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# Exploring the toxicology, socio-ecological impacts and biodegradation of microplastics in Africa: Potentials for resource conservation

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ABSTRACT

Achieving upcycling and circularity in the microplastic economy predominantly depends on collecting and sorting plastic waste from the source to the end-user for resource conservation. Microplastics, whether from packaging or non-packaging materials, pose a significant environmental challenge as they are often not prioritized for collection or recycling initiatives. The presence of additives impedes the quality of plastic recyclates and the persistence of microplastics as shredded resultants remain a threat to the aquatic and terrestrial ecosystem and its biodiversity. Despite the increasing global research on microplastics, the success of plastic and microplastic waste management in Africa is yet to be fully attained. Considering the improper disposal, limited recycling and upcycling intervention, lack of policy, and strict laws against plastic waste management defaulters, the ecosystems in Africa remain immensely impacted by several socio-ecological factors leading to the loss of aquatic organisms through reducing fertility and increasing stress. As a ripple consequence, the disruption of economic activities, toxic effects on animal/human health, and climate crisis are among their impact. This review therefore provides comprehensive detail of microplastic production and challenges in Africa, the toxicology concerns, socio-ecological issues associated with microplastic waste management, and insight into approaches to mitigate plastic pollution through recycling, upcycling, bioprocessing and their biodegradation with social insects and microorganisms which may form the basis for adoption by policymakers and researchers, thereby minimizing the consequences of plastic pollution in Africa.

## 1. Introduction

Pollutants of emerging concern like microplastics (MPs) continue to be a major concern source of environmental contamination in Africa due to population expansion and rising demand for plastic products. This issue has seriously endangered the ecosystems and human health, resulting in climate change-related weather patterns, sickness, and poverty. Drawing parallels with the need to understand MPs origin and accumulation in several ecosystems, plastic pollution has been widely investigated across different continents. Unfortunately, the issue of plastic pollution has remained threatening as it bedevils different aspects of Africa's ecosystem due to the incessant mishandling of plastic waste. Typically, MPs are broken down particles of plastic origin with sizes less than 5 mm, however, there exists an even smaller fraction (1–100 nm in size) referred to as nanoplastics [1]. These plastic particles are generated by the disintegration of larger plastic particles or directly for their applications in paints, fertilizers, cosmetics, detergents, and cleaning products [2]. Due to their ubiquity and small sizes, they are widely transported and distributed across numerous media, thereby wrecking serious environmental hazards and human/animal health risks such as digestive tract obstruction, inflammatory responses, and decreased aquatic organism population [3,4]. Moreover, MPs contain

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toxic chemical compounds like bisphenol A, phthalate esters, plasticizers, stabilizers, antistatics, and fillers that are incorporated in the manufacturing cycle. Due to changes in the environmental conditions, these compounds could disintegrate into smaller units where they release their toxic effects on the environment and cause serious health challenges [5–7].

Africa is ranked among the highest consumers of plastic materials with an estimated amount of $285 billion arising from the utilization of over 172 million tons of polymers and plastics, thereby posing serious plastic waste generation burdens on the African populace [8]. In this region excluding South Africa, the status of MPs has been extensively reported for over three decades [9]. In West Africa, much wastewater containing MP debris from municipal and industrial sources is discharged directly into the coast/marine environment with little or no treatment, thereby causing health challenges to aquatic organisms and humans. In addition, the African coastline is severely harmed by plastic pollution, which also endangers human well-being, increases the risk of flooding (by blocking drainage infrastructure), and lessens the area's appeal to tourists [10]. Tanzania has recorded a significant amount of post-consumer plastic litter in the marine beach and seabed sediments. This region in East Africa is home to over 58.5 million inhabitants with millions of tourists exploring the area [11]. There are also reports on the contamination of table salts in Africa via an emission source of micro-fibers/plastics into the human food chain, with serious consequences on human health [12]. The heterogeneous distribution of MPs in fresh water and sediments in South Africa poses a deleterious threat to humans due to contaminants has been examined as well [13]. Interestingly, insects have shown social tendencies to influence the degradation of MPs in the environment using several mechanisms, and this approach has not been exhaustively explored in Africa. For example, the nutrient-enzyme pathway that enables the breakdown of MPs into smaller pieces digestible by insects is gaining awareness [14]. Moreover, aquatic insects like caddisflies, certain aquatic midge, dragonflies, some diving beetles, damselflies, mosquito larvae, black fly larvae, stoneflies, mayflies, freshwater worms, as well as many aquatic crustaceans such as copepods and amphipods can eat or utilize MPs thus breaking them down for bacteria actions to act on them and convert them to nonhazardous substances [15]. Typically, Chironomid larvae use esterase to break down ester bonds in MPs, which are then excreted by the larvae. Similarly, Chironomid larvae equally use hydrolases, peroxidase, cellulases, and oxidases to break down other components in MPs into harmless substances [16]. They also produce ligninase which can break down lignin. There is an important interaction between the enzyme produced by these insects and the different temperatures for the successful breakdown of MPs [17]. Another mechanism is the occurrence of gut-inhabiting microorganisms that are capable of acting on MPs. Most terrestrial insects have associated microorganisms in their gut in addition to the enzymes they secrete for the external digestion of MPs [18].

With the growing awareness of microplastic circulation in various ecosystems in Africa, there is limited information on the socio-ecologic impacts that also address the toxicology concerns and biodegradation of microplastics in the region. This current investigation explores the strategies and potentials for recycling and upcycling MPs in Africa and resource conservation for a clean and sustainable environment. The study will provide more insights on the socio-economic and toxicity status of MP pollution in the African environment, will deliver adequate information for policymakers towards reducing the plastic pollution menace in the continent, and also provide significant scientific insights for African researchers to approach the biodegradation of MP, especially with the use of insects.

## 2. Microplastic production and challenges in Africa

Globally, the measure of plastics manufactured has increased from about 1.5–230 Megatons most especially since 2009 [19,20]. More tonnes of plastics are certainly produced today with the rise in world population especially in the African regions and the level of plastic production in the different regions of African has been reported elsewhere as an imported environmental crisis [21]. Microplastics can be sourced mainly from products that make use of sub-millimetric and millimetric plastics as well as health products and medical equipment. Alternative sources of these substances are the plastic production industries and the raw or waste materials used in some of these plastic industries. Microplastics could also be found in water bodies and wastelands where improperly decomposed plastics form little fragments [22]. Plastics and their usability have a long-term tradition in Africa. They gained so much attention due to the low cost of acquiring them as well as the relatively low weight and ease of conversion to other forms. Plastic utilization in Africa was not common until recently when its use escalated. Plastic production in Africa has the potential to rapidly increase, with other developing nations following suit acceptance. This is due to the increased population as well as the growing urbanization in most of these countries [8].

A report from the annual plastic production shows that the volume of plastic waste that ends up in the environment averages 15 %, especially municipal waste which is a serious problem. Water run-offs from surface rivers may move plastic contained in water into wastewater treatment plants which forms the source of about 80 % of plastic manufacturing [23]. Microplastics are generated when bigger plastic particles degrade into small fractions as a result of many factors, such as; cracking, weather-stimulated degradation, environmental disturbances, ultraviolet (UV), and biological attacks [24]. The abrasive effect of waves against rocks and sand could also be responsible for plastic degradation.

North Africa has the largest and oldest cities for instance Egypt. Food production, packaging, consumption, and exportation would be high. The highest proportion of plastic produced in Africa can be attributed to this country in the past 5 years due to the high population and increased economic activity. Egypt has experienced a rapid rate of growth with a gross domestic product (GDP) of $394 billion as of 2021 and this in turn greatly impacts the country's demand for plastics. Also, 2017 research shows that 2.1 million tons of plastics were used in Egypt [25]. The plastic materials used in Egypt in 2016 were reported to have a total value of $1.6 billion which brought the assumption that plastic production increased by 7 % yearly. As of 2018, about 970,000 tons of plastic waste are being generated by Egypt of which the majority of them are incinerated while some are recycled and a small proportion are reused; meanwhile, approximately 12 billion plastic bags are utilized yearly. Further analysis has shown that Egypt is contributing largely to the plastic materials deposit into the Mediterranean amounting to about 0.25 Megatons of plastic waste into this water body [26].

