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Review article

Microplastics in Ghana: An in-depth review of research, environmental threats, sources, and impacts on ecosystems and human health

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A R T I C L E I N F O

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A B S T R A C T

Microplastics pose significant challenges on a global scale. In Ghana, these tiny pollutants infiltrate diverse ecosystems such as coastal areas, rivers, lakes, and forests, vital to the nation's economy and social well-being. This review examines the current depth of knowledge in research and the escalating concern of microplastics, identifying significant gaps in research and understanding. The findings highlight the limited understanding of the extent and distribution of microplastic pollution across different environmental compartments, primarily focusing on coastal environments. Additionally, detection and quantification techniques for microplastics face several complexities and limitations in the Ghanaian context due to constraints such as infrastructure, resources, and expertise. Despite some research efforts, particularly along the coastline, there is still a distinct lack of attention in various regions and ecosystems within Ghana. This imbalance in research focus hinders the understanding and effective mitigation of microplastics in the country. This therefore necessitates the implementation of systematic policy frameworks, emphasizing the importance of recycling and upcycling as effective strategies to address the challenges of microplastics in Ghana with more targeted research and public engagement. This review serves as a call to action for a strategic approach to research and policy-making on microplastic research and pollution in Ghana.

1. Introduction

Microplastics (MPs) are small plastic particles, less than 5 mm in size, that pose a significant environmental challenge worldwide [1]. Like many other countries, Ghana confronts the growing menace of MPs pollution, which detrimentally impacts ecosystems, wildlife, and human health. Ghana is characterized by diverse ecosystems including coastal areas, rivers, lakes, and forests which provide essential services, such as fisheries, tourism, and biodiversity conservation, making them vital for the country's economic and social well-being. However, MPs have infiltrated these ecosystems, creating several environmental threats [2], as a result of this, Ghana's coastal waters, rivers, and lakes are therefore experiencing increasing levels of MPs contamination. MPs enter water bodies through various sources such as industrial discharges, domestic waste, and weathering of larger plastic debris. This is threat to aquatic

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organisms, leading to ecosystem disruption, altered reproductive patterns, and reduced biodiversity [3]. MPs can accumulate in agricultural soils, impacting soil health and agricultural productivity [1].

In Ghana, where agriculture is a major economic sector, the presence of MPs in soils can affect crop growth, nutrient cycling, and overall soil fertility. This contamination also raises concerns about potential MPs transfer from soil to food crops and ultimately human exposure [4]. Ghana is known for its rich biodiversity supporting a wide range of flora and fauna. MPs pose a threat to wildlife as they can be mistaken for food, leading to ingestion and subsequent health issues [2]. Additionally, MPs can enter the food chain, bio-accumulating and biomagnifying as they move up through the trophic levels, ultimately impacting the entire ecosystem [4]. Ingestion of MPs through contaminated food, water, or air could lead to the release of hazardous chemicals associated with plastic, posing risks such as inflammation, organ damage, and potential toxicity [5]. Ghanaian communities dependent on natural resources for food and livelihoods may face heightened health risks due to MPs exposure [6]. Addressing the issue of MPs in Ghana is of great significance and pivotal in the conservation of ecosystems, sustainable development, knowledge advancement, and policy management.

Microplastic pollution has received significant attention in recent years due to its harmful effects on the environment and human well-being. Ghana, like many other countries, is facing concerns regarding the presence of MPs in diverse ecosystems. This review is crucial to consolidate the scattered landscape of microplastic research in Ghana. By identifying challenges and gaps, the study contributes to refining methodologies, promoting uniformity (standardization and consistency in the methodologies used for studying MPs pollution in Ghana), and enhancing the quality of future research. Recommendations aim to overcome hurdles, ensuring more robust investigations. Additionally, pinpointing unexplored areas guides researchers toward novel avenues, fostering innovation and contributing to a comprehensive understanding of MPs pollution in the Ghanaian environmental context. Ultimately, this review serves as a roadmap for advancing MPs research, promoting sustainability, and addressing emerging environmental challenges in Ghana.

2. Overview of MPs in the environment

Microplastics, originating from the fragmentation of discarded plastic products and released through industrial and municipal wastewater, pose a pervasive environmental threat globally. These minuscule particles, also from the breakdown of items like bags, bottles, and fishing nets, infiltrate the food chain, endangering both wildlife and humans [7]. MPs can also accumulate in the environment via diverse routes, including the decay of larger plastic items, the use of plastic-laden agricultural mulches and the disintegration of synthetic textiles [11]. Industrial processes, such as the production of plastic products utilizing nurdles, contribute significantly to MPs pollution. Common materials like polyester and nylon shed microfibers during washing, further contaminating aquatic environments. Microbeads in personal care products and the degradation of tires on roads also contribute to MPs pollution [8,9]. Illustrating the cycle of MPs in the environment, Fig. 1 demonstrates how once released, MPs are transported by wind and water over long distances, leading to widespread. These MPs bio accumulate in organisms at various trophic levels. Marine life, including fish, may ingest these particles. Consequently, humans who consume contaminated seafood may be exposed, with potential health

