Acadlore Transactions on Geosciences
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Quantifying Plastic Waste and Microplastic Contamination in African Aquatic Systems: An Imperative for Sustainable Waste Management

Rapheal Oceng[1], Pertiwi Andarani[2*], Badrus Zaman[2]

[1] Master of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, 50275 Semarang, Indonesia
[2] Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, 50275 Semarang, Indonesia

[*] Correspondence: Pertiwi Andarani (andarani@ft.undip.ac.id)

Received: 05-02-2023 **Revised:** 05-30-2023 **Accepted:** 06-07-2023

Citation: R. Oceng, P. Andarani, B. Zaman, "Quantification of plastic litter and microplastics in African water bodies toward closing the loop of plastic consumption," *Acadlore Trans. Geosci.*, vol. 2, no. 2, pp. 94–111, 2023. https://doi.org/10.56578/atg020204.

Abstract: Escalating issues pertaining to the disposal of plastic waste have emerged as an alarming global concern, underscored by the environmental infiltration of fragmented plastic materials into terrestrial, aquatic, and atmospheric systems. This predicament is notably amplified within the African continent, where rudimentary waste management infrastructures exacerbate the situation. This review dissects the prevalence, abundance, and distribution of plastic litter and microplastics within diverse environmental compartments (namely, sediments, water bodies, and biota) across Africa. Detailed analysis of existing research findings highlights concentrations of plastic debris and microplastics, identifying the predominant types of polymers and shapes of particles present. It is observed that most African research endeavours have primarily concentrated on microplastics, albeit macroplastics or plastic litter posing substantial challenges as well. Marine environments have been the predominant focus of these studies, with freshwater ecosystems relatively understudied. The geographical focal points of these research efforts were primarily South Africa, Tunisia, and Nigeria. Conversely, a glaring lack of comprehensive studies addressing plastic pollution within terrestrial and atmospheric systems calls for urgent research attention. Documented evidence of plastic ingestion by diverse aquatic and terrestrial fauna, including insects, fish, birds, molluscs, and arthropods, reaffirms the pervasive nature of the problem within African water bodies. An evaluation of existing literature identifies polyester, polyethylene, and polypropylene as the most common types of plastics present within both freshwater and coastal systems. Unfortunately, a significant proportion of these studies failed to adequately characterize the identified plastics, thus obstructing the identification of potential sources. Consequently, it is imperative that future investigations prioritize polymer identification, which can facilitate the development and implementation of efficacious strategies for mitigating plastic pollution and curtailing environmental leakage of plastics.

Keywords: Africa; Beaches; Freshwater; Macroplastic; Microplastics; Plastic litter in Africa; River

1 Introduction

Attributed to a multitude of advantages such as lightness, resistance to corrosion, inertness, affordability, and durability, plastic has become ubiquitous since its production onset in the 1940s, with approximately 348 million metric tons globally produced to date [1]. Such pervasiveness results in plastics permeating nearly every application imaginable.

Conversely, the end of the service lifetime of plastic products heralds their transformation into waste. These lifetimes display a stark diversity, with packaging materials barely lasting a year, while building and construction materials prove durable for decades [2]. In the environment, plastics find their way into aquatic, terrestrial, and atmospheric compartments, propelled by factors like wind and water currents [3]. Roads, wastewater pathways, and inadequate waste management systems are known conduits for plastics into marine environments [4].

A significant amount of plastic waste pollutes African coastal areas, beaches, and water bodies, introduced through pathways such as precipitation, surface runoff, and riverine transport [5]. Furthermore, anthropogenic activities including littering by citizens, tourists, and events, as well as waste from agriculture, industry, construction, and demolition contribute to environmental pollution. Inadequate waste management systems in numerous African countries lead to a substantial release of plastic waste into the environment via municipal landfills, transport phases, and untreated sewage discharge [6, 7].

The oceans are not spared either, with plastic waste entering through illicit dumping, fishing boats, equipment, aquaculture, research vessels, and shipping vessels. The distribution and occurrence patterns of microplastics are influenced by both environmental factors [8–10] and anthropogenic pressures, contributing to plastic accumulation [11]. Such environmental factors include tides, cyclones, and wind direction [12].

Despite the myriad of benefits, plastics have evolved into a significant environmental issue. Within the European Union, plastic litter accounts for $80 - 85\%$ of total marine litter [13]. A major challenge is the inherent durability of plastics, resisting degradation [14]. Single-use plastic materials, specifically packaging, pose a high risk of entering the environment. Globally, approximately 10% of total municipal waste comprises plastic waste [14].

Plastic materials, though resistant to biodegradation, eventually break down into smaller particles due to mechanical conditions. These particles are categorized as macroplastics (over 5 mm) or microplastics (under 5 mm) [15]. Plastic particles, once in the environment, degrade into smaller pieces, adversely affecting diverse organisms. These degraded particles are found globally on beaches, in seawater, rivers, lakes, air, land, and even food [15]. The presence of these degraded plastic particles threatens aquatic organisms, with studies documenting plastic ingestion in fish from African water bodies, specifically fishing lakes [16, 17]. This underscores the grave implications of plastic pollution on both the environment and human life.

A comprehensive review of the available literature was undertaken to understand the current state of macroplastic (plastic litter) and microplastic contamination in African water bodies. The review serves to synthesize findings on plastic litter and microplastics in African freshwaters, identify knowledge gaps, and inform potential solutions. It is an appeal for collaborative research, policy interventions, and community engagement to tackle the pervasive issue of plastic pollution in Africa. Swift and decisive action is paramount to mitigate this environmental threat, thereby preserving robust aquatic ecosystems and ensuring food and economic stability across the continent.

2 Methods

2.1 Article Selection Methods

A systematic search strategy was implemented on multiple scientific databases comprising Google Scholar, ResearchGate, Scopus, ScienceDirect, and ISI Web of Science. The keywords employed in the search included "macroplastics and Africa", "plastic pollution in Africa", "microplastics and Africa", "plastic debris", "Marine plastic litter in Africa", "freshwater", "river", and "beaches". These were chosen in alignment with the study's objective and geographical focus. Additionally, a broader search was carried out on Google to find any pertinent documents potentially missed in the scientific databases. A time constraint was set to include papers published from 1990 to March 2023.