South Africa equally has its share of plastic pollution in Africa with the proportion of production following the trend of that in North Africa country (Egypt). The population of South Africa grew to 60 million in 2021 with a GDP of $302 billion as of 2020. Second to Egypt in South Africa in terms of plastic product use a sum of 1.84 million tons of plastic products were reportedly used in 2017. The majority of the plastic products used in South Africa are landfilled and few of them are recycled, while the remnant ends up in the sea and other river systems. Moreover, about 8 million tons of plastic waste end up in the sea yearly [27].

Noteworthily, microplastic wastes can be categorized into primary and secondary sources. Microplastics can be directly and intentionally introduced into the terrestrial environment which later gets into the aquatic environment. The bulk of the primary source of microplastics in Africa is from commercialized and industrial activities, transport activities of humans, and goods, and household activities [28]. On the global scale, seven primary point sources have been detailed; pellets obtained from the disintegrations of macroplastics from household and commercial products, minute plastics associated with dust in cities, fragments from personal care products, activities of marking the roads and coating the marine environment, tyres, and synthetic textiles [29]. In addition, organic fertilizers and agricultural films have also been identified as major sources of microplastics in the soil [30]. Meanwhile, macroplastics that find their way into the marine environment due to erosion and intentional deposition by humans and industrial activities can be broken down into minute particles thus serving as a secondary point source of microplastics [31]. In Africa, anthropogenic activities act as the mediating drive leading to the generation of plastic and non-plastic wastes some of which serve the purpose of landfills. In most cases, waste collectors in cities collect wastes from households and because there are no efficient recycling infrastructures, this waste ends up in abandoned lands and afterward may run off into water systems [32]. These deficiencies in formal waste disposal and recycling infrastructure play a key role in microplastic proliferation in Africa.

In comparison to current research on environmental problems of world relevance, there is growing information on microplastics in Africa. This could be attributed to the fact that until late 2019 and early 2020, governments and researchers paid little attention to the challenges of microplastics in Africa. More importantly, is the fact that there is difficulty in accurately measuring microplastic concentrations. There is a need to get more research done to determine the actual factors that influence the amounts of microplastics in the environment, according to other studies that have revealed that these correlations are not entirely reliable [33].

Every region in Africa experiences challenges in the management of micropollutants and the cleanup process may require so much of funds which makes this adventure very difficult. One of the challenges experienced is the disintegration of macroplastics into minute particles and persisting for a long term in the environment. Timely flow can get these minute plastics into runoffs which end up in in water bodies and food chains when fishes are exposed to them [34].

Another challenge posed by microplastics is the fact that they are responsible for reproductive damage, blockage of enzyme functions, delayed growth as well as pathological stress [35]. Worse-of-these-all is that they can persist in the environment retaining their various toxic chemicals and heavy metals like Cd, Cu, Ni, pesticides, and industrial chemicals that can cause harm. The ability of harmful substances from microplastics to concentrate more than necessary in the surroundings is possible [36]. These pollutants are capable of routing through the mouth of animals by drinking water or small polluted animals and accumulating in body tissues. There is already a report of pollutant fiber in aquatic animals and in this way, they end up in the system of man through consumption [37]. Aquatic organisms like small teleost, and zooplankton feed on microplastics [38]. The ability to ingest hinges on the size and shape of the microplastics which could define the danger level of microplastics, similar to this, is equally the surface area of the pollutant as those with the increased area are more poisonous compared to the small particles [39]. Lakes and dams are the potential recipients of these chemicals because they are utilized in water storage, hence there are more research findings for microplastics in these ecosystems.

Microplastics are more generated in urban areas where the harmful metals embedded are transported to the water system through stormy winds and runoffs [40]. Microplastics are small in size and hydrophobic in their properties. This makes it simple for them to be scavenged as hazardous substances. Additionally, toxic substances that are embedded in plastic during production to prevent fire hazards, such as polybrominated diphenyl ethers, phthalates, nonylphenols, bisphenol A, polybromobiphenyls, and polychlorobiphenyls (PCBs), antioxidants to prevent microbial growth (such as triclosan), and UV stabilizers to inhibit degradation upon exposure to sunlight may also be present in microplastics [41]. Research interest is hinged on elucidating the possible environmental impacts of microplastics, aside from other problems including; ozone layer depletion, climate change, and acidification of the sea, and redeeming the desire for a hazardous-free society which has the continuous impacts of threatening life generally [42].

Only a few studies on the impact of these substances are available in developing nations and as a result, there is little or no legislation and enforcement to regulate their release into the environment [43,44]. Reviews of the possible environmental hazards of microplastics in aquatic ecosystems as well as future research goals are available. Research on the potential health impacts of microplastics on the environment has largely concentrated on effects on animals and aquatic ecosystems, whereas studies on human health are quite rare [45].

In aquatic systems, microplastics can also act as material carriers of pathogens, fecal coliforms, and algal blooms to get to their desired host [46]. Microplastics could have played a crucial role as a potential host for toxic microbes. Studies have linked the epidemiology of disease and resurgence of harmful pollutants to contact with polluted water and persistent chemicals in the environment and show that they are capable of infecting the eyes, nose, and throat and also causing gastrointestinal and respiratory disorders [47].

Microplastics contribute to the increased distribution of infectious diseases and they also help harmful organisms to adapt in marine ecosystems. According to Wright and Kelly [48], the accumulation of microplastic in the body could cause potential acute and long-term health effects. For instance, localized toxicity could be attributed to these accumulations and hence stimulate the immune system, whereas chemical toxicity may be caused by the leaching of additives, leftover monomers, and adsorbed contaminants. Given the durability of microplastics, dose-dependent prolonged exposure to them could be dangerous due to the accumulative effect. Only a few studies relating to the acute and long-term danger of microplastics have been carried out [49]. One major challenge influencing the possible impacts and potential threats of microplastics to human health is the inability to appropriately measure the concentration of microplastics in the blood and serum of man. The dangers of exposure to microplastics have not yet been linked to any well-documented human disease, but exposure to a highly polluted environment with very toxic organic pollutants may accentuate risks to sustainable health.

To better comprehend the human epidemiology and ecotoxicology of microplastics, more research is required to develop extraction procedures to separate small artificial particles and examine the human ecotoxicology of microplastics packed with toxic chemicals. To understand the mechanisms of toxicity, it is necessary to have this knowledge to establish mitigation techniques to safeguard human health [50].

## 3. The toxicology and socio-ecological impacts of microplastic pollution in Africa

Extensive studies of the occurrence, detection, and distribution of MPs in African ecosystems have been conducted by researchers [35,51], however, not many reports have explored the toxicology impact of MPs on the ecological systems (Table 1). Nevertheless, the persistence of ecological degradation and deterioration resulting from MP pollution, particularly in Africa, highlights the need for ongoing research in this area. Such research can provide valuable insights for policymakers and organizations seeking to address this pressing issue [52]. Microplastic pollution poses a significant threat to the socio-ecological system worldwide because they are both toxic and long-lasting [53,54]. This pollution can have far-reaching impacts on the environment, human health, and wildlife. Microplastic pollution is a severe problem in Africa, affecting the continent's socio-ecological system (Fig. 1). It poses a threat to marine organisms, disrupts economic activities, affects human health, and contributes to the climate crisis [55]. Therefore, it is important to study the threats posed by MPs to fully evaluate their environmental impact before mitigating them as a problem.