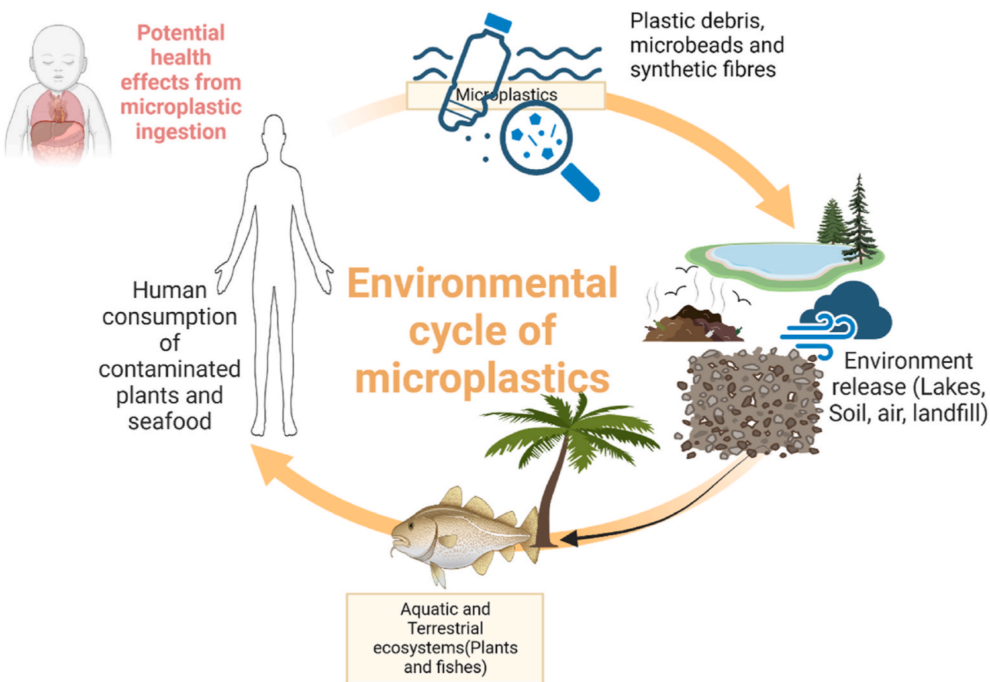

Fig. 1. The Cycle of Microplastics in the Environment (Created with Bio render).

effects [10].

A seminal oceanic study unveiled the staggering presence of over 5 trillion plastic pieces weighing over 250,000 tons, highlighting the magnitude of plastic pollution in oceans globally [9]. Approximately 4.8–12.7 million metric tons of plastic waste entered the oceans in 2010 from land-based sources, emphasizing the necessity for international cooperation [12]. Urban air also harbors MPs, originating from the breakdown of larger plastic objects like car tires and textiles [13]. In another study conducted [15], the findings also confirmed the presence of MPs in urban air. In the United States, all soil samples taken from some agricultural fields were found to contain MPs, these were likely from agricultural plastic mulch films [14].

Microplastics have a wide-ranging environmental impact, affecting both aquatic and terrestrial ecosystems. They enter the food chain through aquatic animals, causing bioaccumulation and biomagnification along the food chain. This global issue is not exclusive to specific regions. For instance, in California, 25 % of sampled fish in seafood markets were found to contain MPs in 2015 [16]. Another study [17] revealed that earthworms exposed to these minuscule plastic particles experienced reduced rates of growth and reproduction, suggesting a potential threat to the delicate balance of soil ecosystems. In 2020, a revelation emerged regarding the association between MPs pollution and greenhouse gas emissions. The study showcased that the presence of MPs in the vast expanses of the ocean could potentially lead to an alarming increase of up to 1.9 million tons of greenhouse gas emissions annually [18].

In Ghana, where environmental challenges and plastic pollution are major concerns, the global overview of MPs assumes paramount significance. While past research works have extensively addressed the widespread presence and environmental repercussions on a global scale, currently, there is a lack of direct attention on the specific conditions of MPs in Ghana's environments. The primary sources, threats, and impact of MPs on ecosystems and human health have not been adequately assessed in Ghana. Ghana grapples with its unique environmental dynamics, including diverse ecosystems, agricultural practices, and urbanization patterns. These past global studies offer a foundational understanding of the sources, pathways, and environmental impacts of MPs in Ghana. It is therefore important to consider the nation's specific challenges and opportunities in combating microplastic pollution through deliberate policies.

There is a significant lack of studies directly evaluating the impact of MPs on Ghanaian ecosystems and human health with the few past studies being solely qualitative. However, the global findings discussed below are instrumental in highlighting potential risks and informing future research directions in the Ghanaian context. This will offer a critical baseline from which to extrapolate potential environmental and health implications, emphasizing the urgency for targeted research within Ghana to address these gaps and develop tailored mitigation strategies. This global context, while not a substitute for localized studies, is essential in understanding the breadth of microplastics' impact and underlines the necessity for Ghana-specific research.

Research has indicated that ingestion of MPs can cause physical harm, block digestive tracts, and induce malnutrition in marine organisms spanning from small zooplankton to large marine mammals [19,20]. Nevertheless, the impact of MPs extends beyond ingestion, affecting the structure and function of aquatic ecosystems. They can disrupt feeding behaviors, reproduction, and health of aquatic organisms, triggering cascading effects throughout the entire ecosystem. Furthermore, MPs can adsorb and accumulate toxic chemicals from surrounding water, such as pesticides and persistent organic pollutants, this exposes marine organisms to heightened concentrations of these harmful chemicals, posing potential health risks [21]. The presence of visible plastic debris, including MPs, can create an unattractive appearance in rivers, lakes, oceans, and other water sources. This pollution can be particularly noticeable along shorelines and beaches [22].

According to Ref. [23], MPs can change the soil's physical structure, leading to changes in its porosity and ability to retain water. This alteration has the potential to impact soil fertility negatively which will result in limited access to water and oxygen to plants and a reduction in productivity. The study by Ref. [24] indicates that MPs can influence nutrient transport and cycling within the soil. They can adsorb and transport nutrients, possibly affecting the availability of essential elements necessary for plant growth. The impact of MPs also extend to soil microbial populations, with some research findings indicating that these particles can modify both the abundance and diversity of microorganisms [23]. This can adversely affect the soil ecosystem as it prevents microorganisms from degrading organic matter which controls the release of plant nutrients. The introduction of MPs into the soil can also restructure the composition and activity of soil microbial populations. Shifts in microbial populations could indirectly impact plant health since plants often rely on these microbes for nutrient cycling and disease resistance. Compelling evidence suggests that plant roots can absorb MPs, which can then be transported to various plant tissues. This raises concerns regarding the potential accumulation of MPs in edible parts of plants, posing potential risks to other organisms throughout the food chain [25].

