MPs) is a global concern jeopardizing environmental safety. Initial studies have extensively concentrated on aquatic ecosystems, leaving their presence in terrestrial environments unknown. Thus, this study was carried out to investigate the vertical distribution of MPs in farmland soils of Mabibo Bonde la Mchicha Farm (MBMF), Dar es Salaam. 39 soil samples collected from MBMF were investigated using a Stereomicroscope and QATR-S FTIR. Results herein showed that MPs were found in all soil samples in different depths up to 15 cm deep, ranging from 4.8 to 82.2 items g^{-1} dry weight (DW). There was a statistically significant difference in MP abundance in depths between 0–5, 5–10 and 10–15 cm layers ($P = 0.033$) at $\alpha = 0.05$. The observations were revealed by the observed colors, in which white (36.5 %) was the most frequently observed, followed by blue (21.4 %), brown (20.2 %), black (12.8 %) and red (9 %). Fibers (49.7 %), fragments (32.9 %) and films (17.3 %) were the dominant shapes. Polyethylene (PE) and polypropylene (PP) were the dominant polymers observed constituting 33 % each, polyethylene terephthalate (PET) 11 %, high-density polyethylene (HDPE) 8 %, polyester (PES) 7 %, polyamide (PA) 7 % and polyvinyl chloride (PVC) 1 %. It can be inferred that PE and PP exhibited greater vertical mobility. However, PA and PVC were only observed in the topsoil layer. This study reveals MPs' occurrence and vertical transfer in urban farmland soils of MBMF in Dar es Salaam.

1. Introduction

Plastics have become an essential resource in the modern Anthropocene era, playing a fundamental role in every aspect of life (Geyer et al., 2017; Himu et al., 2022). The global production of plastics has undeniably surged, with a staggering increase from 234 million tonnes (Mt) in 2000 to 353 Mt in 2019 (OECD, 2022). It has been estimated that over 8.3 billion metric tons of plastic are produced annually. Unfortunately, only 20 % of this amount is recycled, leaving the majority to accumulate in the environment (Cohen and Barbara, 2018; Yu et al., 2022). Due to widespread usage, low recycling rates, and poor handling, plastic waste has become abundant in our environment, often ending up discarded or in landfills (Alimi et al., 2021; Yu et al., 2021). When plastics are disposed of, they tend to break down further due to physical, chemical, and biological factors. This results in the formation of small plastic fragments that are categorized by size as macroplastics (>2 cm), mesoplastics (5 mm-2 cm), and microplastics (<5 mm) (Liu et al., 2018). In addition, microplastics can be categorized as either primary or secondary based on their source (Thomas et al., 2020).

Research on microplastics has primarily centered on their presence in waterways and their potential impact on aquatic species, particularly in rivers (Bellasi et al., 2020; Kataoka et al., 2019; Khan et al., 2020), lakes (Biginagwa et al., 2016), and oceans (Jambeck et al., 2015; Lundsør et al., 2019; Mayoma et al., 2020; Shilla, 2019). Recent studies show that 80 % of marine microplastic pollution comes from land sources. Interestingly, microplastics in deep terrestrial environments have only recently become a focus of research. Scholars suggest that microplastic abundance in the soil can be 4 to 23 times greater than in the ocean (Feng et al., 2020; Kumar et al., 2020; Li et al., 2020; Yu et al., 2022). Despite the belief that human activities such as sewage sludge and manure application, plastic irrigation pipes, plastic storage tanks, plastic mulching for crop yield, tire wear and tear, and atmospheric deposition could be potential contributing factors (Guo et al., 2020). The buildup of microplastics and their persistence in soil for long periods due

Abbreviations: DOM, Dissolved Organic Matter; DW, Dry weight; FTIR, Fourier Transform Infrared Spectroscopy; HDPE, High-density Polyethylene; MBMF, Mabibo Bonde la Mchicha Farm; MPs, Microplastics; OECD, Organization for Economic Cooperation and Development; PA, Polyamide; PE, Polyethylene; PES, Polyester; PET, Polyethylene Terephthalate; PP, Polypropylene; PVC, Polyvinyl chloride; SOM, Soil Organic Matter; US, Urban soil.

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to poor biodegradability can seriously affect soil productivity and fertility (Ren et al., 2021). They can alter soil physicochemical properties (de Souza Machado et al., 2019), affect large communities of microbial communities, be adsorbed by plant roots and even further infiltrate the groundwater thus, threatening human health (Ding et al., 2022; Okeke et al., 2023; Ren et al., 2021; Rillig et al., 2019; Wang et al., 2022). Therefore, it is important to study the vertical distribution of MPs in the soil as a pathway to the soil-groundwater system.

Previous studies have investigated on vertical distribution of microplastics in soils and sediments (Fakour et al., 2021; Li et al., 2023; Liu et al., 2018; Qiu et al., 2023; Xue et al., 2020). The distribution of microplastics in the soil varies differently with soil depths. The general trend is that the abundance of MPs decreases as soil depth increases (Li et al., 2023). For instance, Liu et al. (2018) found MPs abundance of 78.00 ± 12.91 items Kg^{-1} and 62.50 ± 12.97 items Kg^{-1} in 0–3 cm and 3–6 cm soil layers, respectively. The abundance of MPs in Tainan farmland soils was 53.2 ± 34.8 items/m^2 and 34.6 ± 20.3 items/m^2 in 0–5 cm and 20–25 cm soil layers respectively. Li et al. (2023) found the average microplastic abundance from three soil layers (0–20 cm, 20–40 cm and 40–60 cm) of Shouguang City were 1948.1 ± 992.5, 1349.4 ± 654 and 670.1 ± 341.6 items Kg^{-1}, respectively. Furthermore, research is gaining traction on the presence of MPs in fruits and vegetables with a focus on how plants intake MPs through their roots, leaves, and stems, using model plants (Aydın et al., 2023; Dong et al., 2021; Lazăr et al., 2024; Oliveri Conti et al., 2020; Rajendran et al., 2022). As per a 2021 WHO/FAO report, consuming 400 g or more of fruits and vegetables per day promotes optimal health. Moreover, it has been stated that humans can consume up to 80 g of microplastics per day through plants as a food source (Rajendran et al., 2022). Therefore, it is necessary to understand the distribution and transport behaviors of MPs in agricultural soils for the sake of understanding their potential risks to human health.