There have been significant worries about the need to put in place legislative tools that will help regulate the manufacture and consumption of plastic materials in order to ensure their adverse effects on human health and the environment may be reduced [57]. Although, some African countries including Côte d'Ivoire, Ethiopia, Ghana, Kenya, Namibia, Nigeria, Rwanda, South Africa, etc., have necessitated recycling directly or indirectly, however, others such as Congo, Somalia, Sudan, and Zimbabwe are well involved in direct disposal of plastic

**Table 1**
African studies showing the detection, toxicity impact, and occurrence of MPs in the environment.

| Country | Location | Sample | Method of detection/ quantification | Detected MP compounds | Concentration detected or particle size | Toxic impact | References |
|---|---|---|---|---|---|---|---|
| South Africa | Gauteng Province | Tap water | Raman spectroscopy | Fibers, pellets, beads | 4.7–31 particles/L | Carcinogenic and mutagenic colorants that are potentially toxic to humans | [60] |
| Nigeria | Eleyele lake | Fish | Fluorescence microscope | | 124 μm and 1.53 mm | MPs can serve as vectors for the spread of infections and pose direct health threats to aquatic creatures | [61] |
| Nigeria | Osun river | Freshwater gastropods | Micro-Fourier-transform infrared spectroscopy (μFTIR) | Fiber and film | $1.71 \pm 0.46$ $g^{-1}$ and $6.1 \pm 1.05$ $g^{-1}$ | Edible animals (e.g. crabs, snails, fish) can easily transfer MPs to humans via consumption | [62] |
| South Africa | Braamfontein Spruit | *Chironomus* sp. larvae, water, and sediment | Microscope | Plastic polymers are identified based on color and sizes | 53.4 particles $g^{-1}$ wet weight and166.8 particles $kg^{-1}$ dry weight | Larvae of *Chironomus* sp. may consume sediment microplastics, which may then be consumed by more complex species. | [63] |
| Egypt | Eastern Harbor | Fish | Differential scanning calorimetry | Thermoplastic polymers | 3593 – 1450 MPs $fish^{-1}$ | The high levels detected in fish show deleterious pollution concerns that could seriously affect both fish and human health | [64] |
| South Africa | Cape Town Harbor and Oceans Aquarium | Mussel and water | Microscope and attenuated total reflection Fourier transform infrared spectroscopy (ATR-FTIR) | Polyethylene terephthalate (PET) and fragments, poly (methyl methacrylate) (PMMA) | $10.3 \pm 1.1$ MPs/L and $6.27 \pm 0.59$ MPs/individual | High risk potential with negatively impact on organisms in enclosed/ confined areas | [65] |
| South Africa | Park Rynie beach | *H. cineracens* | Stereo electron microscope | Fluorescent microplastic fragments and microfibre | 0.59–2.90 μm (1.22 ± 0.03 μm) | When MPs are swallowed by *H. cinerascens*, the chemicals that desorb from them could be harmful to both the animals and their consumers | [66] |
| Egypt | Aquaponics unit, Al Azhar University | Nile Tilapia | Light microscope | Raw powdered MPs | | MPs caused anemia and perturbations in hemato-biochemical parameters | [67] |

waste [58,59]. Generally, the generation of increased plastic waste especially in Africa could be associated with several factors including social, economic, and political.

The lack of social inclusiveness in many African countries especially in Zimbabwe, Sudan, Somalia, Sierra Leone, Guinea, Eritrea, Congo, Burundi, and Angola has contributed to improper plastic waste management. Programs geared towards the education of the general populace targeted at the grassroots/community level on waste separation (plastic, food waste, and paper), storage, and the conversion of waste to wealth especially in rural communities would play a significant role in proper waste management [68]. The facilitation of this approach requires policies and structural organization from the government to ensure the success of such programs. Social inclusiveness also must involve different educational levels; although community-based programs mostly address educationally deprived individuals, the inclusion of courses aimed at waste management, recycling, and upcycling of plastic waste in primary, secondary, and tertiary institutes of education [69] which is yet to be fully included in the educational curricula of most African countries. Additionally, collaboration between public and private sectors especially private sectors involved in plastic waste management/recycling should be solidified, thereby encouraging every individual to contribute to the reduction of plastic waste. This will in turn transform the commonly seen landfill of plastic waste and also contribute to environmental safety.

According to Joshi [70], the decentralization of plastic production by stakeholders could be the major action point towards the regulation of plastic waste's harmful effect on humans and the environment; sadly, in the context of many African countries, this is yet to be the situation. This proposition seeks to replace the use of photo-degradable materials with biodegradable materials in the production of plastics. Photodegradation of plastics involves the absorption of sunlight by oil-based plastic materials such as polyethylene, polypropylene, polyethylene terephthalate, etc., thereby leading to the weakening or breakdown of polymeric bonds. It was reported that photodegradation of plastic particles in subtropical conditions was below 1.7–2.3 % $yr^{-1}$, and acting as a significant contributor to floating plastic, it could therefore increase the concentration of accumulated nanoplastics in aquatic ecosystems, thereby negatively affecting aquatic creatures [71].

### *3.1. Microplastic pollution impact social and economic activities in Africa*

The presence of MPs in the environment has social and economic implications in Africa. The continent is home to many communities that rely on tourism, fisheries, and agriculture for their livelihoods. With the pollution of beaches, oceans, and waterways, these communities' economic activities are disrupted, affecting their incomes and living standards. Additionally, the pollution of agricultural land with microplastics can lead to reduced crop yields, affecting the food security of the continent.

Tourism is a significant source of revenue for many communities in Africa. With the continent's diverse and unique wildlife and natural landscapes, many countries attract tourists from around the world. For example, tourism is a crucial contributor to South Africa's economy, with a significant impact on GDP. In 2017, it generated US$10.2bn (R136.1 bn), according to the World Travel and Tourism Centre (WTTC) [72]. Due to its potential to serve as a development catalyst, tourism has been acknowledged as an instrument that could uplift millions of underprivileged people out of poverty in Africa [73]. However, the pollution of beaches, oceans, and waterways with microplastics is becoming a growing concern for many of these destinations. The

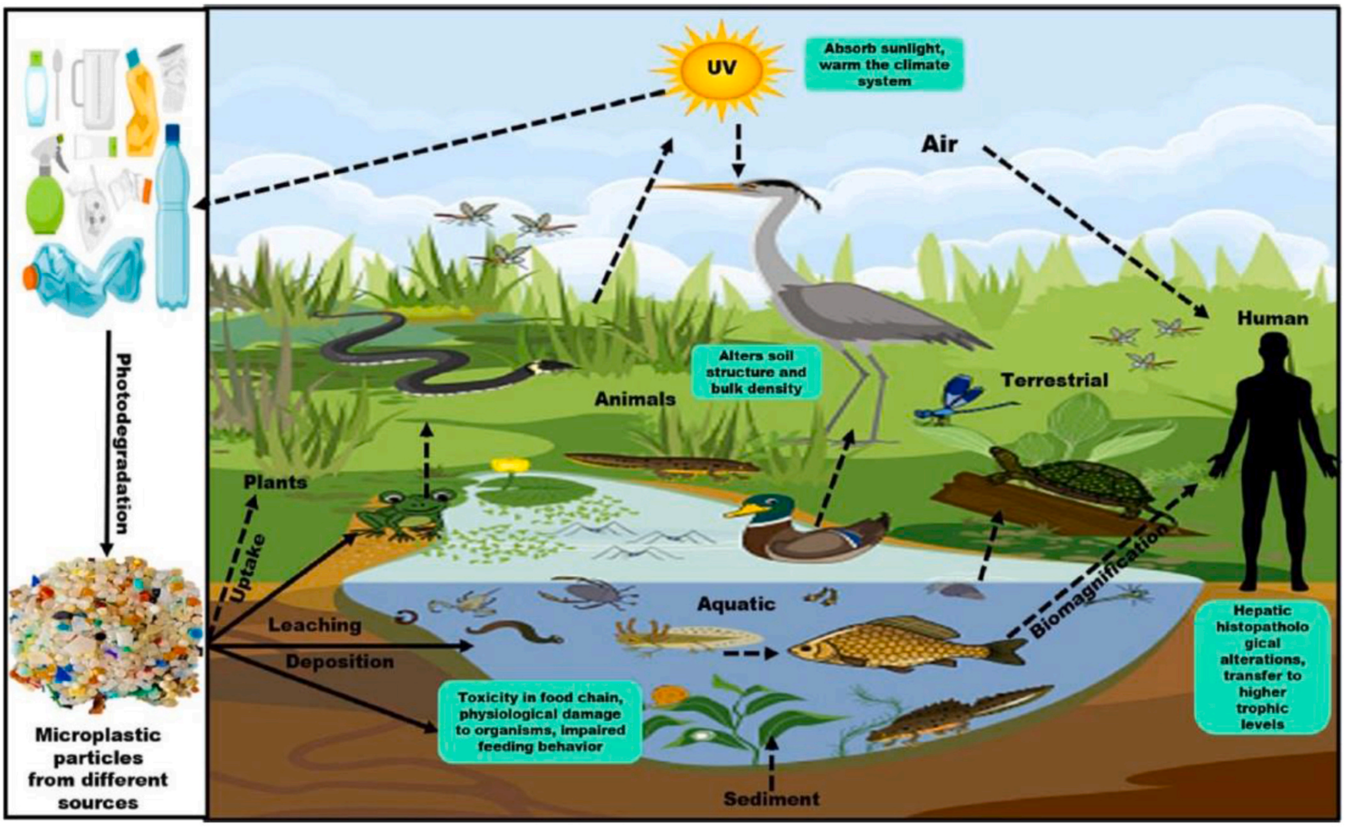


**Fig. 1.** An illustration of the impact of microplastics on the ecosystem. Reproduced with permission from reference [56]. Copyright 2022 Elsevier B.V.

presence of microplastics can be a turn-off for tourists, negatively impacting the tourism industry and the livelihoods of communities that depend on it [55].