The search resulted in a total of 77 relevant documents, encompassing articles from reputable international journals and local African journals spanning the specified time period. These documents served as the basis for this review. Of the 101 used publications, 72 directly offered information on the occurrence and abundance of macro and microplastics in Africa's diverse environmental compartments as illustrated in Tables 1, Table 2, and Table 3.

Data such as the location (country of study), macroplastic composition, microplastic concentration and abundance, research methodologies, polymer type, and references were meticulously extracted from each paper. The extracted data from each paper under review were systematically summarized in tables for each environmental compartment. This was performed separately for macroplastic and microplastic studies.

An examination of the articles showed a higher reportage of plastic pollution in marine and estuary environments (49 articles), followed by freshwater compartments (20 articles), and terrestrial environments (3 articles). The search strategy was only able to retrieve relevant publications from fifteen African countries, including Senegal, Algeria, Morocco, Egypt, Tunisia, South Africa, Botswana, Kenya, Uganda, Tanzania, Ethiopia, Mauritania, Nigeria, Ghana, and Guinea-Bissau. South Africa was observed to have the highest number (31) of peer-reviewed publications.

Additional literature sources were identified through a comprehensive review of the reference lists of the obtained articles. To ensure the precision and relevance of the search strategy, this review was limited to studies conducted in Africa that specifically focused on macroplastics (plastic litter) and microplastics, paying attention to the year of publication, country, and abstract. The goal was to identify existing research gaps and to formulate pertinent recommendations. This was achieved by assessing the total number of publications or articles for each environmental compartment, focusing on the provision of complete information on composition, abundance, polymer shapes and types.

2.2 Characteristics of Included Studies

Within each reviewed article, an assortment of key features was synthesized and arranged in a tabular format. These details encompassed the country of origin, site of the study, composition of plastics, compartment categorization (biological, sediment, water column, water surface, and beach), methodologies employed for macroplastic retrieval during the study, types of polymers detected, and associated references. This aggregated information is encapsulated in Table 1. Similar data was compiled for microplastic studies and illustrated in Table 2 for marine environment and Table 3 for freshwater compartments (lake, river, dams, and canal).

Table 1. Studies conducted on Macroplastic pollution in African waters and estuaries from 1990 to 2023

Location	Country	Plastic Detected (%)	Methodology	Main Polymer Types	Ref.
Marine environments	Algeria, Kenya, Mauritius, Senegal, South Africa	$13.9\% - 95\%$	Various: Mesh, Stock Survey, Observation, Dissection	Not identified, PET, PP, PE	[18–26]
Beach sediment	Kenya	78.40%	Standing stock	PET	[27]
Estuaries	Kenya	90.80%	Litter survey	Not identified	[28]
Freshwater (surface water, sediment, shoreline, irrigated land)	Nigeria, South Africa, Tanzania, Uganda	$0 - 100\%$	Various: Cleanup, Survey, Handpicking	Not identified, PP, PE, PVC, PS, PET, PA, nylon	[16, 29–33]

Table 2. Microplastic pollution in African marine environments and estuaries from 1980 to March 2023

Country	Locations and Compartments	Mainly Found Polymers	Common Extraction Method	Ref.
Egypt	Marine (Fish, Beach sediment, surface water, etc.)	PEVA, PP, PET, LDPE, HDPE, Nylon, etc.	KOH, NaCl	[34–37]
Gulf of Guinea	Marine Sediment	PET, PS, PP	Saturated solution of NaCl	[38]
Kenya	Marine (Surface water, sediment)	HDPE, PP, LDPE, etc.	KOH	[39]
Mauritius	Marine Sediment	Polyethylene (PE)	NaCl $(1.2\ g/cm^3)$	[21]
Nigeria	Marine (Sediment, Fishes)	PE, PS, PP, PVC, PA, etc.	Saturated NaCl, 1MKOH	[40–43]
Tunisia	Marine and Estuary (Sediment, Molluscs, etc.)	PE, PP, PS, Nylon, Cellophane, etc.	Saturated NaCl, saline solution, etc.	[44–52]
South Africa	Marine and Estuary (Sediment, Fish, Biological, etc.)	PE, PET, PS, PP Polyester, etc.	NaCl solution, H_2O_2, etc.	[53–66]
Zanzibar, Tanzania	Marine (Surface water)	Not identified	$100\mu m$ sieve	[67]
Tanzania	Marine (Beach and sediment, Surface water)	PE, PS, Polyester, Acrylic, PA, Aramid, PP	100 mL of NaCl(1.2 kg/L)	[6, 68]

Regrettably, a paucity of studies was noted in the context of macroplastic research in freshwater environments, specifically lakes, with scant attention to plastic accumulation in onshore areas (Table 1). Documented in Table 1 is the presence of plastic pollution across diverse locations in several African nations such as Algeria, Kenya, Mauritius, Senegal, Nigeria, South Africa, Tanzania, and Uganda. Data within this table is accrued from a variety of methods including visual and microscopic analysis, standing stock surveys, litter surveys, and clean-up surveys. Plastic pollution is measured as a percentage of the plastic composition in the respective compartments or locations.

An examination of terrestrial environments yielded a limited number of studies, which are captured in Figure 1.

2.3 Review Scope and Limitations

A caveat that must be acknowledged within the scope of this review pertains to language bias. A potential shortcoming exists in that the selection of studies may have been confined to those published in English or other widely accessible languages. Consequently, research papers published in languages other than English may have been overlooked in this review. This could result in the omission of pertinent studies and potentially affect the comprehensiveness of the conclusions drawn.