The examination of [26] reveals that benthic organisms including filter feeders and deposit feeders, may ingest MPs while consuming their food. The ingestion of these tiny plastic particles can result in physical harm, including abrasions, blockages in the digestive system, and internal injuries. Also, plastics can accumulate in benthic sediments, altering the physical properties of the habitat. This can affect the burrowing and dwelling behavior of benthic organisms, disrupting their normal life cycles and compromising their ability to find food and shelter [27]. Additionally, through biomagnification, the concentration of microplastics increases as they move up the food chain. This can lead to higher exposure levels for predators that consume contaminated benthic organisms. Exposure to MPs can induce immune system suppression in benthic organisms, heightening their susceptibility to diseases and infections. This weakened immune response can have cascading effects on the population [28].

3. Environmental landscape of Ghana

Ghana, situated on the Gulf of Guinea in West Africa as shown in Fig. 3, has a rich and diverse environment characterized by tropical rainforests, savannahs, and a substantial coastline. The environmental landscape of Ghana is undergoing significant changes, influenced by factors such as population growth, urbanization, and land use alterations. This urbanization is closely linked to major industries including mining, manufacturing, and agriculture, which contribute significantly to the national economy [29]. According to the World Bank, as of 2021, approximately 57 % of Ghana's population resides in urban areas [30]. Urbanization brings about shifts in lifestyle and consumption patterns, potentially contributing to the generation and improper disposal of plastic waste, a known source of MPs. The rise in urbanization and industrial activities in Ghana has therefore led to an increased generation of MPs. Urban centers like Accra, Kumasi, and Takoradi, which are hubs for commercial and industrial activities, are major contributors to plastic pollution. The waste generated is both local and, to a lesser extent, derived from international sources, primarily through imported goods and packaging materials.

The rapid expansion of urban areas resulted in increased plastic consumption and improper waste management practices, further exacerbating the release of MPs into the environment [31]. Agricultural expansion and rapid urbanization in Ghana have resulted in land use changes, alteration in land use largely influences the runoff patterns of rainfall, transport, and distribution of MPs, potentially carrying MPs from urban areas to freshwater bodies and, ultimately, the oceans [10]. Currently, Ghana is witnessing a growing public and political interest in managing MPs. This interest is driven by the visible impact of plastic pollution on the environment and public health. The Ghanaian government has initiated policies like the National Plastic Management Policy to mitigate this issue. However, the effectiveness of this policy is still evolving [66].

3.1. Plastic waste management in Ghana

Plastic waste management is a significant challenge in Ghana, as in many other countries around the world. Plastic waste poses serious environmental and health risks, including pollution of water bodies, clogging of drainage systems, and harm to wildlife [32]. Plastic waste management in Ghana faces significant challenges such as limited resources for waste management infrastructure, inadequate enforcement of regulations, and a lack of public awareness and participation [33]. Plastic waste is generated in Ghana from a variety of sources, including households, markets, and industries [33]. Reported that plastic bags were the most common type of plastic waste generated by households in Accra, Ghana, followed by plastic bottles and food packaging materials. According to a study by Ref. [3], the average daily plastic waste generation per household is 0.77 kg. A similar study conducted on plastic waste generation in Kumasi, Ghana, by Ref. [34] also discovered that plastic bags were the most common type of waste generated in the markets, followed by food packaging and water sachets with the average daily plastic waste generation per market in Ghana being 70 kg.

Plastic waste management in Ghana relies heavily on waste collection and disposal [35]. However, the insufficient waste management infrastructure in the country has resulted in low waste collection rates and indiscriminate waste disposal, including plastic waste, in open spaces and water bodies. Several studies on waste collection and disposal in Ghana have been conducted: A study by Ref. [36], examined waste management practices in Tamale, a city in northern Ghana, and attributed the ineffective waste management to underlying factors such as lack of resources and ineffective routine waste collection. According to Ref. [37], only 46 % of households in Tamale, Ghana had access to formal waste collection services, and the vast majority of households dispose of their waste in public places [38]. Discovered that the current waste management system in the Kumasi Metropolitan Assembly (KMA), Ghana was inefficient and ineffective. In Ghana, the most common method of plastic waste disposal is open dumping, followed by landfilling and burning. The study discovered that to address the issue of solid waste in Ghana, systematic policy frameworks and procedures should be implemented to curb poor urban and rural waste management practices. In Ghana, some researchers such as [31,34,39,40] have looked into the extent of plastic waste pollution and its effects on the environment and human health [41]. Discovered that plastic waste pollution affected water quality, aquatic life, and ecosystem services in their study of the Korle Lagoon in Accra, Ghana. Another study on the health risks associated with plastic waste burning in Agbogbloshie, Accra, by Ref. [42] discovered that plastic waste burning released toxic chemicals into the environment, resulting in adverse health effects such as respiratory problems and skin diseases.

Recycling and upcycling are effective ways of reducing plastic waste in Ghana. However, the country's lack of proper recycling facilities and infrastructure has hampered the development of a long-term plastic waste management system [43]. Investigated the feasibility of upcycling plastic waste into building materials such as roofing tiles. The study discovered that upcycling was feasible and could provide an alternative to traditional construction materials [44]. Conducted another study to investigate the feasibility of recycling plastic bottle packaging waste into plastic sand bricks for use in construction. The study discovered that recycling was technically feasible and could help to reduce the environmental impact of plastic waste. There has been an increase in policy and regulatory interest in addressing the issue of plastic waste management. Ghana's government has taken several steps to address the problem, including the implementation of a plastic waste management levy in 2015 and the establishment of the National Plastic Action Partnership in 2019. Measures included in the policy include a ban on single-use plastics, the creation of a plastic waste management fund, and the promotion of recycling and composting [32]. [41] Suggested that the existing legal framework should be strengthened to encourage all Ghanaians to participate in the management of plastic waste. The framework should ensure that all aspects of the legal system are by the country's supreme law and the current political, socio-cultural, and economic policies, as well as the principles of sustainable development enshrined in international conventions.