The impact of microplastic pollution on fisheries is another major concern for communities in Africa. The ingestion of microplastics by marine life can cause physical harm, such as digestive issues and blockages, leading to decreased growth rates and ultimately death. This poses a significant threat to those who depend on fishing as a source of livelihood, as well as the food security of communities that rely on fish as a primary source of nutrition. Many coastal communities in Africa rely on fishing as a primary source of income and food. However, with the increasing presence of microplastics in the oceans, marine life is becoming contaminated with these particles. Shabaka and colleagues [64] conducted the initial research in Egypt that measured MPs in fish. Their findings showed that the fish from Egyptian waters had the largest quantity of MPs among any other region worldwide. Alimi et al. [33] categorized these waters as one of the most MP-polluted areas in Africa. In numerous African countries, fisheries are a crucial source of protein and employment [74,75]. However, overfishing and climate change pose a significant risk to the depletion of fish stocks, which can have severe consequences for the nutrition of many Africans [76,77]. Furthermore, if microplastic pollution damages aquatic organisms, it poses an additional threat to fishing resources. This issue has global ramifications due to the existing globalization of fisheries and fish trade, potentially extending the negative influence of microplastic pollution on African fish to a worldwide scale.

In addition to impacting the tourism and fishing industries, microplastic pollution can also hurt agriculture in Africa. Globally, approximately 90 % of single-use plastic waste is deposited in the terrestrial ecosystem, leading to an increased risk of contamination of agricultural end-products and the health of consumers [78,79]. Microplastic particles possess the ability to move across different ecosystems, including land, water, and air, because of their small size [80]. The effects of these particles are widespread and substantial. They may alter the physical and chemical composition of the soil, skew the shape of plant roots, impair the uptake of nutrients, as well as affect seedling growth, germination rates, gene expression, chlorophyll content, nutrient cycles, and nutrient depletion. Microplastics can also lead to oxidative stress, disrupt the digestive systems of organisms that consume them, accumulate in living tissues, and magnify in concentration, even aiding in the proliferation of specific aquatic species. Moreover, many studies have revealed that microplastics disperse harmful chemicals, additives, heavy metals, and toxins [81–84]. Agroecosystems are estimated to receive between 1.15 and 2.41 million tonnes of plastic waste annually [85]. Numerous factors, including rising anthropogenic activity, small sizes, ubiquity, sheer volume, and compound chemicals, affect the environmental impact of microplastics. Microplastic pollution can have both direct effects, like hurting plant growth and development, and indirect effects, such as interfering with microbial decomposers' and nutrient cycles' activities. Microplastics can also serve as attachment points for organisms that reproduce quickly and as carriers of harmful substances. Microplastic pollution of agroecosystems affects food production, elements of the food chain, food security, and human health.

The social impact of microplastic pollution in Africa should not be underrated. The impact of microplastic pollution on the environment can have broader social implications, including displacement of communities and social unrest. For example, the degradation of natural habitats due to pollution can lead to the loss of biodiversity, which can impact the cultural heritage and identity of indigenous communities. Additionally, the disruption of economic activities due to pollution can lead to social and economic inequality, as some communities may be more impacted than others, depending on their proximity to polluted areas.

### *3.2. Microplastic pollution in Africa impact climate crisis*

The impact of microplastic pollution on the environment is a growing concern globally, especially in Africa. Africa is a continent that is home to a diverse range of ecosystems, including oceans, rivers, forests, and deserts. Unfortunately, these ecosystems are increasingly being threatened by microplastic pollution, which poses a significant risk to the continent's environment and the global climate crisis. The problem with MPs is that they do not degrade or biodegrade but rather persist in the environment for hundreds of years, posing a severe threat to wildlife and the environment [86].

According to the Organization for Economic Co-operation and Development (OECD), in 2022, Plastics accounted for 3.4 % of greenhouse gas emissions globally, emitting over 850 million tonnes of greenhouse gases into the atmosphere [87]. The presence of microplastics in the environment is known to contribute to the global climate crisis. When MPs are released into the environment, they break down into minute particles, which absorb heat from the sun. These particles then contribute to an increase in temperatures, leading to climate change. Due to the high temperatures and drought-prone regions of Africa, MPs in the environment can exacerbate the crisis of climate change, such as desertification and land degradation. MPs can also contribute to the melting of glaciers, further affecting the earth's ecosystem. Additionally, MPs can also leach harmful chemicals into the environment, further exacerbating the climate crisis [39].

## 4. Strategies for managing microplastic waste in Africa

### *4.1. Microplastic recycling in Africa*

Microplastic pollution is a critical issue in Africa that requires a comprehensive approach to address. By promoting awareness, investing in recycling infrastructure, promoting responsible waste disposal, and encouraging collective action, the proliferation of microplastics in the environment can be reduced and subsequently mitigate the effects of climate change (Fig. 2a). Ultimately, it is the responsibility of all stakeholders to act and ensure a sustainable future for a greener planet.

Microplastic pollution challenges in Africa is a complicated problem that requires a multifaceted approach. It involves not only reducing plastic waste but also implementing effective strategies for recycling and waste management. To address this issue, there is a need for legislation and enforcement of policies on proper waste management. For instance, to combat the effects of plastic trash pollution, just four of the ten Southern African countries as of 2018 had enacted taxes and prohibitions [88]. Some Western African countries have also taken steps to reduce single-use plastic pollution by implementing legislative bans on plastic bags. Out of 16 countries, eleven have already instituted bans, while one country has a market-based instrument and four countries have no strategy [89]. However, these policies have not been entirely successful due to several factors, such as inadequate stakeholder consultation, insufficient time between announcement and implementation, and the lack of cost-effective reusable alternatives [90]. Although these legislative bans have penalties and prison sentences, they lack important provisions such as effective enforcement and alternatives to single-use plastics.

One of the primary challenges facing Africa in addressing microplastic pollution is the lack of proper waste management infrastructure. Many countries on the continent lack the resources and capacity to manage waste effectively, leading to plastic waste being discarded in the environment. This can have significant implications for the proliferation of microplastics, as plastic waste that is not properly disposed of can break down over time and release microplastics into the environment. To address this challenge, there is a need for increased awareness and action. This includes educating the public about the risks associated with microplastics and promoting the use of alternative materials that are less harmful to the environment. For instance, governments can provide incentives for businesses to use eco-friendly materials and encourage individuals to reduce their consumption of single-use plastics.