Mabibo Bonde la Mchicha Farm (MBMF) is a prominent vegetable production base in the Ubungo municipality, known for growing diverse green leafy vegetables for over 30 years. Farmers have been utilizing open spaces and underdeveloped plots in Dar es Salaam for urban agriculture since 2001, as it offers a larger market and helps improve their living standards. The soil in Dar es Salaam is sandy, thanks to the use of organic fertilizers like chicken manure, which increases the organic matter content. Research suggests that the use of chicken manure and surface water for irrigation could potentially introduce plastics into the soil (Liu et al., 2018; Pérez-Reverón et al., 2022). Moreover, Kataoka et al. (2019) revealed that there is a significant correlation between the concentration of microplastics and the population density of an area. Dar es Salaam is a city characterized by a fast-growing population, business center and dominating plastic leakage into the environment by 71 % (IUCN-EA-Quantis, 2020). However, there is still a paucity of vertical distribution studies on MPs in agricultural soils. Therefore, we selected MBMF, a typical vegetable farm, as the study area and analyzed soil layers at 0–5, 5–10 and 10–15 cm depths. The purpose of this article is to quantify the abundance of soil MPs in MBMF and identify the vertical distribution characteristics (abundance, morphology and color) of soil MPs in the 0–15 cm soil layer. The study would contribute to a deeper understanding of soil MPs distribution and inform potential impacts of MPs in agricultural ecosystems for holistic risk assessment. Moreover, the results will inform stakeholders involved in the plastic industry and farmers about plastic pollution in agricultural soils.

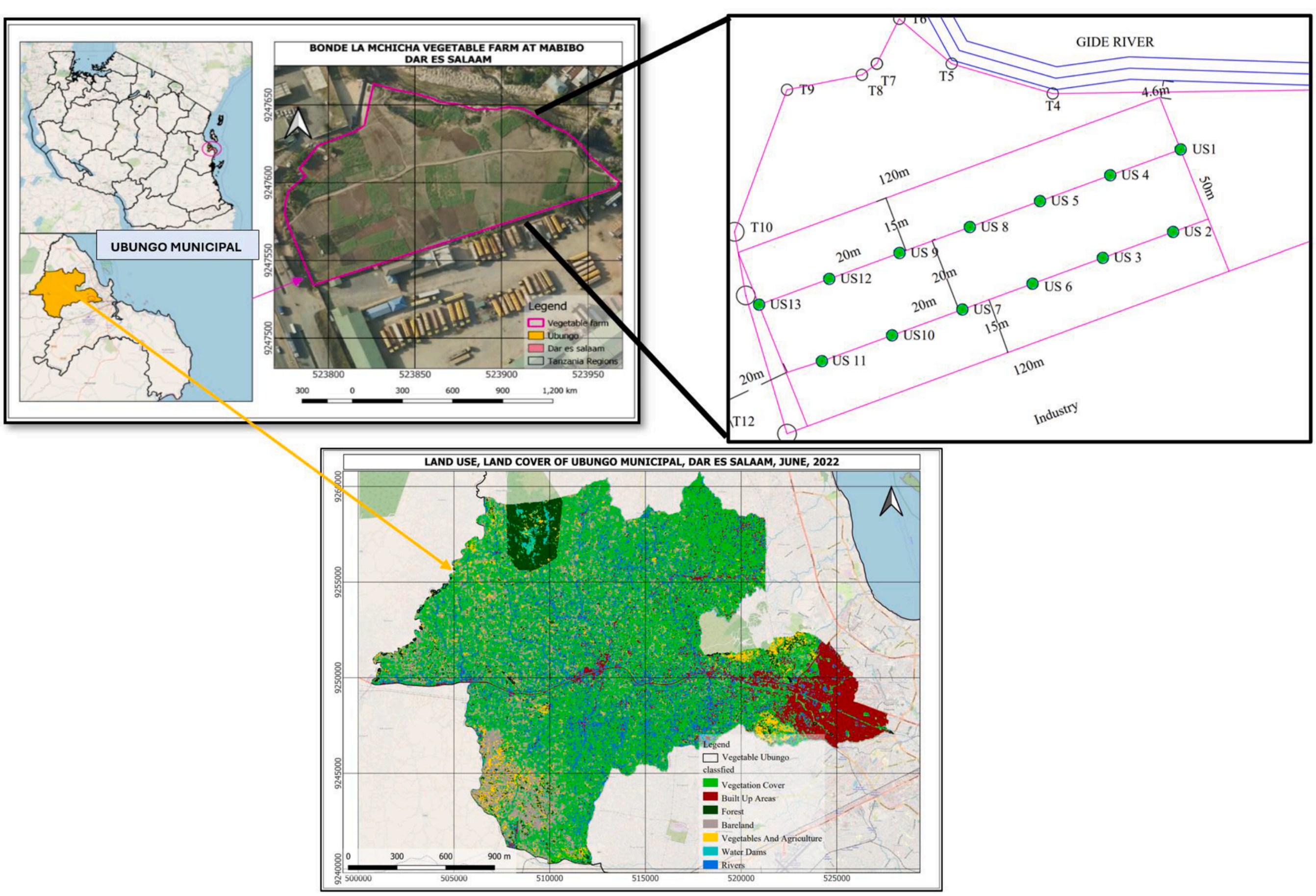

Fig. 1. Location of the study area and soil sampling sites at MBMF (Codename US: Urban Soil).