4. Microplastic research in Ghana

In recent times, MPs research in Ghana has gained momentum, shedding light on the pervasive but understudied issue along the coastline. While the Gulf of Guinea is confronted with escalating concerns over MPs pollution, studies have predominantly focused on very few regions such as the Greater Accra, Volta, and Easter regions as shown in Fig. 3, this limits a broad coverage and comprehensive understanding of the extent and implications of this environmental challenge in Ghana. To date, there have been seven documented studies on MPs in Ghana, Fig. 3 shows the mapping of these MPs studied locations across Ghana, this is essential to explore the geographic research landscape in Ghana with the reported levels of MPs from various studies in Table 1.

A study conducted by Ref. [45] in the greater Accra region of Ghana on MPs in the gastrointestinal tract of fish suggested that the ingestion of MPs could be linked to various toxicological effects, posing risks to growth performance, oxidative stress, and the development of digestive and neurological disorders in exposed organisms, this agrees with the findings of [4] In India. The gut of fish may serve as a translocation and bioavailability pathway for toxic chemicals present in MPs, which may compromise the safety of seafood. This study further examined the characteristic features of MPs present in the examined samples, which may influence the rate of ingestion of MPs particles using Fourier Transform Infrared Spectroscopy (FT-IR) and categorized under a stereo microscope. The results indicated that MPs were present in the studied fish species, with Sardinella maderensis recording the highest abundance (1.49 ± 1.48 items/fish) as shown in Table 1. In the study, the characteristics of MPs revealed that fibers were the predominant shape, with the most common size ranging from 0.1 mm to 1.0 mm. Polymer identification analysis identified polyethylene (PE), polyvinyl acetate (PVA), and polyamide (PA) as the main polymer materials found in the fish samples, PE was the most prevalent polymer, constituting more than 50 % of the polymers detected. The likely implication of this finding in Ghana is that the polymers identified in this study may contain toxins and could end up in the human system through fish consumption potentially causing adverse health effects such as the risk of chemical exposure and endocrine disruption as confirmed in a similar study by Ref. [46]. The prevalence of MPs, particularly polyethylene (PE), polyvinyl acetate (PVA), and polyamide (PA), in fish from the Gulf of Guinea could therefore pose ecological and health risks. However, the recovery rate of MPs in the reported study may not be 100 %, as some smaller fibers may be digested, also while FT-IR is effective in identifying many types of MPs, it may face challenges in distinguishing between different polymers with very similar chemicals compositions. To enhance microplastic identification via FT-IR, complementary techniques such as Raman spectroscopy and pyrolysis GC-MS can be employed.

In a similar study conducted by Ref. [47] in the Greater Accra region of Ghana, the Mukwei Lagoon was found to contain significant levels of MPs as shown in Table 1. The levels of MPs in the sediment columns of the examined lagoons may signify an urgent environmental concern. Peak MPs concentrations were identified at around 10 cm depth. This finding raises intriguing questions about the dynamics of plastic breakdown and deposition in shallow sediments. There is a need for a deeper understanding of the mechanisms governing the fate of plastic in shallow sediment environments, this may be a potential avenue for future investigations. The microplastics analysis methodology employed in the study demonstrates key strengths in line with established practices, including the use of Jackson's method for organic material removal and particle size analysis with the Malvern Mastersizer 2000. However, notable

Table 1
Microplastics research overview: A compilation of studies in various ghanaian environments.

Type of Study	Location of Study	Concentration on microplastic	Analytical Technique Use	References
Microplastics in sediment	Ledzokuku (Accra)	-Core KLC2 (Kpeshie lagoon the second near the mangrove forest remnant) (2.16 wt% gr-1 -MLC (Mukwei Lagoon) (0.96 wt% gr-1 -KLC1 (Kpeshie Lagoon; one near the coastline) 0.75 wt% gr-1	fluorescent microscope	[47]
Microplastics in fish, water, and sediment	Atewa (Eastern) and Weija (Accra)	Black-chinned Tilapia from the Densu Delta (2.25) MP/individual and the Weija Dam (2.50) MP/individual Bagrid Catfish from the Densu Delta (4.17) MP/individual and the Weija Dam (1.58) MP/individual The mean number of microplastics for combined sediment and water in the Weija Dam (2.00 ± 0.577) and Densu Delta (2.50 ± 0.477)	Leica EZ4 HD stereo microscope with image analyses system IC80 HD camera.	[49]
Microplastics in wild oysters	Sekondi, Capecoast, Accra and Volta	2.1 ± 0.9–3.4 ± 1.0 items/individual-	Stereomicroscope (Leica EZ4D) equipped with an inbuilt camera (Leica ICC550E)	[48]
Microplastics in the gastrointestinal tract of fish	Jamestown (Accra)	0.94 ± 1.18–1.49 ± 1.48 items/fish	microscopic observation using a Leica EZ4HD stereo microscope.	[51]
Microplastic in sediments	Western	456 particles/10 g (Ankobra estuary) - 728 particles/10 g of the entire 1184 particles/10 g (Pra estuary)	OPTIKA dissecting microscope	[52]
Microplastic in sediment		0.078 ± 0.020 items/g (DW) at Sekondi to 0.217 ± 0.012 items/g (DW) at Denu	Stereomicroscope	
Microplastic in fish	Volta, Tema, Capecoast and Sekondi	I. Africana – 13.60 ± 5.95(MPs/individual) at Denu to 20.95 ± 12.72 (MPs/individual) at Sekondi S. maderensis – 18.80 ± 8.36(MPs/individual) at Denu to 13.10 ± 5.56 (MPs/individual) at Sekondi	Stereomicroscope .	[53]
Microplastic in Ghanaian Coastal Sea	Denu (Volta), Tema, Capecoast and Sekondi	1.14 ± 0.63 particles m− 3 - 2.36 ± 1.95 particles m− 3	Optika stereo microscope.	[50]

gaps exist, such as the absence of calibration checks for the particle size analyzer, a standard procedure for ensuring measurement accuracy. In the study, the microplastic analysis, while employing commendable practices like using glassware to minimize contamination and applying Nile Red dye for identification [5], is crucial for future analysis of MPs with similar methods to explicitly detail the quality control measures and detection limits, to ensure accuracy and reliability of results. These measures will help to elevate the robustness and reliability of the microplastic analysis methodologies in Ghana.