Another effective approach to curbing microplastic pollution in Africa involves establishing recycling facilities. Recycling has gained popularity in Africa mainly due to poverty, unemployment, and socio-economic needs, rather than as a result of public and private sector initiatives. According to the United Nations Environment Programme (UNEP) report, only 4 % of plastic waste in Africa was recycled in 2018 [91]. Building more recycling facilities will increase plastic waste collection, preventing it from ending up in landfills or polluting the environment, and instead reusing it, which can lower the demand for new plastic production. Materials such as textiles, construction materials, packaging materials, and household items can be produced from microplastic recycling [92] (Fig. 2b). Governments can invest in

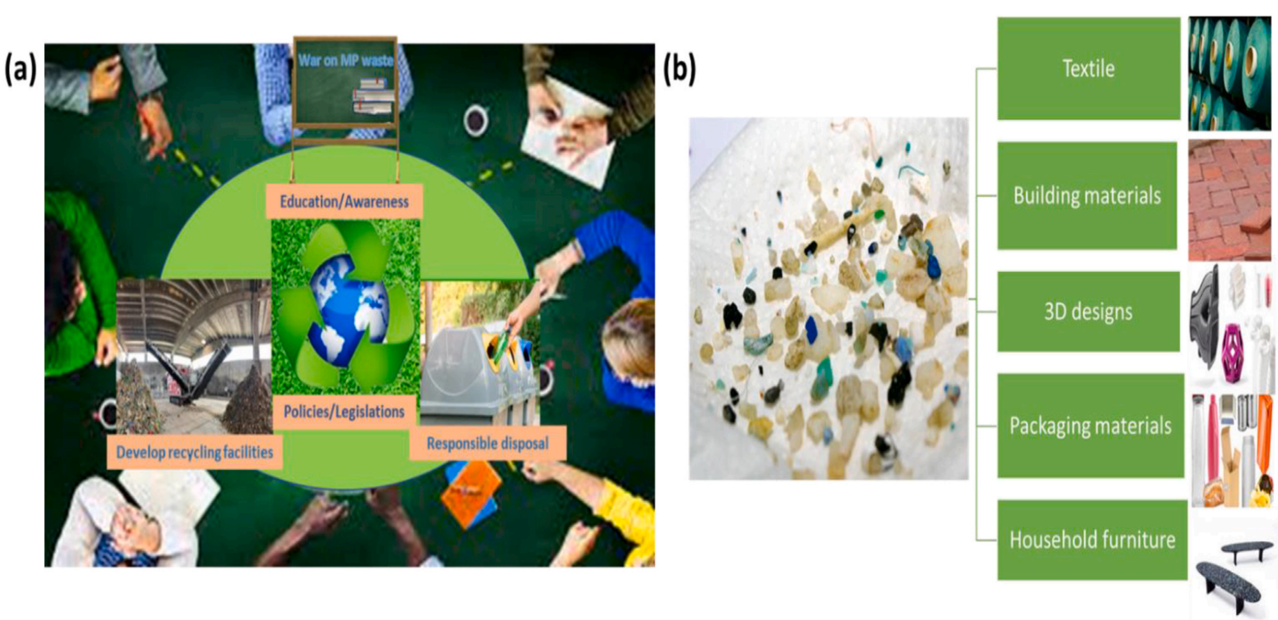


**Fig. 2.** Pictorial representation of (a) strategic approach to microplastic recycling (b) Materials obtainable from recycled MPs.

recycling infrastructure and offer incentives to businesses that participate in recycling initiatives. In addition, responsible waste disposal is crucial in addressing microplastic pollution. Governments can promote responsible waste disposal practices through public education campaigns and the enforcement of regulations. This includes providing easily accessible waste disposal sites and enforcing penalties for illegal dumping. Furthermore, governments can encourage the adoption of biodegradable and compostable materials, which degrade more quickly and do not contribute to microplastic pollution. For instance, Rwanda has set an example by prohibiting the utilization of non-biodegradable polyethylene bags since 2008. Rwanda has effectively decreased its usage of plastics by prohibiting single-use plastics and plastic bags, as well as encouraging the replacement of plastic building materials. This approach has been instrumental in curbing plastic consumption in the country [8]. Addressing microplastic pollution in Africa requires joint action by governments, the private sector, and civil society. Governments can provide funding and support for recycling and waste management programs, while the private sector can develop sustainable products and invest in eco-friendly manufacturing processes. Civil society can also play a role by raising awareness about the issue and advocating for policy change.

### 4.2. Microplastic upcycling in Africa

Microplastic upcycling in Africa represents a paradigm shift in the approach to plastic pollution, turning a global environmental crisis into an opportunity for innovation, economic growth, and community empowerment. By adopting sustainable practices and harnessing the creative potential of upcycling, African nations can lead the way in transforming microplastic pollution into valuable resources. Through collaboration, education, and active engagement, Africa can build a greener and more sustainable future, setting an inspiring example for the rest of the world.

Inadequate waste management systems, combined with factors such as improper disposal, littering, and limited recycling infrastructure, have added to the alarming levels of microplastic pollution in African ecosystems. Microplastic upcycling involves repurposing and converting microplastic waste into useful products, reducing its environmental impact. This approach differs from traditional recycling, which focuses on downcycling, wherein plastic materials are converted into lower-grade products. Upcycling, on the other hand, aims to create high-value products from waste materials. The process typically involves sorting, cleaning, and transforming MPs into new materials or products, minimizing their environmental footprint. Throughout Africa, several initiatives have emerged to convert plastic waste into lucrative retail ventures. An exemplary demonstration of this can be observed in the case of the All Women Recycling initiative, a significant undertaking aimed at empowering women in South Africa. This initiative concentrates on the process of upcycling plastic bottles and transforming them into the revolutionary Kliketyklikbox™ (Fig. 3a) [93]. As a result of its noteworthy accomplishments, this innovative product has garnered worldwide acclaim and widespread distribution. In the year 2016 alone,


**Fig. 3.** Images showing (a) Some kliketyklikbox™ made from used PET bottles with ingenious opening mechanisms launched by All Women Recycling. (b) Rethaka backpack is made entirely from recycled plastics.
(a) Reproduced with permission from reference [93]. Copyright 2022 PlasticsleMag. (b) Reproduced with permission from reference [95] Copyright 2023 Informa Markets.

this initiative successfully repurposed more than 500,000 plastic bottles, effectively diverting them from the waste stream [94].

Another remarkable upcycling known as Repurpose Schoolbags (Fig. 3b) is an innovative initiative that addresses the needs of underprivileged schoolchildren by manufacturing schoolbags using recycled plastic bags and billboard materials [95]. These bags have a unique portable solar panel feature. The solar panel serves a dual purpose - it charges while the children walk to school and can be used as a desk lamp during the night. By repurposing discarded materials, Repurpose Schoolbags not only provides essential schoolbags to children in need but also promotes sustainability and environmental consciousness. The backpacks also include strips of reflective material for added safety, making the children more visible to traffic during the early hours [96]. Highlighting successful microplastic upcycling projects and case studies from Africa can inspire and motivate further initiatives. Projects such as transforming MPs into construction materials, creating art installations, or producing fashion accessories have already demonstrated the feasibility and potential of microplastic upcycling in Africa.

### 4.3. Bioplastic processing in Africa

Despite Africa's significant role as a major producer of agricultural products, the continent faces a challenge in terms of limited industrial and technological development, which hampers the efficient conversion of biomass into value-added products such as biopolymers [97]. As a result, Africa lags behind the world's leading processors in this field. The production of bioplastics exhibits an imbalanced geographical distribution. According to Fig. 4, the majority of manufacturing capacities are concentrated in Asia and Europe, with North America and South America following suit. However, the production of bioplastics in Africa is insignificant [98], highlighting a potential opportunity for development.

Bioplastics, such as polylactic acid, have the potential as an eco-friendly substitute for traditional plastics [99]. However, the environmental impacts of bioplastics are not fully understood [100]. Bioplastics from food waste have a lower environmental impact, but economic feasibility and supply stability need evaluation. Another option is biodegradable plastics with petroleum and additives, but improper collection can still cause debris and pollution [101]. A well-developed and adhered waste management supply chain is always crucial to address plastic consumption issues [102].

Bioplastic processing in Africa presents a promising path toward an environmentally sustainable and economically viable strategy for managing microplastic waste. By embracing biodegradable alternatives, the continent can reduce plastic pollution, protect ecosystems, and stimulate economic growth. Despite the challenges faced, Africa has the potential to establish a thriving bioplastic industry, driven by innovation, local entrepreneurship, and strategic partnerships involving governments, private sector stakeholders, and civil society [103]. To ensure success, concerted efforts require investment in infrastructure, fostering education, and creating an enabling environment for bioplastic processing. Through these collective endeavors, Africa can become a beacon of sustainability and a model for other regions in their pursuit of a greener future.

Moreover, partnerships between governments, private enterprises, and non-profit organizations are vital for the widespread adoption of bioplastics in Africa. These collaborations can provide funding, technical expertise, and regulatory support to facilitate the transition to bioplastics and strengthen the waste management infrastructure. By working together, stakeholders can create a comprehensive and integrated approach to tackle the plastic waste crisis effectively.