2. Material and methods

2.1. Description of the study area

The Mabibo Bonde la Mchicha Farm (MBMF) is located along the Kibangu River, a tributary of Msimbazi Valley in Ubungo Municipality, Dar es Salaam region (Fig. 1). The Msimbazi River is one of Tanzania's most polluted rivers and serves principally as a major water source for the production of vegetables in Dar es salaam. The Farm is situated at latitude 6°48'S and longitude 39°12'N covering an area of approximately 14,000 m^2 where extensive small-scale farmers grow green leafy vegetables throughout the year. The vegetables grown include Green Amaranth, Spleen Amaranth, Collard greens and Chinese. Vegetable cultivation in MBMF has a long history of over three decades and after production, these vegetables are supplied over Dar es salaam's markets a city with over 5.8 million people. Due to the nature of the climate and soils in Dar es Salaam, being unsuitable for vegetable farming. The farmers from the investigated field have been using chicken manure as fertilizer and surface water from the Kibangu River to irrigate vegetables. MBMF is centrally located and surrounded by the Nelson Mandela Road, the Kibangu River, high residential areas and industries including textile which all contribute significantly to its environmental pollution.

2.2. Sampling

Soil sampling was conducted in May 2023 and was performed according to the protocol established by the Marine Strategy Framework Directive (MSFD) Technical Subgroup on Marine Litter with some modifications (Galgani, 2014). The study area was divided into two areas: the margin and central area of the farmland considering the possible impacts from nearby field roads. Briefly, 13 evenly distributed samples were collected and aligned in two transects within the central area of the farmland. To assess the influence from the surrounding area, a minimum distance of 4.5 m and 20 m was left out from the river and adjacent road respectively. Sampling depths were established by considering the root size of vegetables grown at the farm. Each sample was taken from a 30 cm x 30 cm quadrate at the depth of 0–5 cm, 5–10 cm and 10–15 cm using a tape measure. Thus, at each sampling point around 1kg of soil was scooped using a soil auger and transferred into 500 ml glass bottles using a metallic spatula and taken first to Dar es Salaam University College of Education Chemistry Laboratory for pretreatment and extraction then to Nelson Mandela Material, Energy, Water and Environmental Sciences Laboratory for further analysis. Afterward, each subsample was analyzed for microplastics as directed by Hurley et al. (2018).

2.3. Microplastics extraction

2.3.1. Soil preparation and extraction

The collected soil samples were subjected to pretreatment analysis following the sieving and dry oven method. Briefly, in each sample, 10 g was initially weighed on an analytical balance and then placed in an oven for drying at 60 °C for 48 h. After oven drying, the samples were passed through a 5 mm sieve to remove large debris of visible particles including stones, roots and all other impurities (particles > 5 mm).

2.3.2. Digestion

The pretreated soil kept in an oven at 60 °C for each sample was subjected to an oxidation process by digestion with hydrogen peroxide. Briefly, 10 g of soil samples were initially placed in a 250 ml beaker, which was labeled accordingly. The samples were continuously treated with 30 % Hydrogen Peroxide and 0.05 M Fe (II) solution in a ratio of 1:1 until the reaction stopped and color change was observed (dark green to brownish red). Before placing samples in the oven for drying, 5 ml of zinc chloride solution was added to each beaker to avoid soil agglomeration. The samples were then dried in an oven at 60 °C for 24 h.

2.3.3. Density separation and filtration

The treated dried soil samples in the 250 ml beaker were subjected to a zinc chloride floatation solution following the density separation process. The $ZnCl_2$ solution with a density of 1.6 g/cm^3 was prepared by dissolving 1600 g of zinc chloride in distilled water to make a solution of 1000 ml. The floatation process was achieved by adding 40 ml of zinc chloride solution to the digested soil samples and then the mixture was magnetically stirred for 30 min and left to stand out for 48 h. The extraction using Zinc Chloride solution was repeated three times to fully extract plastics from soils. Subsequently after 48 h treatment, the supernatant from each beaker was decanted slowly and subjected to a filtration process with the aid of a vacuum pump. Filtration was carried out using cellulose nitrate gridded membrane filters with a diameter of 47 mm and pore size of 0.45 μm. The membrane filter containing residue was removed and preserved in a glass petri dish to dry at room temperature for further MP identification.

2.4. Microplastic identification, observation and validation

The visualization of MPs was carried out and microplastics were classified based on their abundance, shape and color. MP samples were optically sorted, photographed and further examined under an optika stereomicroscope (40X), where microplastics were counted twice and scrutinized by quadrants moving from left to right, bottom to top to avoid miscounting of microplastics. The Marine and Environmental Research Institute (MERI) guidelines consider a particle to be microplastic if it exhibits the following characteristics; small size of less than 5 mm, particles should exhibit clear and homogeneous color throughout, fibers must have a thick uniform length and most particles should be relatively flexible that cannot break when tweezed. For further confirmation, a hot needle test was performed to justify microplastics under consideration and magnification was increased to enhance clear visualization of smaller particles.