In another investigation by Ref. [48], the abundance and characteristics of MPs in the oyster species Crassostrea tulipa were collected from four estuaries (Volta, Densu, Nakwa, and Whin) along the Ghanaian coast. The results revealed a heterogeneous distribution of MPs, with higher abundances in estuaries near urban centers compared to those near rural settlements. Fibers and fragments, with sizes ranging from 33 μm to 4870 μm and black-colored MPs were prevalent as shown in Table 1, potentially originating from the indiscriminate disposal of polyethylene carrier bags commonly used for shopping in Ghana. The identified polymers included polyethylene, polypropylene, polyamide, polystyrene, cellophane, cotton, and cellulose [49]. Also investigated the occurrence and distribution of MPs in the Densu River, an important urban river in Ghana. The research examined microplastic pollution in both lentic and lotic sections of the river by focusing on water, sediment, and two economically important fish species, the Black-chinned Tilapia and the Bagrid Catfish. This study presents data on fish morphometrics, growth, and condition, revealing that the Black-chinned Tilapia exhibited good condition and isometric growth, while the Bagrid Catfish showed poor conditions and negative allometric growth. Significant levels of MPs were detected in water, sediment, and the gastrointestinal tracts of both fish species as shown in Table 1. The study found no significant differences in the abundance of microplastics between the Weija Dam and Densu Delta locations. In the free-flowing delta section of the river, no size selectivity in the deposition of microplastics was observed; however, in a section of the river upstream of a dam where flow velocities are much reduced, larger-sized microplastics typically suspended within the water column and smaller particles deposited in sediments. This is because the hydrodynamics of the river change significantly due to the dam's presence. In comparison with marine environments, this indicates that the abundance of MPs might be higher in coastal areas than in freshwater ecosystems in Ghana. The microplastics analysis method employed in the study is a Leica EZ4 HD stereo microscope with an image analysis system IC80 HD camera, this method of microplastics may have limitations that could potentially influence the study results; the resolution of the microscope and the detection limits of the image analysis system may hinder the identification of very small microplastic fragments. To address this, future studies could benefit from complementing advanced microscopy techniques like Fourier-transform infrared spectroscopy (FTIR) and Raman spectroscopy with mass spectrometry, which offer enhanced resolution and complement microscopy with techniques like scanning electron microscopy (SEM) and transmission electron microscopy (TEM) would provide more detailed information on particle characterization [50]. Also conducted an investigation, considering both sediment and fish samples from various locations in the Gulf of Guinea, specifically along the coast of Ghana. MPs were present in all sediment samples and both analyzed fish species, Sardinella maderensis and Illisha Africana as shown in Table 1. The distribution of microplastics in sediment samples varied across locations, with Cape Coast exhibiting the highest abundance, followed by Denu, Tema, and Sekondi. This variation suggests the influence of local factors, such as human activities, industrial development, and population density, on microplastic pollution. The research sheds light on the ingestion of microplastics by fish species, revealing that both S. maderensis and I. africana showed contamination. The research also provides insights into the types and colors of microplastics found in both sediment and fish samples. Pellets, fragments, fibers, film, and foam were identified as common microplastic types, with varied levels across locations. However, the sources of these MPs need to be investigated to help in effective remediation strategies in Ghana.

Table 1 provides an overview of microplastic research in various regions of Ghana, Incorporating a variety of environmental settings. In sediment studies, locations such as Ledzokuku (Accra), Atewa (Eastern), Weija (Accra), and Western regions reveal varying concentrations of microplastics. The reported research extends beyond sediment analysis to explore microplastics in fish, water, and even wild oysters. Noteworthy findings include the number of microplastics per individual in Black-chinned Tilapia (Sarotherodon

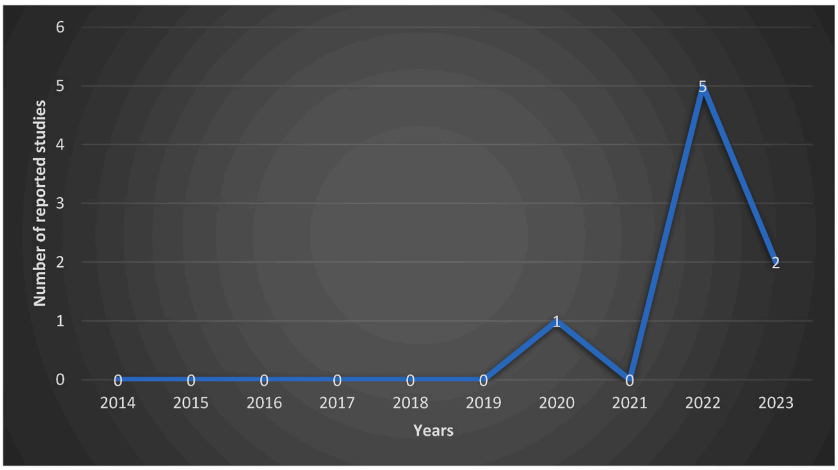

Fig. 2. Statistics of Reported Scientific studies of microplastics in Ghana over the past decade.

melanotheron) and Bagrid Catfish (Bagrus bayad) from the Densu Delta and Weija Dam as shown in Table 1. Additionally, studies on wild oysters and the gastrointestinal tract of fish offer insights into microplastics' presence in diverse ecosystems. The analytical techniques employed in the studies indicate methodological diversity across studies, there is therefore the need for standardization of analytical techniques and methodologies for microplastic research in Ghana. The MPs quantitative data presented in Table 1 indicates that MPs research in Ghana largely spans coastal areas like Sekondi, Cape Coast, and Accra, there is a need for a holistic understanding of microplastic distribution in the country by promoting and encouraging more research in MPs in research institutions. These findings, particularly the higher concentrations in biota like Black-chinned Tilapia and Bagrid Catfish, underscore the potential for direct ingestion by humans consuming seafood. The presence of microplastics in critical habitats such as lagoons and coastal seas further suggests a broader ecological impact, likely affecting food safety and quality.