Another dimension of bias possibly influencing this review is geographical in nature. Despite a concerted effort to incorporate studies from an array of African countries, there is potential for disparities in the representation of different regions. Some areas or countries might be underrepresented while others might have a higher number of available studies. This bias could skew the generalizability of the findings and may fail to capture the full extent of plastic pollution across all African regions.

Table 3. The prevalence of microplastic pollution in Africa's freshwater bodies from 1990 to 2023

Country	Freshwater name	Freshwater compartment	Composition	Ref.
Egypt	Nile River	Fish	PET, PP	[69]
Botswana	River Okavango Panhandle	Sediment	PET, PP, PE, PS, and PVC	[70]
Ghana	River Akora	Water and fish	Not applicable	[71]
Kenya	Lake Naivasha	Surface water	PP, PE, PET and polyester	[72]
Nigeria	Ox-bow lake	Water column, sediment	PET, PVC, LDPE	[73]
Nigeria	Osun and Ogun Rivers	Macroinvertebrates	Styrene ethylene, PE, polyester, PP	[74]
Nigeria	Osun river	Macroinvertebrates	PE, PP, Nylon	[75]
Nigeria	Lake	Fish	Not identified	[76]
Nigeria	Rivers	Water column	PP, PE, PVC, PS, PET	[30]
Morocco	Moroccan Atlantic shelf	Pelagic fish	PA, acrylic, PS	[77]
South Africa	River Bloukrans	Sediment	Not identified	[78]
South Africa	Focused on Wetlands	Biological organisms	Not identified	[79]
South Africa	Focus on dams	Water column	Not identified	[80]
South Africa	Reservoirs	Sediments	PP, PE, PS, PVC, polyester, HDPE	[81]
South Africa	Braamfontein Spruit	Water, sediment, invertebrate	Not identified	[82]
Uganda	Lake Victoria	Water surface	PE, PP, PS, polyester	[83]

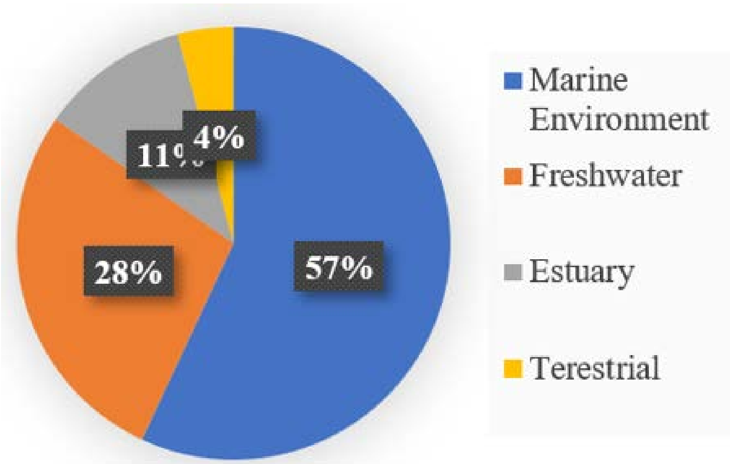

Figure 1. Studies conducted on plastic pollution in various African environmental compartments from 1990 to 2023

A further limitation was encountered in the form of methodological variation across the studies included in this review. Differences in research methods, sampling techniques, and analytical methods were noted, which can introduce heterogeneity and challenge direct comparisons. Such variations can influence the reported occurrence and abundance of plastic pollution, necessitating a cautious approach to interpreting and comparing the results.

3 Results and Discussion

3.1 Clarification of Macroplastics and Microplastic Terminology

The broad term 'macroplastics' encompasses plastic materials varying in size, from minute fragments to large items such as shipwrecks and trawl bags. A diameter exceeding 5mm categorizes plastics as macroplastics [84–86], whereas smaller particles are classified as microplastic or nanoplastic [87]. Notably, in the scientific literature, the definition of macroplastics is not standardized, resulting in varied usage. For instance, Barnes et al. [14] characterized macro debris as having a diameter greater than 20 mm, whereas the European Commission [88] delineated macroplastics as those with a diameter exceeding 25 mm. Additionally, Hartmann et al. [89] considered items with a diameter larger than 1 cm as macroplastics. Macroplastics often constitute recognizable objects; however, a proportion consists of unidentifiable plastic fragments. Macroplastics and microplastics occur worldwide, present in both terrestrial and aquatic environments. An extensive review of literature involving macroplastics, marine litter, macro debris, plastic litter, plastic debris, and anthropogenic litter from African countries was undertaken due to the lack of a standardized definition for macroplastics. This review accounted for a range of studies, ultimately adopting the definition of macroplastics as items with a diameter greater than 5 mm.

Investigation of macroplastics in African water bodies and beaches is sparse, with notably fewer studies conducted in Eastern and Northern Africa. A literature search utilizing keywords such as "macroplastics and Africa", "macro litter and Africa", "marine litter and Africa", and "macro debris and Africa" revealed more publications stemming from South and Western Africa. The majority of these studies were conducted in countries along the western Indian Ocean, including Tanzania, South Africa, Botswana, Mozambique, Kenya, Somalia, Madagascar, Mauritius, La Réunion, Comoros, Gulf of Guinea, and Seychelles.

3.2 Production and Usage of Plastics in Africa

The upswing of large-scale plastic production in the 1940s ushered African countries into an era of widespread plastic importation and utilization, spurred by its myriad applications that span packaging, food preservation, construction, textiles, liquid transportation, electronics, and industrial machinery. This diverse application spectrum of plastic stems from its inherent properties of being lightweight, durable, and robust [90]. Contemporary reports by Plastics Europe [1] reveal a significant contribution of Africa to global plastic production, estimated to be 7.1%. Predominantly utilized plastics encompass polyethylene terephthalate (PET), polyurethane (PU), polystyrene (PS), polyvinylchloride (PVC), polypropylene (PP), polyester, polyethylene (PE), and polyamide (PA), often recognized as nylon [91].