2.5. Microplastic analysis by QATR-S Fourier transform infrared spectroscopy

The suspected materials were further analyzed using QATR-S FT-IR (Attenuated Total Reflectance Single Reflection Fourier Transform Infrared) (SHIMADZU) spectroscopy which was initially calibrated using polystyrene film, and checked for laser, light source and detector control parameters. In the analysis, the spectrum was recorded in a wavenumber range of 4000 cm^{-1} to 400 cm^{-1} and 40 scans averaged at a resolution of 4 cm^{-1}. The ATR diamond crystal was washed with ethanol (70 %) and before the spectrum of each sample was recorded a background scan was run. A subset of 100 suspected MPs were randomly selected from 39 sampled soils of MBMF for FTIR analysis. These particles were randomly picked with the help of a syringe and 70 % ethanol and then placed in the ATR diamond glass. To ensure valid identification of the polymers, the measured spectra were compared with a reference spectrum available in the FTIR's ATR-Polymer Library Database. The reference database and free online software developed by a joint enterprise between Aalborg University, Denmark and Alfred-Wegener-Institute, Germany (siMPle) was used for further confirmation as relying on only an automated library database may result in the misidentification of polymers.

2.6. Quality control in experiments

During all stages of sampling, pretreatment, extraction and analysis, all measures were taken into consideration to prevent additional plastic exposure including filtering saturated $ZnCl_2$ solution. The distilled water used for rinsing equipment and preparing reagents was prior-filtered with a 0.01 μm sieve. Additionally, no plastic tools or plastic containers were used for sampling or laboratory work. In this study, 500 ml glass bottles were used for collecting samples. Moreover, all glassware used were acid-washed and rinsed with filtered distilled water and 70 % ethanol before use. Cotton-made lab coats and Nitrile gloves were used when working with samples and all samples were covered with aluminum foils to avoid contamination from airborne particles.

2.7. Statistical analysis

The data collected were analyzed using the Origin Pro version 2021 software. The abundance of MPs was expressed as items/g of dry weight. The normality test was done using the Shapiro-Wilk test. The normality test of all data collected revealed that the abundance of MPs in 0–5 cm, 5–10 cm and 10–15 cm were not normally distributed. That being the case, the Kruskal-Wallis H test was adopted as a statistical tool for assessing the significant differences and correlations between data obtained (Table 1).

3. Results and discussion

3.1. MPs abundance in soils

It was established that MP pollution was predominantly widespread in the soils of MBMF. MPs were found at all 13 sampling points, within a range of 4.8 to 82.2 items g^{-1} dry weight. The mean concentration of MPs was found to be 29.5 items g^{-1}, 32.1 items g^{-1} and 18.9 items g^{-1} in 0–5 cm, 5–10 cm and 10–15 cm soil layers (Fig 2). In 76.9 % of top soils (0–5 cm), the abundance of soil MP was less than 30 items g^{-1}. In 5–10 cm intervals, it was 53.8 %, and in the deep layer (10–15 cm), it was 84.6 %. On the other hand, MP abundance with a value of more than 30 items g^{-1} accounted for 23.1 %, 46.2 %, and 15.4 % in the 0–5 cm, 5–10 cm and 10–15 cm soil layers respectively. Sampling sites US 11 and 10 were found with the highest and the lowest MP concentrations, respectively, with a difference of almost 17 magnitudes (Fig 2a). The highest MP concentration observed in this study was found at site US 11 at a depth of 0–5 cm with an abundance of 82.2 items g^{-1}, much higher than those found in agricultural soils in Chile (0.6–10.4 items g^{-1}) (Corradini et al., 2019), tropical home gardens in Mexico (0.87 items g^{-1}) (Huerta Lwanga et al., 2017) and irrigation farms along Themi River in Arusha (0.21–1.5 items g^{-1}) (Kundu et al., 2021) (Table 2).

The high concentration of MPs in the US 11 location can be linked to its peculiar characteristics as it was highly flooded during sampling and adjacent to the urban road which is also considered a major source of microplastics as a result of tire wearing (Fakour et al., 2021; Hong et al., 2023; Rolf et al., 2022). Although the results do not justify clearly that the types of MPs identified are similar to the plastics released due to road runoff, several studies have justified higher abundance levels of MPs in farms adjacent to urban roads than those far from roadsides due to the friction between tires and road surface (Fakour et al., 2021). Moreover, Chen et al. (2020) attested that in the suburbs of Wuhan, soil MP abundance in vegetable fields near suburban roads was 1.8 times that in the adjacent residential areas. The Sampling location US 10 was unflooded and appeared to have a low concentration of MPs. Besides, Kruskal-Wallis test analysis results showed a statistically significant difference in MP abundance between 0–5, 5–10 and 10–15 cm layers ($P = 0.033$) at $\dot{\alpha} = 0.05$.