4.1. *Visualizing microplastic research in Ghana: figures on study characteristics and regional focus*

The data presented in Fig. 2 illustrates the trends in reported scientific studies on MPs in Ghana over the past decade. Although

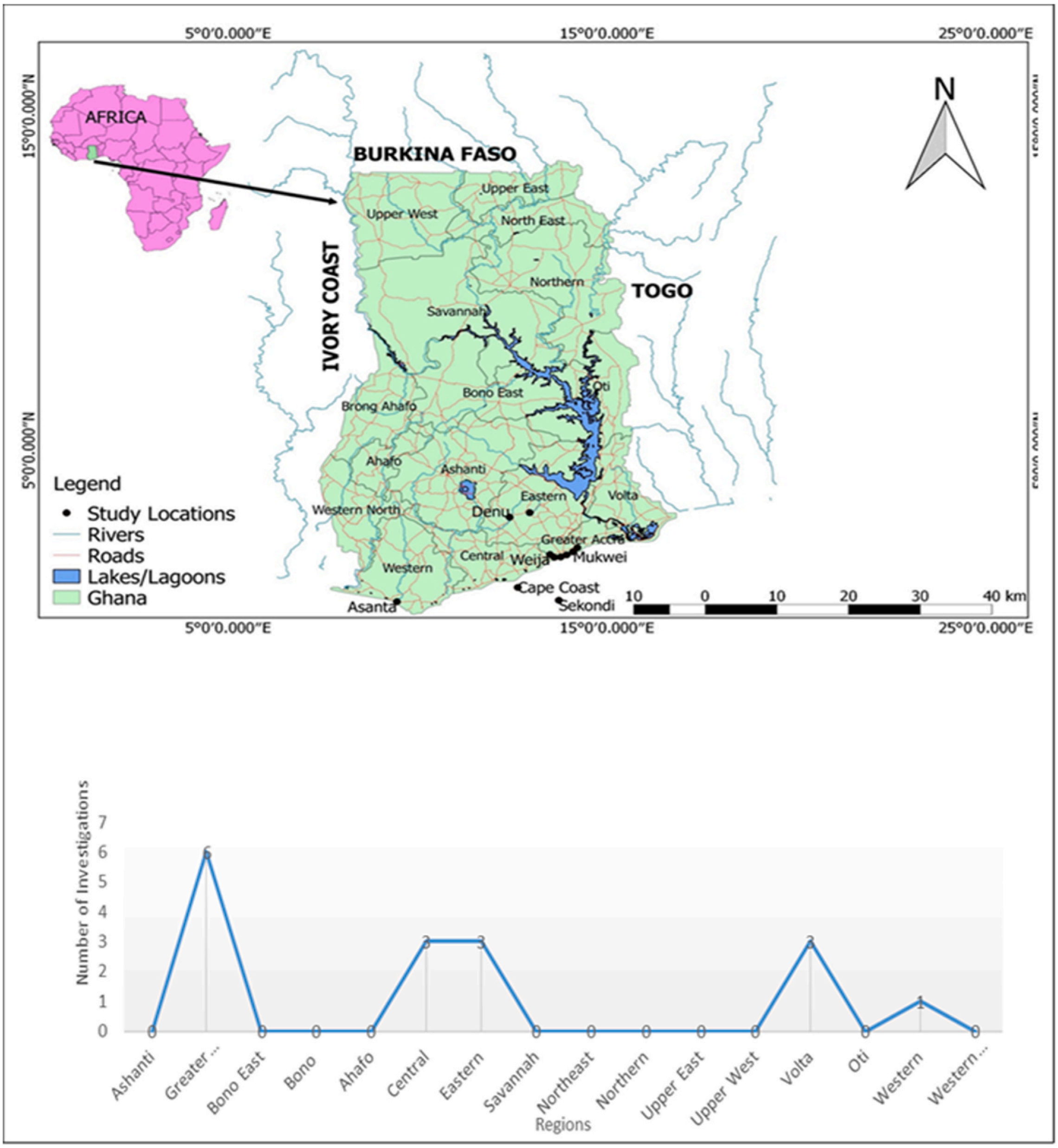

Fig. 3. Mapping the regional distribution and geographical landscape of microplastic studies in Ghana.

number of studies is low, there is a notable increase in research activity in the field, particularly in the more recent years. In 2020, the graph shows the initiation of studies with one reported research endeavor. Subsequently, in 2022, there is a notable surge with five studies, signifying a substantial growth in research attention. The year 2023 continues this momentum with two additional studies. The preceding years, from 2014 to 2019, reflect a lack of reported studies, suggesting a relatively recent emergence of interest and awareness in the MPs research landscape within the Ghanaian context. This upward trend in research endeavors in the last few years underscores the growing recognition of the importance of studying and understanding MPs in Ghana's environmental context.

The distribution of reported studies on microplastics in Ghana reveals a notable imbalance as shown in Fig. 3, with Greater Accra being the focus of the majority of research (6 studies), while numerous regions, such as Ashanti, Bono East, Bono, Ahafo, Savannah, Northeast, Northern, Upper East, Upper West, Oti, and Western North, have not been studied. This asymmetry raises concerns about the limited environmental knowledge, impact assessment challenges, and policy formulation difficulties in regions lacking research. To address these gaps, efforts should be directed toward fostering collaborative research, enhancing community awareness, and ensuring equitable allocation of resources. This will empower local communities, build research capacity, and develop targeted policies for mitigating microplastic pollution, ultimately contributing to a more comprehensive understanding of the environmental landscape across Ghanaian regions.