An examination of the African plastic production landscape identifies a significant concentration in North Africa and South Africa, with the latter emerging as the continent's largest plastic producer. Following South Africa, Egypt, Nigeria, and Algeria have been identified as the subsequent major contributors [92]. The presence of developed petrochemical industries in these countries provides a platform for plastic production, generated as a by-product of oil refining operations. Production facilities for plastic are also operative in other countries including Morocco, Tunisia, Kenya, and Ethiopia. Yet, when juxtaposed with other global regions, the overall plastic production capacity in Africa appears considerably subdued.

Despite local production, Africa's plastic demand is significantly supplemented by imports. An approximate 172 million tonnes of polymers and plastics, valued at 285 billion dollars, were documented as imports into Africa from 1990 to 2017 [93]. A substantial portion of these imports was received by Egypt, Nigeria, South Africa, Algeria, Morocco, and Tunisia, with Egypt leading at 18.7% (43 million tonnes), trailed by Nigeria at 17.0% (39 million tonnes), and South Africa at 11.7% (27 million tonnes) [93]. This influx of imported plastics presents waste management challenges, particularly as African countries might lack control over the plastic types and volumes entering their markets.

The consumption patterns of plastic in Africa are not uniform, exhibiting considerable variations across countries and their specific contexts [94]. Certain nations, like Kenya and Rwanda, have enforced stringent regulations on single-use plastics, resulting in a broad adoption of alternatives such as paper bags. Conversely, other countries manifest high usage of plastic, specifically in the form of bags and packaging for food and consumer products. The recognition of this stark variability in plastic usage and waste management practices within and across African countries is pivotal.

Regrettably, underdeveloped waste management systems lead to a substantial leakage of plastic waste into the environment [94]. Projections by Meng et al. [94] forecast an escalation in the volume of mismanaged plastic waste in Africa by 2050. Global plastic production has witnessed a dramatic surge from 2 million metric tons in 1950 to 380 million tons in 2015, primarily propelled by China, Europe, and North America [2]. Nevertheless, Rhodes [95] underscores the concurrent rise in plastic polymer production by African countries to meet the burgeoning demand for plastic products, such as bottles, water storage tanks, waste bins, food packaging, and washing basins within their populace. A particular area of concern is the accelerating demand for single-use plastic packaging in African markets. Additionally, the presence of insufficient waste management systems intensifies the threat of plastic pollution in Africa, particularly in countries heavily reliant on the importation of finished plastic products [93].

3.3 Why Plastic Pollution is a More Significant Threat for Many African Countries

As the plastic waste management crisis intensifies in Africa, the systemic lack of adequate waste collection, recycling infrastructure, and public awareness has resulted in a mere 10% of the continent's generated plastic waste being recycled [92]. The rest finds itself subjected to landfill disposal, open incineration, or discarded in the environment, including water bodies. Annually, Africa produces approximately 4.9 million tonnes of plastic waste, with Nigeria contributing the most, generating 1.1 million tonnes [92]. This problem is compounded by the fact that access to formal waste disposal systems remains a significant challenge in numerous African communities.

The pervasive issue of plastic pollution presents a critical threat to the African environment, an issue which thus far has been subjected to limited investigation in terms of its extent and impact. A critical concern is the impact on aquatic life due to the high number of settlements located proximal to coastal regions, rivers, and other freshwater systems. In such areas, plastic waste, which has not been appropriately managed, frequently permeates the environment, thus endangering aquatic life [96, 97].

Underpinning the escalation of plastic pollution globally are the pillars of population growth, industrialization, and urbanization, with African countries shouldering a disproportionate impact. The continent's population growth rate outstrips that of the Organisation for Economic Co-operation and Development countries by nearly ten-fold, and 2.5 times higher than the rest of the developing world [98, 99]. Notably, a significant proportion of this population resides near water bodies, contributing to a substantial volume of solid waste, much of which infiltrates surrounding water bodies due to insufficient solid waste management infrastructure. The resultant plastic pollution threatens the African aquatic environment and the life it supports.

In an alarming observation, many African countries exhibit a lack of regulation pertaining to solid waste dumping on open spaces, along roads, riverbanks, coasts, and other freshwater systems. These solid wastes often contain a significant percentage of plastic [98, 100, 101]. Landfilling only accounts for 4 to 15 percent of plastic waste disposal in Africa, with a large portion of the remaining waste discarded in both aquatic and terrestrial environments [100]. The problem is exacerbated by the fact that many African households lack access to potable water, leading to an increased consumption of water packaged in plastic containers [102].

Moulds et al. [102] observed that many homes in African countries, including Uganda, lack access to safe drinking water, resulting in the consumption of packaged water. However, this practice contributes to plastic pollution as packaging materials such as plastic bottles and polyethylene bags are discarded in the environment [103]. The discarded plastic bottles often litter landscapes, and runoff can transport them into water bodies, creating a further threat to aquatic life [97]. Thus, plastic pollution in Africa presents a significant and complex challenge, underpinned by socioeconomic, infrastructural, and regulatory factors. The environmental impacts are considerable and require further research and dedicated efforts to address them effectively.

3.4 Occurrences of Macroplastics in the Environmental Compartments of African Countries

Macroplastics, encompassing plastic debris, are abundant in African countries, particularly in coastal regions, with plastic being the predominant component, as evidenced in Table 1. Nevertheless, a study conducted in Algeria revealed that a mere 13.9% of the debris consisted of plastic [18]. A 2019 investigation reported that macroplastics constituted 59% of debris along surveyed shorelines in Nigeria, with an average concentration of 3,487 $\#/\mathrm{m}^2$ [30]. Remote beaches in Kenya exhibited a plastic composition of 30%, with PET, PP, and PE identified as the dominant polymer types [20].

Bergmann et al. [104] posited that plastics comprise the largest proportion, approximately 75%, of floating marine waste. Research on macroplastics in marine and coastal areas has been undertaken in a few African countries, including Mozambique, Kenya, Mauritius, Algeria, Tanzania, South Africa, Seychelles, Madagascar, Senegal, Comoros, Reunion Island, and Somalia. However, the reviewed articles suggest that studies on microplastics in marine environments have been more prevalent than those focusing on macroplastics.