In the MPs abundance survey results along the soil profile (Fig. 2b), The soil MPs abundance showed an increasing trend with soil depth, except at 10–15 cm. The findings were inconsistent with other vertical distribution studies (Fakour et al., 2021; Li et al., 2023; Liu et al., 2018; Qiu et al., 2023). For instance, Fakour et al. (2021) found top soils (5 cm) have a higher abundance of MPs than deep soils (20 cm). This decreasing trend is also evident in both studies conducted by Li et al. (2023) and Qiu et al. (2023) on vertical distribution of MPs in different land use types in Yixing and Shouguang Cities respectively. The vertical transfer of MPs in the soil can be impacted by leaching, gravity, buoyancy, soil fauna activity, and plant root agitation (Li et al., 2020; Zhou et al., 2020). Due to their small size and hydrophobicity, MPs can travel vertically in the soil through biotic and abiotic processes and pool in the lowest layer of the soil profile (Guo et al., 2020). Moreover, the size of MPs and the soil texture in this study may explain why the abundance increased with depth. A large number of MPs may fill the soil pores preventing further vertical migration of MPs (Qiu et al., 2023). This may explain why the MPs abundance decreased from the 10–15 cm soil layer. Moreover, roots and soil aggregates can act as filters for the vertical migration of soil MPs (Qiu et al., 2023). The difference in the vertical mobility of MPs in soils could be attributed to a combination of factors such as soil texture, tillage and MP extraction methods. However, these key factors (MPs size, soil texture and root and soil aggregates) remain a limitation of this study hence calling for further studies.

Table 1
Normality test for soil MP abundance in different soil layers.

Soil depth	DF	Statistic	P-value	Decision at level (5 %)
0–5 cm	13	0.6845	3.89996E-4	Not normal
5–10 cm	13	0.94195	0.48271	Normal
10–15 cm	13	0.84159	0.02221	Not normal

3.2. Morphology characteristics

Three kinds of shapes, including fragment (hard angular pieces/irregular-shaped pieces), fiber (elongated strings) and film (soft transparent flakes/nylon) were determined in this study (Fig. 3a). Fiber, fragment and film were the most dominant shapes of MPs in the whole soil profile, accounting for 49.7 %, 32.9 % and 17.3 % respectively. Similar results were obtained by Ding et al. (2020), Kundu et al. (2021) and Corradini et al. (2019) in which fibers were most dominant. The results from the study by Ding et al. (2020) and Corradini et al. (2019) in soils of Shaanxi province and soils of urban centers in Chile respectively, linked the dominance of fibers with irrigation with wastewater and the application of sewage sludge. In this study, it could be attributed to the usage of surface water resulting from residential areas for irrigation. The surface water used is composed of released wastewater including domestic laundry discharges which has been regarded as a major source of fibrous MPs (Fakour et al., 2021). Films and fragments are believed to emerge as a result of onsite degradation of used agricultural plastic wastes such as plastic bags, plastic packaging materials and agricultural tools.

MPs fibers were found all along the soil profile (Fig 3b). In the 0–5, 5–10 and 10–15 cm soil layers, fiber microplastics were dominant (45.5 %, 49.8 % and 56.3 %, respectively), fragment microplastics (41.2 %, 28 % and 28.4 %, respectively) and film microplastics (13.3 %, 22.2 % and 15.3 %, respectively). The percentage of fiber microplastics increased with depth which was inconsistent with studies conducted by Liu et al. (2018) in shallow (0–3 cm) and deep soils (3–6 cm) in Shanghai, China and Feng et al. (2021) in the analysis of MPs in a remote region of the Tibetan plateau. Qiu et al. (2023) conversely, indicated that fibers have substantial vertical mobility in soil, allowing them to easily move through different soil layers. Moreover, Chen et al. (2022) emphasized that PE fibers demonstrate greater mobility during simulated rainfall than film and other particles. The percentage of fragment microplastics decreased with depth. Fragments from agricultural plastics or other sources may leach to deep layers in the soil as a result of earthworm activity (Sajjad et al., 2022). Through organism activity, these MPs may be ingested and gain further entry into the food chain (Feng et al., 2020). Film microplastics increased with depth except at the depth of 10–15 cm. Feng et al. (2021) found the percentage of film microplastics increases with depth. Li et al. (2022) explained that large-size film microplastics migrate less down the soil profile. Although this cannot be justified by this study, the size of MPs is also a major influence on the vertical mobility of MPs. One of the contributing factors to this pattern may be the soil texture of the study area although further research is needed to justify the correlation between soil texture and mobility of soil

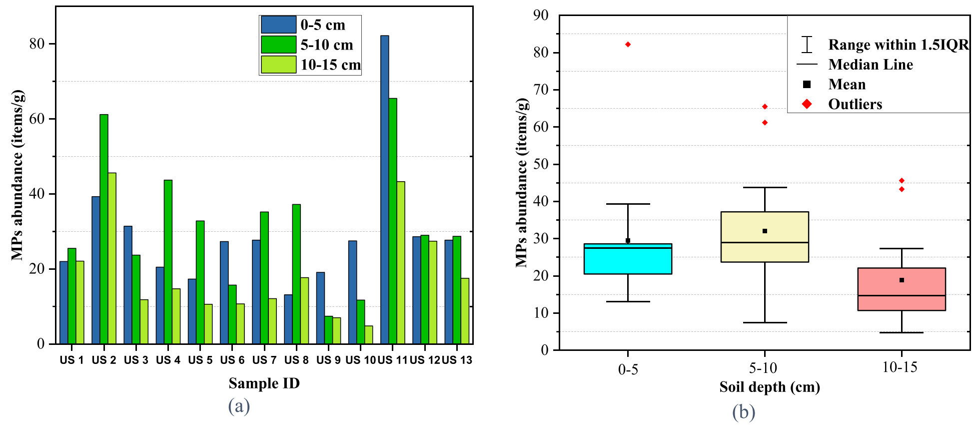

Fig. 2. MPs abundance (a) MPs abundance levels in MBMF sampling locations (b) Box plot represents the mean abundance of MPs in soil layers of MBMF (0–5 cm, 5–10 cm and 10–15 cm).