4.2. Gaps in microplastic research in Ghana

A thorough examination of microplastic studies conducted in Ghana has unearthed critical research gaps that demand immediate attention for a better understanding and management of the MPs landscape in the country. One glaring concern is the geographic imbalance in study concentration, notably, the major focus in regions like Greater Accra, Volta, and Eastern as shown in Fig. 3. Greater Accra is a predominantly urbanized region, characterized by dense populations and bustling industrial and commercial sectors. This urban landscape predisposes areas within Greater Accra to heightened levels of plastic waste generation and pollution, a consequence of intensified human activities. While urban environments typically boast robust waste management infrastructure, challenges like insufficient disposal facilities and improper waste handling practices persist, contributing to plastic contamination in water bodies and surrounding ecosystems [6]. The Volta region presents a diverse landscape with a blend of urban and rural areas, featuring both agricultural landscapes and industrialized zones. Plastic waste originating from agricultural practices, household sources, and transport via rivers. The significance of the Volta River as a vital water resource and habitat for aquatic life underscores the need to investigate MPs pollution within this region. The Eastern region of Ghana boasts a mosaic of landscapes, comprising urban centers, fertile agricultural lands, and expansive forest reserves. Parallel to the Volta region, the Eastern region exhibits a spectrum of plastic pollution levels influenced by a combination of urban and rural activities [7]. Consequently, comprehending MPs distribution within these regions assumes paramount importance, offering insights into the ramifications of urbanization on environmental well-being and human exposure to plastic pollutants. Also, there's a need for more research in underrepresented regions like Bono, Bono East, Ahafo, Upper East, Upper West, Northern, and Ashanti to provide a comprehensive understanding of microplastic distribution across Ghana. Future research could focus on a more equitable distribution of studies across various regions, ensuring a geographically diverse assessment of microplastic presence. Additionally, the predominant focus on coastal environments, with limited attention to terrestrial (soil, and air ecosystems), highlights a significant gap in investigations on MPs in Ghana. While coastal areas certainly warrant attention due to their susceptibility to plastic pollution and ecological significance, it is essential to examine other environments as well. Terrestrial ecosystems, including soil and air, are integral components of Ghana's environment and may serve as reservoirs for MPs, posing potential risks to both wildlife and human health. Future research could broaden the scope for a holistic understanding of the impact of MPs on diverse environments. The neglect of ecosystem diversity, particularly the lack of MPs research data on aquatic plants and benthic organisms in the Ghanaian environment, underscores the importance of adopting a more inclusive approach in future studies.

Another critical gap is the lack of source identification of microplastics, studies in Ghana have so far focused on quantitative analysis of microplastics. Developing new methodologies to differentiate between various sources of MPs for effective mitigation will significantly help minimize the impact on the Ghanaian environment. MPs originate from diverse sources, each with unique characteristics that contribute to their environmental distribution and persistence. By refining existing techniques and inventing novel approaches, researchers can better identify and quantify the sources of MPs present in Ghanaian ecosystems. This differentiation is essential for understanding the pathways through which MPs enter the environment, assessing their potential risks to organisms and ecosystems, and designing effective mitigation measures tailored to specific sources.

Also, the limited use of advanced analytical instrumentation such as pyrolysis GC-MS and Raman spectroscopy in past MPs research in Ghana could be attributed to challenges in infrastructure, resources, and expertise. Ghana, like all other developing economies, faces difficulties in this area. This signifies a notable gap that requires concerted efforts to enhance laboratory capabilities. Past research in Ghana did not use the most advanced instrumentation for MPs analysis such as GC-MS pyrolysis, this is an indication of the scarce availability of advanced analytical instruments for the accurate detection and analysis of MPs is a major issue in Ghana, the existing instruments experience overuse due to the high demand and limited alternatives, leading to potential damage. This overreliance on a restricted number of analytical tools compromises the accuracy and efficiency of MPs research outcomes in Ghana. Moreover, the scarcity of these instruments in-country necessitates researchers to resort to external facilities for analysis, incurring additional costs and logistical challenges. Also, the effective use and maintenance of advanced analytical instruments require skilled technicians and technical staff, however, the scarcity of these instruments has resulted in a lack of adequately trained personnel, addressing this limitation mandates strategic investments in instrument accessibility, training programs, and initiatives for the sustainable development of technical expertise within Ghana. The deficiency of such instruments poses a significant challenge to researchers, as it impedes their ability to assess the extent and distribution of microplastic pollution across diverse environmental compartments.

The absence of a clear assessment of the temporal dynamics of microplastic pollution highlights the need for longitudinal studies to reveal trends and changes over time, contributing to a more robust evaluation of environmental impact. This could be addressed through frequent research on MPs in most Ghanaian academic institution and deliberate government policies. Addressing these gaps will undoubtedly enhance effective microplastic research in Ghana. By monitoring MPs levels over extended periods, researchers can identify patterns, fluctuations, and potential factors influencing the distribution and accumulation of MPs in different ecosystems.

In addition, there is insufficient attention given to the biogeochemical aspects of microplastics, particularly their impact on nutrient cycling and growth dynamics in ecological systems in Ghana. MPs can interact with various biotic and abiotic components of ecosystems, potentially altering nutrient availability and uptake processes. However, current research efforts in Ghana have not yet explored this crucial aspect, limiting understanding of the broader ecological implications of MPs pollution. A study by Ref. [24] revealed that MPs can influence nutrient transport and cycling within the soil. The absence of such in-depth biogeochemical investigations creates several knowledge gaps in mechanisms through which microplastics may alter ecological balances and disrupt vital processes. More research is needed in this area to establish the ecological implications of MPs in Ghana, this will help to formulate effective mitigation and conservation strategies.