It has been indicated that plastic litter originates from human activities. However, the abundance of microplastics does not seem to be significantly influenced by the level of anthropogenic activity, as household density, a proxy for human population density, does not correlate with macroplastic debris abundance [31]. Other factors, such as wind speed and direction, precipitation, and waste management services, may play a more substantial role in determining macroplastic abundance.

Macroplastic abundance monitoring has been regularly conducted in many countries, but this has not been the case in several African countries, particularly concerning macroplastic studies [105]. Recent investigations have primarily focused on microplastics. Hamid et al. [106] underscored that the African continent has contributed the least research data on the occurrence and abundance of plastics in its environment, with numerous countries lacking data on macroplastic studies in their water bodies or beaches. The identification of studies on macroplastic abundances and occurrences in African countries yielded limited results, emphasizing the need for increased research on macroplastics. Nevertheless, more data is available for countries situated near or bordering ocean bodies, especially South Africa and Kenya, with regard to macroplastic occurrence in the marine environment.

Jambeck et al. [107] reported that many African countries lack effective plastic waste management methods, which heightens the risk of global plastic contamination in aquatic ecosystems. Although several studies, particularly targeting freshwater environments, have been conducted, the level of plastic pollution in numerous African freshwater bodies remains high, as summarized in the accompanying table. The findings from these studies align with Jambeck et al.'s suggestion [107]. However, the present research identified only a few studies on macroplastics. Several investigations have primarily concentrated on microplastics in the environment, as indicated in Table 2 and Table 3.

3.5 Transport Mechanisms of Macroplastic into Different Environmental Compartments in Africa

Macroplastics are prevalent in various environments, such as shorelines, beaches, rivers, and marine ecosystems, and their presence can be attributed to multiple causes. A study conducted by Tavares et al. [22] in Senegal highlighted the considerable role of seabirds in plastic pollution, with up to 90% of their nests being constructed from plastic materials that eventually find their way into waterways. This finding was consistent with the research by Blettler and Mitchell [108], which emphasized the importance of effective waste management practices to restrict birds' access to plastic materials.

Furthermore, on land, macroplastics can originate from diverse human activities, including agriculture. Kundu et al. [33] documented the occurrence of macroplastics in farmlands in Arusha, Tanzania, as a result of agricultural practices such as plowing, the use of plastic-based farm inputs and packing materials, and the improper disposal of these materials by farmers. Consequently, runoff from the farmlands can transport macroplastics to major water bodies. Therefore, the implementation of proper waste management and control measures is crucial to prevent and mitigate macroplastic pollution in both marine and terrestrial environments.

In addition to shorelines and terrestrial areas, it is crucial to recognize that macroplastics can also be found in the aerial or atmospheric environment. Lightweight macroplastics possess the potential to be transported over long distances by the wind, ultimately accumulating in regions such as deserts or mountains [109]. The shape and weight of macroplastics are critical factors influencing their aerial transport. Although the majority of plastic in the atmosphere consists of micro- and nano-sized particles, larger items can remain suspended if they possess certain characteristics, such as disposable plastic bags and balloons [110]. Nonetheless, the storage of plastics in the aerial environment is typically temporary and depends on meteorological conditions [110].

3.6 Prevalence of Microplastic Research in African Environmental Compartments

To assess the disparity between macroplastic and microplastic investigations, a comprehensive review of studies reporting microplastic occurrences in African water bodies was conducted. Separate studies in marine environments, including estuaries, and freshwaters were analyzed, as depicted in Figure 2 and Figure 3. A larger number of publications on microplastic studies in the marine environment was observed, particularly in South Africa, Tunisia, and Nigeria. These regions hold significant importance for shipping transportation, given their proximity to the Mediterranean Sea and the Atlantic Ocean, respectively. Focus was placed on studies investigating the identification and abundance of microplastics in sediments (17 studies), water surface and column (12 studies), and organisms (16 studies) along coastlines of oceans and freshwater bodies. The research publications reporting these findings are listed in Table 2 and Table 3.

Specifically, studies that reported average and/or range of microplastic abundances were selected, which were quantified as the number of particles per unit compartment (e.g., #/kg dry weight for sediment, #m3 for water, and #/individual and #/kg for biota). It should be noted that studies often did not specify a minimum or maximum size limit for microplastics or focused only on specific size classes. All particles reported as microplastics were included, irrespective of their polymer composition, as not all studies conducted polymer identification. Additionally, the choice of identification method could impact the size range of microplastics identified. For instance, Raman spectroscopy can detect particles down to $> 5\ \mu m$ [87]. Different methods used in the studies contributed to a wide range of measurements, spanning six orders of magnitude across all sediment and water compartment studies. However, data on microplastics in biota were relatively limited, with only 12 investigations reporting abundance in #/individual and 4 studies reporting abundance in #/kg. Consequently, the variation in biota data was smaller, up to three orders of magnitude.

During the review, studies reporting plastic pollution in multiple environmental compartments, encompassing both macroplastics and microplastics, were identified. For instance, Jaouani et al. [111] conducted a study in Tunisia examining plastic pollution in the sediments of Rimel Beach, Bizerta lagoon, and Ichkeul lake. Their study encompassed macroplastics, mesoplastics, and microplastics. Sediment samples, weighing 2 kg, were collected using a stainless steel shovel. Similarly, Tata et al. [112] investigated the Annaba Gulf ecosystem in northeast Algeria and reported on the occurrence of both macroplastics and microplastics in the sediment. Merga et al. [17] conducted a study in Lake Ziway, Ethiopia, focusing on four fish species and the sediment; they reported the presence of microplastics and small macroplastics. Sediment samples were collected using an Eckman grab sampler; plastic particles were extracted using a 500 mL saturated NaCl solution (354 g/L) and sieved through a 0.1 mm sieve. Fish sampling was performed using nets; the polymer identity of the plastic particles detected in the sediment and the fishes' gut was characterized using ATR-FTIR spectroscopy.