### 4.4. Biodegradation of microplastic by insects and other animals

Microplastics of different types have been degraded using several technological approaches including; photo-oxidation and catalysis, weathering, incineration, adequate landfilling through planned sanitation, degradation caused by potential microbes, ozonation, catalytically degrading the polymeric bonds, composting, and plastic recycling [104]. Biotechnological strategies which include gene editing and bioinformatics are effective in modifying these organisms by introducing exogenous genes for specific enzymes to increase the degradation of MPs [105]. Microbes in line with the factors of the environment and plastic-type can help degrade plastics. These microorganisms can degrade MPs based on the cascade effects of various enzymes that they secret, which help to convert MPs into oligomers and monomers or trigger their mineralization to $CO_2$ and $H_2O$ [106]. Bacterial enzymes like polyethylene terephthalate (PET) hydroxylase and PCL cutinase are bacterial enzymes used in microplastic degradation. Other bacterial species such as *Bacillus* sp, *Escherichia* sp, and *Pseudomonas* sp. are known species that degrade polyethylene (PE), PET, and polyarylsulfone (PAS) [107]. Some plastic-degrading bacteria are grouped under the

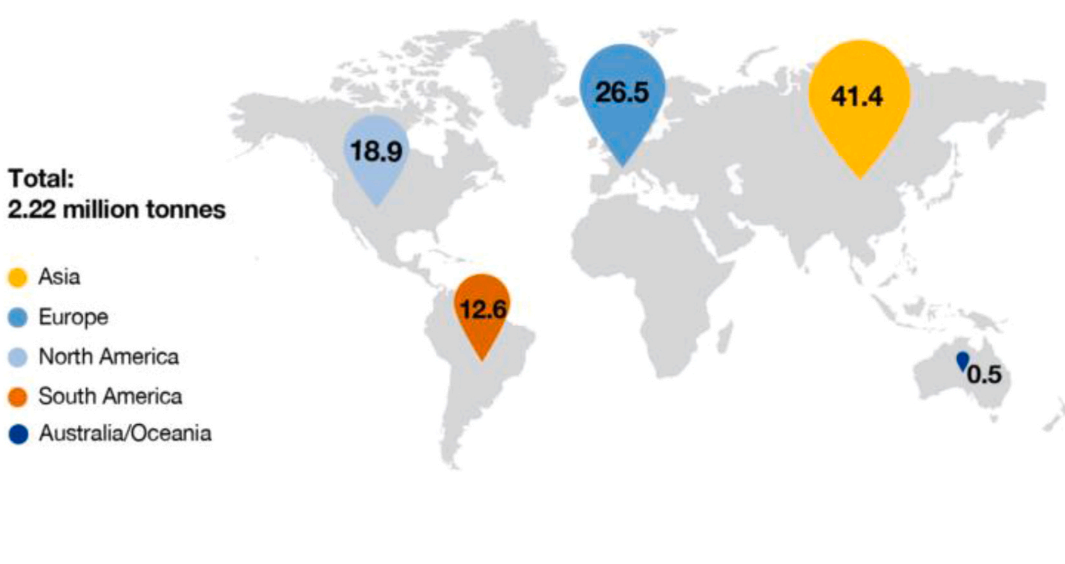


**Fig. 4.** Global production capacities (in %) of bioplastics in 2022 by continent.
Adapted from European Bioplastics (2022) [98]. Copyright 2022 European Bioplastics e.V.

phylum Firmicutes, Actinobacteria, and Proteobacteria [108]. Plastic biodegradation by filamentous fungi are potential bio-agent for plastic degradation including PE and PET [109]. Also, fungi like ocean bottom mushrooms and bacterial strains have been highlighted as a viable way to get rid of plastic trash without producing secondary pollution [110]. However, some drawbacks of microplastics include a slow rate of degradation and the need for ideal biodegradation conditions. The potential of some mussels in the cleanup of microplastic contaminations has been observed in oceanic environments. An emerging alternative is the biodegradation of plastic trash by arthropods; many plastic-eating worms are capable of ingesting plastic and transforming it into non-hazardous compounds [111]. Hyperreal lugworms, certain birds, other plastic-eating worms, zooplanktons, deep-sea animals, water crabs, spiders, and so on have been known to directly consume microplastic in aquatic environments [112]. Plant-sucking bugs mosquitoes and predators of small animals can pick up bio-accumulated plastic pollutants in tissues and fluids of infected hosts indirectly (see Fig. 5). It is not yet certain if bio-accumulated microplastics in mosquitoes can be passed through blood feeding to their host. This could be disastrous. Most mosquitoes such as *Culex* and some *Aedes* breed in very polluted water bodies. *Culex* mosquitoes can even thrive in plastic-polluted breeding sites and as such the chances of picking up doses of microplastics are possible if disintegration occurs within the life cycle in water [113].

Soil animals are essential consumers in the material cycle of ecosystems because they may actively assimilate various compounds from their environment for their own growth, development, and other activities (Fig. 6). Studies have revealed that some insects, including some invertebrates [114,115] and social insects [116], can consume and chew plastic products, using them as their only source of carbon to break down microplastics into $CO_2$ and $H_2O$ through a variety of biochemical processes [117] as well as physical methods like biting, chewing, or digestion. The gut microbial symbionts of these insects are primarily responsible for their ability to degrade microplastics.

Microorganisms are an efficient and cost-effective way to remove microplastics since they can easily adapt to practically all settings and have the capacity to break down a variety of organic contaminants [118]. Microplastics are utilized by microbes as a substrate for the development of biofilms during the breakdown process. The microplastic structure degrades as the biofilm thickens, and subsequently, specialized and non-specific enzymes released by bacteria and fungi break down the microplastic fragments. Microorganisms in the biofilm can easily assimilate microplastics with fragment weights of less than 600 kDa.

Fungi are potential decomposers known for their highly prolific nature in soil environments, and it has been shown repeatedly that they can break down microplastics [119]. For instance, species in the phylum Ascomycota, such as *Aspergillus* and *Fusarium*, are linked to the breakdown of microplastics [120], followed by *Basidiomycota* and *Zygomycota*. Microplastic degradation has also been linked to bacteria like *Bacillus*, *Pseudomonas*, *Rhodococcus*, *Arthrobacter*, *Oscillatoria subbrevis*, and *Alcanivorax borkumensis* [121]. Since the capacity of insects to disintegrate microplastic is largely dependent on the activity of the microorganisms in their stomach, it is possible to separate bacteria that are capable of breaking down microplastic in a different method than by taking them straight from the plastic circle. More enzymes are produced by fungi than bacteria, and their mycelium clings to microplastics with a tight grip and can engulf particles. Fungi may also lessen the hydrophobicity of microplastics by promoting the creation of chemical linkages like carbonyl bonds, which may disrupt the hydrophobic bilayers in the particles. However, bacteria should be more biodegradable than fungi because they require a less stable external environment [122]. The