Table 2
Microplastic concentration in different agricultural soil studies.

Agricultural soil samples	Location	MP abundance (items/g)	Morphology	Main Polymers	Reference
Tropical home gardens	Campeche, SE Mexico	0.87 ± 1.9	/	/	Huerta Lwanga *et al.* (2017)
Agricultural soils	Mellipilla, Chile	0.6–10.4	Fiber, film, fragment, pellet	/	Corradini *et al.* (2019)
Agricultural soils	Shaanxi Province, China	1430- 3410*	Fiber, film, fragment	PE, PP, PS, HDPE, PVC, PET	Ding *et al.* (2020)
Farmland soils	Tainan, Taiwan	12–117**	Fiber, pellets, film, fragments, foam, microbeads	PE, LDPE, oxidized PE, PP, PS	Fakour *et al.* (2021)
Vegetable soils	Arusha, Tanzania	0.21–1.5	Fiber, Fragment, Film, microbeads	PE, PP and PS	Kundu *et al.* (2021)
Vegetable soils	Dar es Salaam, Tanzania	4.8- 82.2	Fibers, fragments, film	PE, PP, PET, HDPE, PA, PVC, PES	This study

* **stands for items(particles)/Kg **stands for items/m^2.**

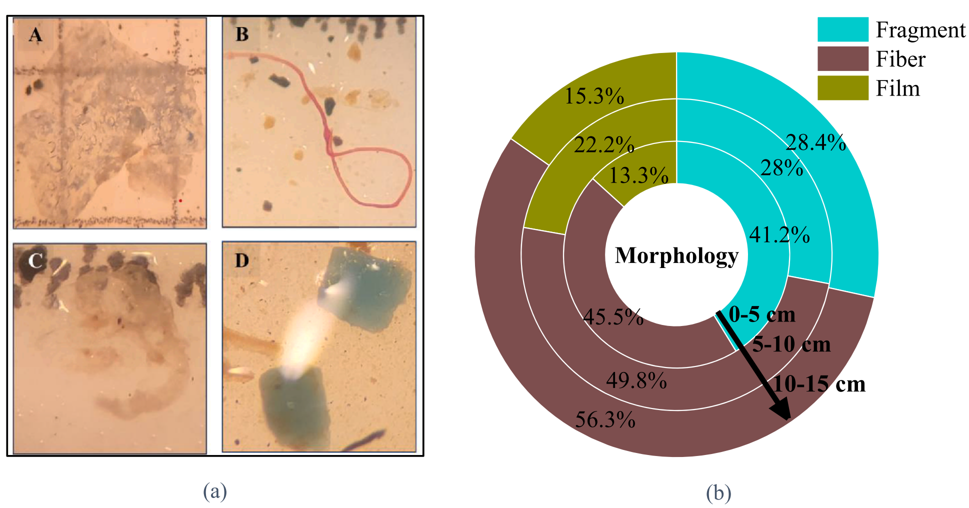

Fig. 3. Morphology Distribution (a) Example of microplastics found in soils of MBMF (A = Light Blue Film; B = Fiber; C = Film and D = Fragment) (b) Morphology distribution by depth (inner ring = 0–5 cm, middle ring = 5–10 cm and outer ring = 10–15 cm).

MPs. Other external factors also contribute to the vertical migration of soil MPs including the physical movement of soil by fauna or plant roots known as bioturbation and tillage.

3.3. Color distribution

A total of five colors of microplastics were observed black, white, brown, red and blue in this study. Generally, white (36.5 %) was the most frequently observed, followed by blue (21.4 %), brown (20.2 %), black (12.8 %) and red (9 %). Microplastics of different colors usually have different sources. The colors observed in this study reflect the plastics normally generated to produce carrier bags, plastic bottles and woven bags. Colored MPs were most dominant similar to other findings in soil systems for instance, Hao et al. (2023) discovered that 84 % of the MPs were colored in vegetable soils along Taihu Lake in China. They explained that colored plastics are more detrimental to soil and crops than colorless plastics because they are manufactured with the help of color masterbatches and chemical additives. Hence, they progressively release harmful chemicals such as aromatic amines, heavy metals and fluorescence whitening agents.

Plastic color distribution was observed along the soil profile (Fig 4). In the 0–5, 5–10 and 10–15 cm soil layers, white-colored microplastics were most dominant (37.1 %, 36.5 % and 35.9 %, respectively), blue-colored MPs (26.3 %, 19.1 % and 17.6 %, respectively), brown-colored MPs (17.9 %, 21.1 % and 22.2 %, respectively), black microplastics (10.7 %, 13.2 % and 15.6 %, respectively) and red (8 %, 10.2 % and 8.7 %, respectively). According to Oanh Doan et al. (2023), Color is a qualitative indicator of MPs age and origin. The colored microplastics identified in this study originate probably from urban plastic wastes including plastic bags, packaging and food wrappings and other potential sources including atmospheric deposition, organic fertilizers and surface water irrigation.