3.7 Microplastic Shapes in African Marine and Freshwater Compartments

Table 2 and Table 3 provide comprehensive insights into the studies conducted on microplastics in the marine compartment, revealing a significant focus on fragments, lines, films, foam, pellets, and beads. The wide variation in shapes can be attributed to the different size ranges of microplastics investigated in the studies, as well as the varying water densities observed in marine and freshwater environments, which can influence the shapes of reported plastics. In this review, studies that reported well-defined microplastic shapes, including fibers, fragments, filaments, lines, and foams, were specifically examined. Among the 44 articles analyzed, which reported on microplastic shapes,

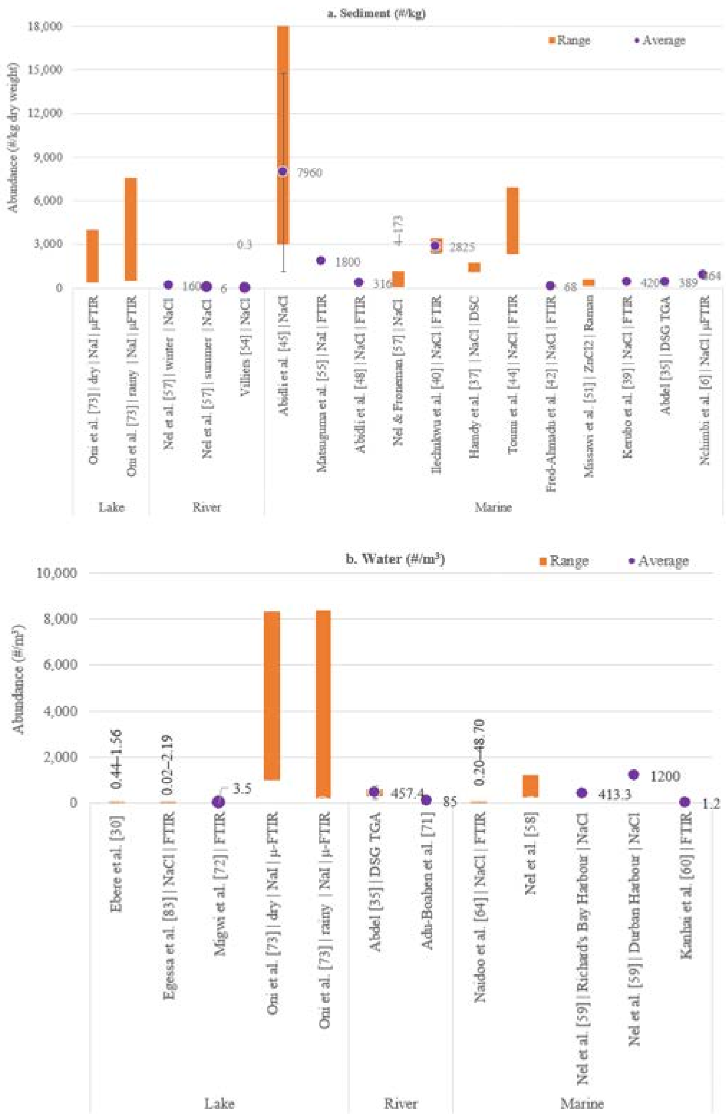

Figure 2. Abundance of microplastic particles in the environment of African countries: a. sediment; b. water

the observed plastic shapes were ranked in decreasing frequency as follows: fragments, fibers, films, foam, pellets, lines, granules, spheres, nurdles, and microbeads, as illustrated in Figure 4. This order likely indicates the relative prevalence of different microplastic shapes in African water systems. Notably, beads were exclusively observed as the most common microplastic shape in Ox-Bow Lake in Nigeria [73].

3.8 Polymer Types Identified in African Water Systems and Terrestrial Environments in Microplastics Studies

Of the 73 reviewed papers, information on the polymer types of recovered plastics was provided by 48, enabling a comprehensive analysis of polymer diversity in African water systems. To minimize potential bias, the relative frequency of polymer types was employed instead of their relative abundance, as the latter can vary depending on the particle size range used for identification. The identified polymer types included Polypropylene (PP), Polyethylene (PE), polystyrene (PS), Polyethylene terephthalate (PET), Polyvinyl chloride (PVC), Polyethylene vinyl acetate (PEVA), and high-density polyethylene (HDPE). PP, PE, PS, PET, PVC, PEVA, HDPE, LDPE, Polyester, Nylon, and PA were consistently reported in six or more studies, indicating their prevalence in African water systems, as depicted in Figure 5. The order of relative frequency of abundance for microplastic polymer types was found to be PP¿PE¿PS¿PET¿PVC¿PEVA. Notably, studies focusing on water surface and water column reported relatively lower abundances of PET and PVC, possibly due to their higher densities leading to increased settling. Conversely, the lower densities of PE and PP may explain their higher abundance in the water surface and column across the reviewed studies.

Macroplastic contamination has also been documented in settlement areas and soils associated with various