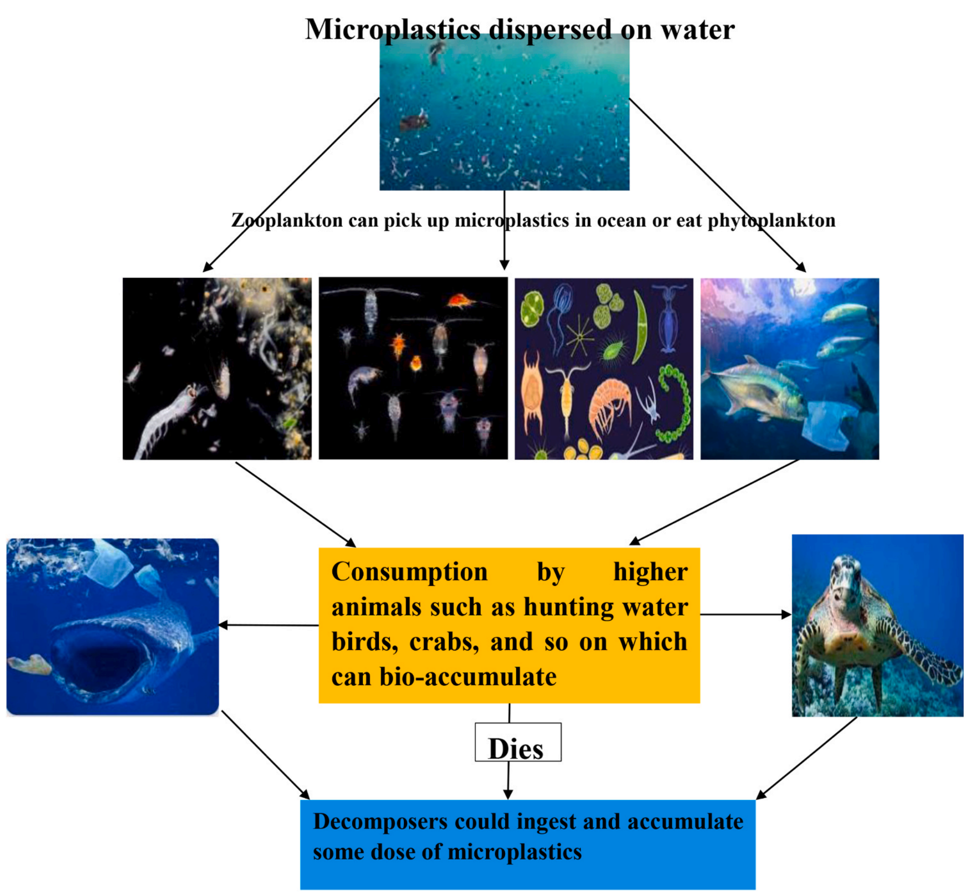


**Fig. 5.** Biodegradation and Pathway of microplastic transfer in food chain/web (Reference point: Aquatic system).

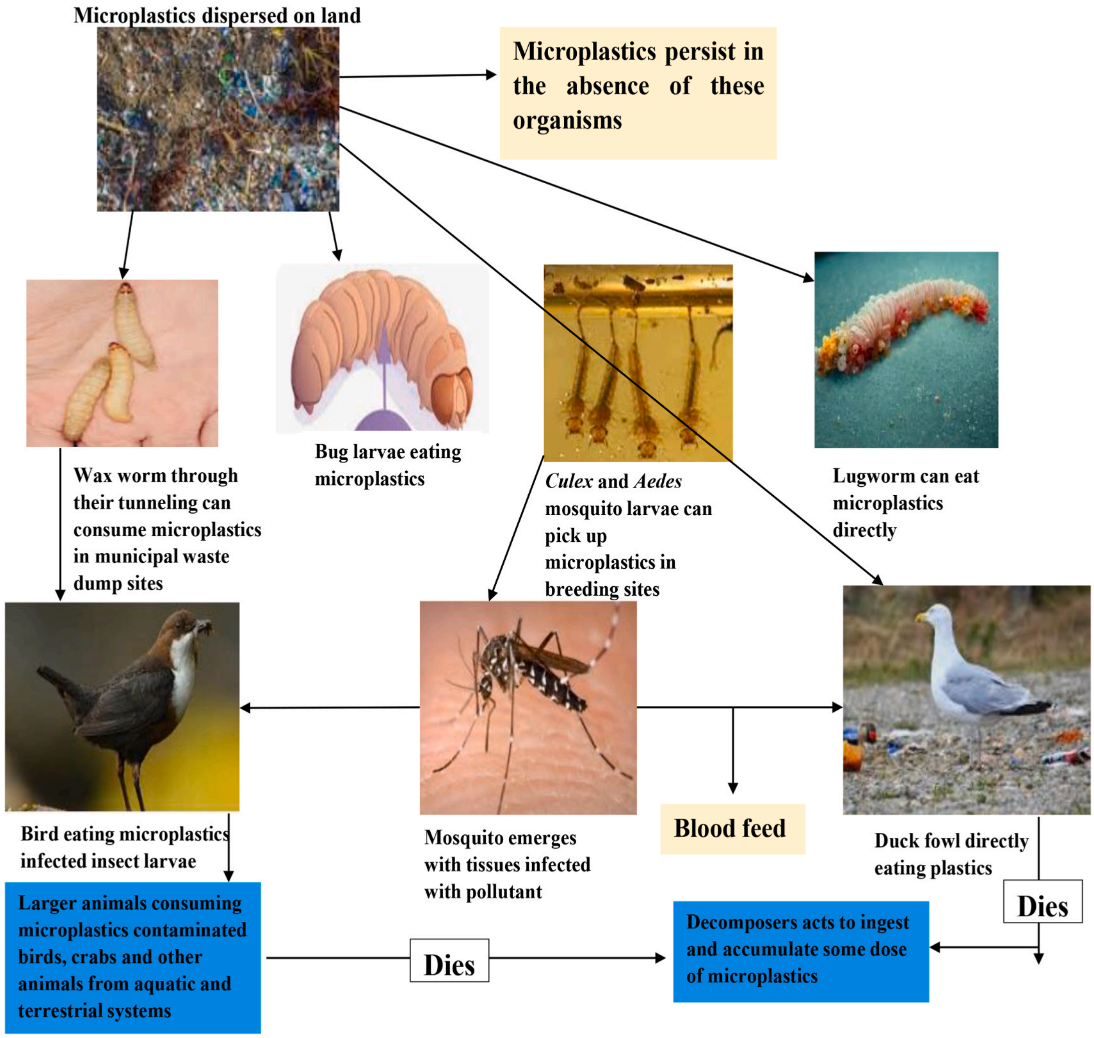


**Fig. 6.** Pathway of microplastic transfer in food chain/web and biodegradation (Reference point: terrestrial system).

rate of breaking down of materials by microorganisms is considerably slow and needs about 21 days to reach the requisite disintegration, despite the huge number of research done on assessing microplastic-degrading bacteria [120]. Furthermore, the rate of material degradation by single cultures of fungi and bacteria is normally low, and the rate of material degradation by mixed cultures of fungi and bacteria only rises over time. However, as the mechanism of interaction between microorganisms and microplastics is still unclear and cooperation between different flora is challenging, additional research is needed to obtain the desired degrading impact by altering the ratio between bacterial strains.

### 4.5. *Insects identified as plastics eating insects*

Although research on how plastics break down in insects is still ongoing, there are some theories that enzymes and gut bacteria play a role (Table 2).

#### 4.5.1. *Lepidoptera*

Moths and butterflies are members of this order of insects. Moths such as *Achroia grisella* (smaller wax moth), *Galleria mellonella* (greater wax moth), and *Corcyra cephalonica* (rice meal worm) are some of the species in this order, Pyralidae family, that are known to feed on plastic. Because they can eat and digest beeswax, waxworm *G. mellonella* larvae may chew and devour Polyethylene (PE) films [114]. Because beeswax and PE are structurally similar, the biochemical machinery used for beeswax metabolism by *G. mellonella* might also be utilized for PE metabolism. The role of gut microbiota and *G. mellonella* enzymes in PE breakdown inside the gut lumen and in vitro conditions is yet unknown. There has been a controversy that the enzymes of *G. mellonella* and the microbiota are crucial for the breakdown of PE [123]. The ability of *G. mellonella* larvae to utilize their pre-existing metabolic processes to use PE as their only source of food is extraordinary [124].

#### 4.5.2. *Lesser wax worm*

Silo bags, which include three layers of polyethylene and one anti-UV layer, are edible to *A. grisella*. Lesser waxworms fed PE finished their life cycle in full. A spike in unsaturated hydrocarbon and the appearance of new carbonyl and alcoholic groups in the frass of PE samples fed to smaller waxworms point to the creation of biodegraded intermediates [125].