3.4. Chemical composition of MPs

Seven types of polymers were identified in this study by QATR-S FTIR, among which Polyethylene (PE), Polypropylene (PP), Polyethylene Terephthalate (PET), High density Polyethylene (HDPE), Polyester (PES), Polyamide (PA) and Polyvinyl Chloride (PVC) were detected. Generally, PE and PP were the most frequently detected polymers constituting 33 % each, followed by PET (11 %), HDPE (8 %), PES (7 %), PA (7 %) and PVC (1 %) (Fig. 5). The difference in the composition of polymer types detected could be explained by the differences in plastic usage and the scale of human activities. The findings are quite similar to other studies for instance, Koutnik et al. (2021) discovered that 80 % of the studies reviewed detected PE, PP and PET as dominant polymers. These polymers (PE, PP and PET) are referred to as commodity plastics because they are highly produced globally. For instance, PE is widely used in the production of agricultural films, plastic bags, pesticide bottles and fishing gear (Wang et al., 2022). PP is crucial for producing food bags, woven bags, ropes and fishing nets (Ding et al., 2020). Most agricultural soils have frequently detected polymer types confirming that MPs can infiltrate soil as a result of agricultural activities embedded with intentional or unintentional use of plastics such as PVC pipes, plastic containers and from surface water irrigation.

Different distribution of polymer types along the 0–15 cm soil layer was observed (Fig. 6). In the 0–5 cm soil layer, PE accounted for 29.7 % followed by PP (27 %), PA (18.9 %), PET (8.1 %), PES (8.1 %), HDPE (5.4 %) and PVC (2.7 %). In the 5–10 cm layer, PE dominated 38.2 % followed by PP (29.4 %), HDPE (14.7 %), PET (8.8 %) and PES (8.8 %).

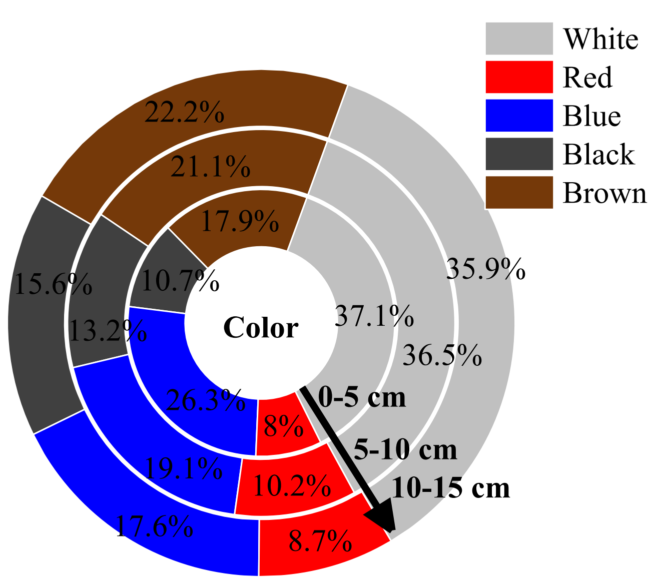

Fig. 4. Color distribution of MPs by depth (inner ring = 0–5 cm, middle ring = 5–10 cm and outer ring = 10–15 cm).

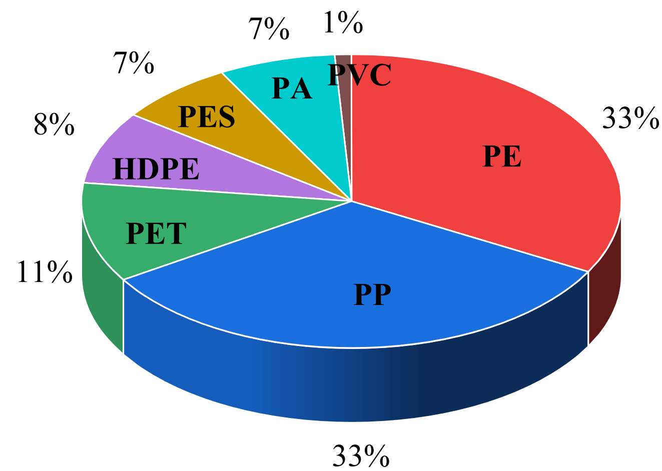

Fig. 5. Polymer types of MPs detected in MBMF soils.

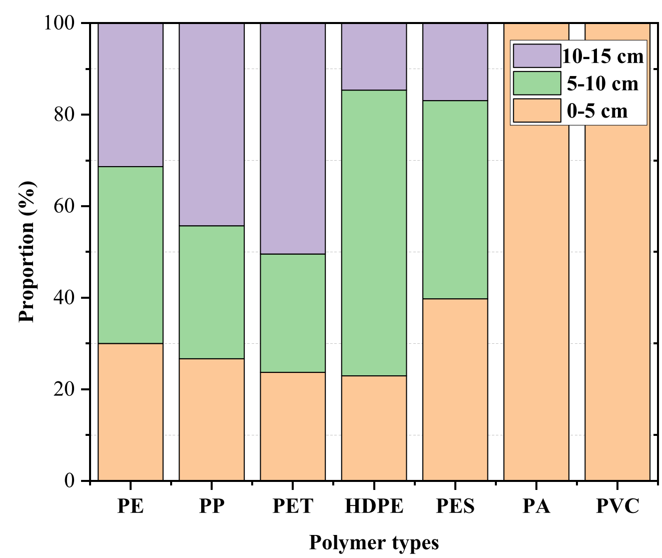

Fig. 6. Polymer distribution in soil layers.