Finally, the absence of bioavailability studies on MPs in Ghana is another significant research gap, hindering a precise understanding of their real-time impact on the human population. Investigating the bioavailability of microplastics is vital to assess their potential to enter food chains and affect human health. Future research could prioritize studies that examine the pathways and extent of microplastic ingestion by organisms, animals, and humans within the Ghanaian ecosystems. This knowledge is essential for informed decision-making, policy formulation, and the development of effective mitigation strategies to address the emerging threat of microplastic contamination in the country.

5. Remediation and bioremediation of MPs in the ghanaian environment

In Ghana, a critical research gap exists regarding the remediation and bioremediation of microplastics (MPs). Despite the absence of reported studies on this front within the country, understanding and addressing the impact of microplastics remain paramount. While Ghana lacks specific investigations, studies conducted in other global regions have explored remediation strategies, providing a framework that could be mirrored to tackle this issue locally. Recognizing the urgency of addressing microplastic pollution, insights from international research efforts offer valuable guidance for developing tailored remediation and bioremediation approaches suitable for Ghana's unique environmental landscape. There are several obstacles to effective microplastic remediation in Ghana. Limited public, policymaker, and professional awareness and understanding of microplastic pollution impedes the development and implementation of appropriate remediation strategies [54]. Inadequate funding, technical expertise, and laboratory facilities stymie research and monitoring efforts as well.

Considering the environmental challenges posed by microplastics in Ghana, the following bioremediation strategies conducted in other regions offer a promising framework for implementation. Future research efforts could significantly benefit from focusing on the development and optimization of these effective bioremediation techniques, tailored to the specific contexts and ecosystems within the Ghanaian environmental landscape. Leveraging the enzymatic potential of microorganisms, bioremediation stands out as a promising strategy for the effective removal and degradation of microplastics [55]. In this approach, microorganisms deploy various mechanisms to break down microplastic polymer chains, with extracellular enzymatic degradation being a common and impactful process. Notably, enzymes like esterases, lipases, and proteases, produced by bacteria and fungi, exhibit significant potential in degrading diverse types of microplastics [56,57]. Another avenue involves intracellular assimilation and mineralization, where microorganisms internalize microplastic particles, subsequently breaking them down and utilizing them as a carbon source [58]. Additionally, biofilm formation and attachment play a crucial role in facilitating the colonization of microplastic surfaces by microorganisms, leading to subsequent degradation [59]. A wide variety of microorganisms have shown promise in the bioremediation of microplastics. Bacterial species like Pseudomonas, Bacillus, and Rhodococcus have been shown to degrade microplastics via enzymatic activities [60]. Fungal species such as Aspergillus, Penicillium, and Trichoderma have also demonstrated promising results in the degradation of MPs [61]. It is noteworthy to mention that industrial-scale deployment of microorganisms for waste breakdown typically occurs within controlled facilities, ensuring containment and monitoring of the process. However, environmental bioremediation approaches is carried out by the introduction of microorganisms into contaminated sites under carefully managed conditions to facilitate natural degradation processes.Furthermore, microbial consortia made up of multiple microbial species have been shown to have synergistic effects in microplastic degradation. By utilizing a broader range of enzymatic activities and metabolic pathways, these consortiums can improve degradation efficiency [62]. These bioremediation strategies should be explored and utilized by microplastic-based researchers in Ghana for effective remediation and bioremediation.

Developing a practical strategy to remediate MPs in Ghana involves the integration of multiple effective approaches, consisting of public awareness, improved waste management, wastewater treatment, cleanup initiatives, research and innovation, and the formulation of effective policies and regulations on plastic waste. Raising public awareness through educational campaigns can instigate behavioral changes, encouraging responsible waste management and reducing plastic consumption. Strengthening waste management systems, including proper waste collection infrastructure and recycling programs, is vital in preventing plastic waste accumulation. Enhancing wastewater treatment facilities, organizing regular cleanup initiatives, and engaging in scientific research and innovation are essential for capturing, removing, and studying MPs. Additionally, enforcing policies to restrict single-use plastics and promote sustainable alternatives is crucial, necessitating collaboration between the Ghanaian government and stakeholders to prioritize environmental protection [63–65]. Finally, mitigating the microplastics challenge in Ghana necessitates addressing the scarcity of scientific instruments and skilled personnel. A key remediation strategy involves the creation of an Environmental Research Fund. This fund would enable the acquisition of advanced instruments for precise MPs analysis while concurrently supporting training programs to cultivate a proficient workforce. By investing in technology and expertise, Ghana can significantly bolster its capability to thoroughly study, monitor, and counter the environmental implications of MPs.

6. Conclusion

Microplastic research in Ghana has gained traction, particularly in coastal areas like Greater Accra, Volta, and Eastern regions. However, a geographic imbalance prevails, hindering a holistic understanding of microplastic distribution nationwide. Studies on fish, sediments, and oysters revealed the presence of microplastics, the most common MPs found in the Ghanaian environment include Pellets, fragments, fibers, film, and foam. This review revealed critical research gaps such as limited studies in various regions, a lack of source identification of MPs, and insufficient attention to the biogeochemical impact of MPs and their bioavailability in the human system. The findings indicate a recent surge in research activity, however, the concentration in specific areas raises concerns. Also, MPs remediation strategies have not been specifically studied in Ghana, there is a need for bioremediation of MPs, public awareness, improved plastic waste management, and deliberate policies to address the surge in MPs pollution in Ghana, creating an environmental research fund is proposed to address the scarcity of scientific resources and personnel, enhancing Ghana's capacity to tackle the pervasive issue of microplastic pollution. Ghana can mitigate microplastic pollution, protect ecosystems and human health, and work towards a sustainable circular economy. It is crucial to address the identified research gaps and develop tailored strategies to effectively address microplastic pollution in the Ghanaian context.

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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.

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