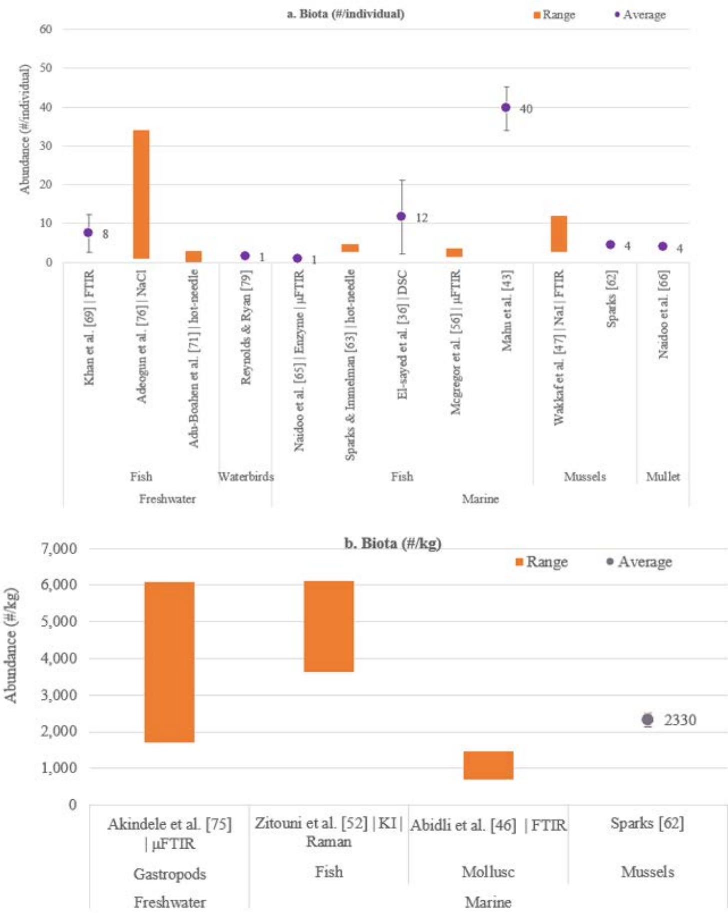

Figure 3. Abundance of microplastic particles in the environment of African countries in: a. Biota (#/individual); b. Biota (#/kg)

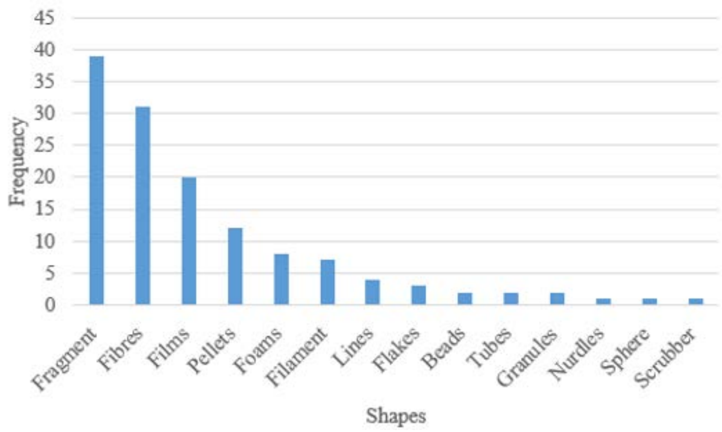

Figure 4. Number of studies reporting a particular shape of microplastic particles (from a total of 73 records)

human activities. In this review, significant macroplastic and microplastic abundances were discovered in the irrigated farmlands of Arusha [33]. The study identified PET as the dominant macroplastic type, with an occurrence frequency of up to 55%. Kundu et al. [33] further reported microplastic abundances ranging from 0.21 to 1.5#/g in the irrigated farms, offering valuable insights into the impact of plastic pollution on soil health in African farmlands.

In addition, Enyoh et al. [113] observed macroplastics in urban roadside soils in Nigeria. The study measured the amount of small macroplastics (SMaPs) per 30 g of soil, ranging from 20.2 ± 2.59 at Orji Mission to 10.4 ± 2.6 at Orji Town Primary School. The identified polymers through FTIR analysis included PET, PP, PS, PVC, polycarbonate (PC), PE, and macro rubber, with fragments comprising 70% of the SMaPs. Despite the significance

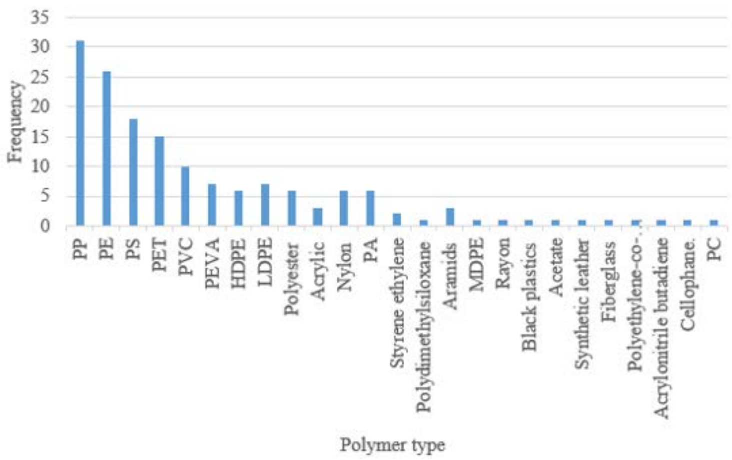

Figure 5. Number of studies reporting a particular polymer type of microplastic particles (48 out of 73 records reported polymer type)

of plastic pollution in soil, studies investigating its occurrence and abundance in African countries remain limited [113].

It should be noted that polyethylene, including PET, LDPE, and HDPE, is a commonly encountered plastic type due to its wide range of applications, such as plastic bags, packaging, and pipes. Additionally, some African countries have implemented policies to ban or restrict the use of single-use plastics like plastic bags, which can influence the prevalence of specific plastic types in those regions. However, it is important to highlight that in another case study, the plastic bag ban did not have a substantial impact on plastic bag littering in water bodies [114].

Further details regarding the polymer type analysis can be found in Tables 1, Table 2, and Table 3, which provide a comprehensive list of all observed polymer types for each reviewed article. These tables are available in the supplementary materials of the relevant research articles.

3.9 Macroplastics as a Source of Microplastics

Emphasis should be placed on further research and studies aimed at characterizing the abundance and occurrence of macroplastics, considering their role in the generation of microplastics. Lechthaler et al. [3] highlighted that a single plastic bottle of 0.5 liters can break down into up to 550,000 plastic particles (films) measuring 0.3*0.3 mm. These statistics underscore the potential danger faced by many African countries, especially those with inadequate waste management infrastructure. Table 4 provides an overview of the major processes through which macroplastics degrade into microplastics. Interestingly, this review revealed that the polymer types (particularly PE and PP) identified in macroplastics were consistent with those identified in microplastics within the same locations or countries, as reported in ten studies. Given the breakdown of macroplastics into microplastics, it becomes increasingly important to emphasize the characterization and reporting of macroplastic abundance and occurrence in various environmental compartments across Africa.