In the 10–15 cm soil layer, PP dominated accounting for 44.8 % followed by PE (31 %), PET (17.2 %), HDPE (3.4 %) and PES (3.4 %). Compared to other polymer types, PE and PP occurrence in a maximum depth of 10–15 cm indicated greater vertical mobility. However, polymers such as PA and PVC were predominantly retained in the 0–5 cm soil layer. Similar findings were observed by Qiu et al. (2023) in soils from different land use types in Yixing City, they observed the occurrence of PE and PP in even deeper soils with maximum depths of 70–80 cm and 90–100 cm. PE and PP are commonly found in irrigation water and rainwater. The density of MPs and surface hydrophobicity may explain why PA and PVC were only predominant in the 0–5 cm soil layer. Bodor et al. (2024) explained that polymers with higher densities tend to migrate into deep soil layers while low-density polymers tend to transport horizontally. Surface hydrophobicity is believed to be a crucial factor in the mobility of MPs. Gao et al. (2021) found that the surface hydrophobicity of MPs has a greater impact on vertical transport in porous media than density. Additionally, surface hydrophobicity depends on the hydrophobicity of matrix polymers and additives. Therefore, further evaluation is needed to understand the movement of polymers in the soil.

The spatial distribution of MPs indicated that vertical migration of MPs in the soil (Fig. S-1) could be attributed to multiple factors such as the ploughing tendency by local farmers every planting season since soils are usually ploughed 1–2 times per year. Moreover, soil texture although further research is needed. For instance, Gao et al. (2021) stated that dissolved organic matter (DOM) and frequent wet-dry cycles promoted vertical migration of MPs in sand soil. This could be attributed to sandy soils having higher water infiltration capacity and large pore spaces which could enhance the migration of MPs down the soil profile. Additionally, microplastics deposited on the surface layers of soil could easily be washed away by runoff or carried by wind in the agricultural field. However, migration of MPs in farmland soils is a complex process that requires further investigation.

The QATR-S FTIR spectra of MPs extracted from various soil samples were plotted as shown in Fig. S-2 available in Supplementary information. Seven plastic debris categories, including PE, PP, PET, HDPE, PES, PA and PVC were identified. Polyethylene (PE) and Polypropylene (PP) were identified with a mean match degree of 81.8 % with the ATR polymer standard database. According to Afrin et al. (2020), one of the significant bands for identification purposes is the C-H stretching absorption band for plastic monomers and polymers like alkanes, and alkenes which have few bands. The absorption bands of the detected polymers were compared with other reference spectrums presented in other studies (Afrin et al., 2020; Chércoles Asensio et al., 2009; Jung et al., 2018). Table S1 available in the supplementary information represents the IR spectrum of the corresponding sample showing absorption bands (cm^{-1}) of PE, PP, PET, HDPE, PES, PA and PVC. The spectrum of PET for instance shows the following bands: C=O stretching at the peak of 1712 cm^{-1}; C—O stretching at the peak of 1244 cm^{-1}; C—O stretching at the peak of 1098 cm^{-1} and Aromatic CH out of plane bend at 717 cm^{-1} in comparison with the reference spectrum (Jung et al., 2018). The IR spectrum of PP shows the following bands: C—H stretching at the peaks of 2915 and 2360 cm^{-1}; CH_3 bend at 1370 cm^{-1}.

4. Conclusion

In this study, we investigated the occurrence and vertical distribution of MPs from three soil layers (0–5 cm, 5–10 cm and 10–15 cm) of Mabibo Bonde la Mchicha Farm in Dar es Salaam. Soil management practices (surface water irrigation, chicken manure) influenced microplastic accumulation. There was a significant difference in MP abundance in depths between 0–5, 5–10 and 10–15 cm layers ($P = 0.033$) at ὰ = 0.05. Compared with other studies, the microplastic abundance was at a higher level, ranging from 4.8 to 82.2 items g^{-1}. The soil MP abundance along the soil profile increased with depth except at 10–15 cm, which was inconsistent with other vertical distribution studies. The main microplastics were fibers (49.7 %), fragments (32.9 %) and film (17.3 %). The percentage of fibers increased with depth. White colored-MPs dominated (36.5 %) followed by blue (21.4 %), brown (20.2 %), black (12.8 %) and red (9 %) indicating the essence of most highly used plastics typically used in manufacturing plastic bottles and packaging. Seven types of polymers were identified by QATR-S FTIR including Polyethylene (PE), Polypropylene (PP), Polyethylene Terephthalate (PET), High-density Polyethylene (HDPE), Polyester (PES), Polyamide (PA) and Polyvinyl Chloride (PVC) with commodity plastics dominating which attests the relation of MPs detected with plastics production. PE and PP migrated more to the deep soil layer (10–15 cm). However, PA and PVC were predominantly observed only in the topsoil (0–5 cm). This study provides comprehensive data about soil MP pollution in Dar es Salaam city.

5. Recommendations

The accumulation and migration of MPs in soils and ultimately to groundwater can lead to unprecedented environmental and ecological risks. Significant strides are needed to restrict further entry of MPs in soils. We suggest strengthening recycling and management of plastic waste. The study also calls for Policy formulation in managing soil pollution from microplastics to monitor agricultural practices. Moreover, considering the limitations of this study and the complexity of the migration processes of MPs in the soil. We recommend more detailed field studies on their potential presence in vegetables and their possible entrance into the subsurface environment to the food chain. Our data presented herein hopes to inform regulatory interventions, recycling and management of plastics in Tanzania where such efforts are at present lagging.

CRediT authorship contribution statement

Emmanuel T. Kato: Conceptualization, Methodology, Investigation, Writing – original draft. **Zainab J. Katima:** Conceptualization, Resources, Writing – review & editing, Supervision. **Rwaichi J.A. Minja:** Conceptualization, Resources, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envadv.2024.100558.

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