Table 4. Processes of macroplastic breakdown

Category	Processes	Driving factor
Physical	Mechanical, thermal	Wave movement and fire
Chemical	Photochemical, oxidative, hydrolytic	UV radiation, oxygen, water
Biological	Bacteria	Microbes

3.10 Gaps in Plastic Studies in Africa Comparedto Other Regions

This comprehensive review examined 73 studies investigating plastic pollution in African terrestrial and aquatic environments, focusing on both macroplastics and microplastics. It is noteworthy that the majority of these studies (56 out of 73) concentrated on microplastics, with only 17 specifically addressing macroplastics. This discrepancy is significant given the abundance of water bodies in Africa, suggesting an underrepresentation of macroplastic pollution research. Furthermore, not all microplastic studies provided sufficient information to effectively address plastic leakage. Among the reviewed macroplastic publications, only seven detailed polymer types, and for microplastics, 25 studies failed to identify polymer types, hindering efforts to trace the sources of plastic pollution.

The scarcity of research on plastic pollution is evident across various compartments, including the atmosphere. Studies in other continents have documented the presence of microplastics in the air and associated health risks [115]. Evidence of microplastic occurrence in the atmosphere has been reported in various locations, such as the northwestern South China Sea [116], Shanghai-China [117], eastern China [118], Asaluyeh-Iran [119], Ahvaz-Iran [120], Surabaya-Indonesia [121], Bandung-Indonesia [122], and Guangzhou-China [123]. In America and European countries, microplastic studies have also been conducted, including in Mexico [124], Ireland [125], Denmark [126], Paris-France [127], Italy [128], and Edinburgh-United Kingdom [129]. However, to the best of our knowledge, no studies on atmospheric microplastics have been undertaken in African countries, revealing a significant gap in this area.

In aquatic ecosystems, the ingestion of microplastics has been shown to have substantial impacts on aquatic organisms, causing reproductive issues, reduced growth rates, and oxidative stress [130]. The limited knowledge regarding potential risks to human health from microplastic exposure presents challenges in determining whether extensive regulatory actions are required to protect public health and well-being globally [131]. Based on monomer toxicity, Polyurethane (PUR), Polyacrylonitrile (PAN), Polyvinyl chloride (PVC), Epoxy resin, and Acrylonitrile-butadiene-styrene (ABS) are classified as the most toxic polymers [132]. Considering the potential health impacts of inhaled and ingested microplastics, as well as macroplastics in animals, there is an urgent need for studies on microplastics in the atmosphere and water bodies in Africa. With respect to exposure from water bodies, most plastic pollution research has primarily focused on marine environments. South Africa, Tunisia, and Nigeria have emerged as countries with the highest number of conducted studies, as depicted in Figure 6. In contrast, research investigating plastic pollution in terrestrial environments remains limited, indicating a critical need for further investigation in this area.

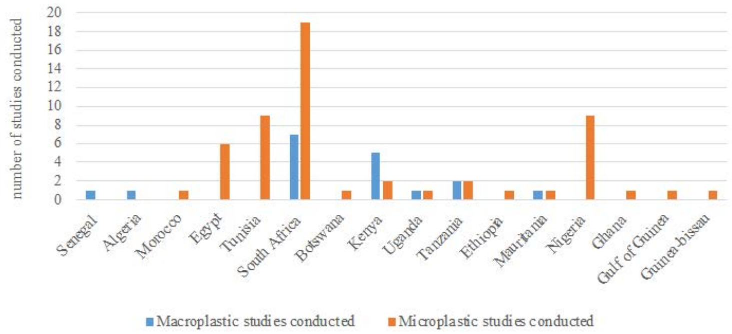

Figure 6. Comparison of microplastic and macroplastic studies in African countries between 1990 and 2023

4 Conclusions

A review of recent research in African countries has revealed a predominant focus on microplastics, particularly in coastal environments, rather than freshwater systems. The literature analysis indicated that polyester, polyethylene, and polypropylene were the most commonly occurring plastics in both freshwaters and coastal areas. However, numerous studies failed to provide adequate information about the nature of the identified plastics. It is recommended that future research includes polymer identification to facilitate the determination of plastic sources and the implementation of effective solutions for addressing plastic pollution and preventing plastic leakage into the environment. Moreover, it has been observed that many studies utilized low-cost methods, suggesting that funding may be a limiting factor for plastic research in Africa.

It is of concern that no study has yet investigated the occurrence and abundance of plastics in the atmospheric environment in African countries, despite the recognition of this phenomenon in some European nations. This underscores the need for greater efforts to advance plastic research across various environmental compartments in Africa. Although a significant number of studies in African countries concentrate on microplastics, it is essential to place more emphasis on quantifying riverine and freshwater plastic debris, as these are primary sources of microplastics. The findings imply that macroplastic pollution constitutes a significant environmental issue in African countries, particularly in coastal regions and rivers. Comprehensive research is required to determine the magnitude of macroplastic pollution in African countries and its potential impacts on the environment and public health. Investigations into plastic debris in freshwater systems should be expanded, as this represents a critical area warranting increased attention. Examining the occurrence, distribution, and abundance of plastic debris is vital, given that these materials serve as the source of microplastics. Consequently, the occurrence and distribution of macroplastics in African waters must be investigated to gain a thorough understanding of the plastic pollution issue. Prioritizing plastic waste management is crucial to prevent further accumulation of plastic debris in the environment.

Author Contributions

Conceptualization, R.O., P.A., and B.Z; methodology, R.O. and P.A.; formal analysis, R.O. and P.A.; data curation, R.O. and P.A.; writing—original draft preparation, R.O.; writing—review and editing, R.O., P.A. and B.Z.; visualization, R.O and P.A..; supervision, P.A. and B.Z; resources, P.A. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data of reviewed articles supporting our research results are included within the article or supplementary material.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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