#### 4.5.3. *Super Worm*

Polystyrene, polyethylene, and polyphenylene sulfide (PPS) foams are all consumed by *Z. atratus* larvae [121,126]. In mealworms that consume plastic, more bacteria have been discovered, and their capacity to degrade PS is still being assessed. These bacteria were found to support the biodegradation of ingested Styrofoam. In *Z. atratus*, *Pseudomonas aeruginosa* gut bacteria can break down the polystyrene, and PPS. The composition and characteristics of intermediate molecules generated when plastic biodegradation occurs may have an impact on bacterial growth rates, as *P. aeruginosa* growth rates are not necessarily

**Table 2**
Biodegradation activities of some potent insects.

| Insect group | Plastic-type | Degradation condition | Degradation product | Mechanisms | References |
|---|---|---|---|---|---|
| Yellow meal worm (*Tenebrio molitor*) | Vulcanized rubber waste | Specific gut biota | Small degradable plastic particles | Gut-inhabiting bacterium, *Acinetobacter* sp. BIT-H3 | [127] |
| | Polystyrene | Generalist gut biota | Small degradable plastic particles | Several gut microbiome | [128,129] |
| | Polyethylene | Generalist gut biota | Small degradable plastic particles | Several gut microbiome | [130] |
| | Polyvinyl chloride (PVC) | Generalist gut biota | Small degradable plastic particles | Several gut microbiome | [131] |
| Superworm (*Zophobas atratus*) | Polystyrene | Generalist gut biota | Small degradable plastic particles | Several gut microbiome | [132,133] |
| Greater wax moth (*Galleria mellonella*) | Polystyrene, Polyethylene | Generalist gut biota | Small degradable plastic particles | Several gut microbiome | [134] |
| | Low density Polyethylene | Generalist gut biota | Small degradable plastic particles | Several gut microbiome | [135] |
| Indian meal worm (*Plodia interpunctella*) | Polyethylene | Specific gut biota | Small degradable plastic particles | *Enterobacter asburiae* YT1 and *Bacillus* sp. YP1, *Meyerozyma guilliermondii* ZJC1 (MgZJC1) and *Serratia marcescens* ZJC2 (SmZJC2) | [136] |
| Rice moth (*Corcyra cephalonica*) | Low density Polyethylene | Generalist gut biota | Small degradable plastic particles | Several gut microbiome | [137] |
| Darkling beetle (*Plesiophthalmus davidis*) | Polystyrene | Generalist gut biota | Small degradable plastic particles | Several gut microbiome | [138] |
| Caddisfly (*Lepidostoma basale*) | Polyvinyl chloride (PVC), polyethyelene terephthalate (PET) | Matabolisable case | Small degradable plastic particles | Enzyme; Cutinase | [139] |
| Aquatic midges (*Chironomus riparius*) | Low density Polyethylene | Enzyme action | Small degradable plastic particles | Enzyme; oxidase, peroxidase, and many more | [140] |

inversely correlated with biodegradation rates [110].

## 5. Prospects of microplastic management for resource conservation

Following the global economic decline in 2020 due to the widespread coronavirus disease 2019 (COVID-19), commercial vendors/markets experienced a slowdown in transactions, leading to lower plastic waste generation. However, in Kenya and Morocco, a contrary situation was reported due to the sudden increase in single-use plastic consumption. This has resulted in less or no chance of recycling and aggravating the level of mismanaged plastic waste discharge into the environment [141]. These macroplastic fragments over time through various processes (such as photodegradation, weathering, microbial degradation, corrosion, or mechanical forces of water) are transformed into persistent microplastics, disrupting air, land, and aquatic ecosystems [142,143]. Therefore, minimizing the socio-ecological effects of microplastics in Africa will likely require environmental management

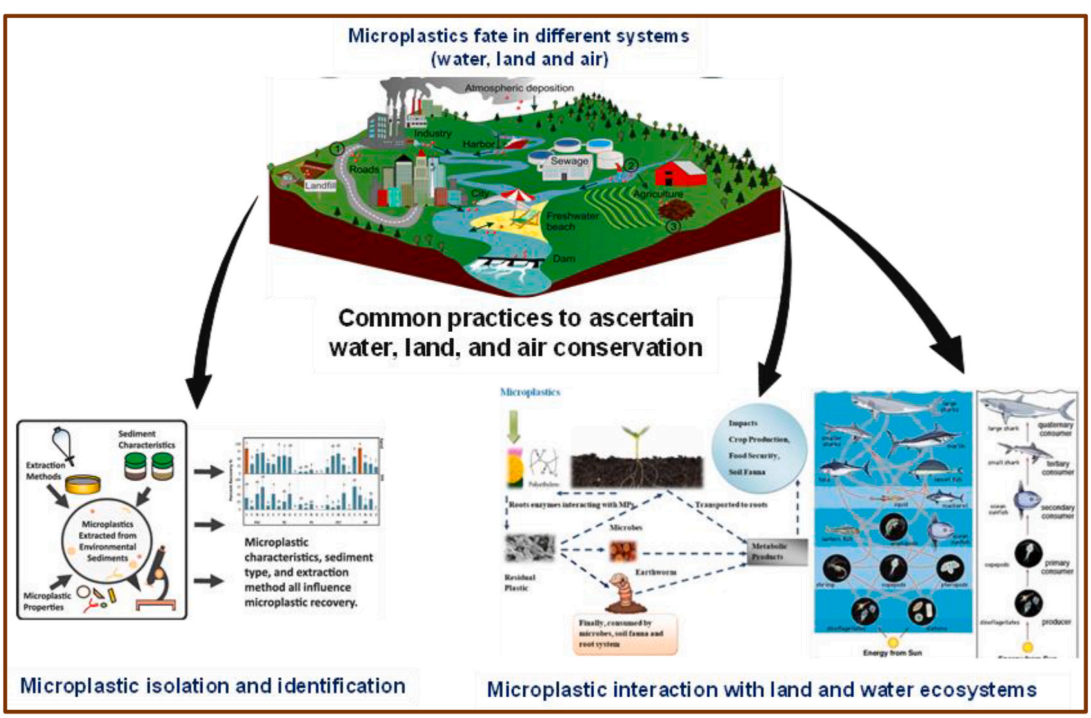


**Fig. 7.** Microplastics in water, land, and air environmental conservation by reflecting microplastic isolation, identification, role as a contaminant in the environments, and interaction with other systems. Source: [144–146].

policies and laws to ensure proper disposal, recycling, and conservation of ecosystems. Microplastic management can be addressed through public awareness, government and plastic waste management systems, and scientific research to bridge knowledge gaps. To limit microplastic pollution, accountability is needed, and reliable information is necessary for individuals to act accordingly. While possible microplastic management strategies are being explored, conserving environmental resources centers on sources in everyday life sinks in aquatic/terrestrial ecosystems, and effects on the living organisms (Fig. 7).

### 5.1. Water and aquatic life conservation

A recent global-scale evaluation of microplastic pollution in seawater across marine protected area boundaries using Geographic Information System (GIS)-based vector analysis identified one-third more contaminated areas, with fiber being the most abundant shape and polyethylene and polypropylene as the dominant polymer types [147]. Marine protected areas are typically designed to safeguard, rehabilitate, and preserve the world's marine legacy by establishing a network of conservation units representative of the ecosystem, serving as an umbrella for economic resource sustainability, biodiversity conservation, and species protection [143,148]. Lamprey and sediment habitats are also vulnerable to microplastic contamination, with protected lamprey species commonly inhabiting coastal and fresh waters reported to contain 1.00–27.47 particles $g^{-1}$ in dry lamprey gastrointestinal tract tissue using micro-Fourier transform infrared (μFTIR) spectroscopy [149]. Furthermore, 830 species of wild fish, including 606 species that are important to commercial and subsistence fisheries, were found to contain microplastics in a global systematic analysis of microplastics in wild fish populations. This poses a threat to the preservation of biodiversity worldwide, the sustainability of wild fish stocks, and the safety and security of human food [150].

The concentration of microplastic, which is primarily made up of fibers and likely comes from the fragmentation of fibrous goods like clothing and fishing lines, is higher in the creeks along the Kenyan coast in Africa than in observations from other parts of the world [151]. Investigation into exposure routes for microplastics from macroplastics in the water system is needed. However, potential sources such as bottled and sachet water containers commonly reported in African water systems, as well as tap water, well water, and other groundwater, are yet to be investigated for potential microplastic contamination in Nigeria [152]. In protecting and sustaining surface and groundwater resources in the Central Region of Ghana, microplastic was identified as an emerging contaminant in water resources, although concentrations were relatively lower than those previously reported in China, Australia, and KwaZulu-Natal in South Africa [142]. The Ghana Water Company Limited (GWCL), established in 1965 by the parliament of Ghana, is a key player in water resources management in the region. In the Western Cape of South Africa, the first microplastic investigation in the Plankenburg River revealed anthropogenic activities contributing to microplastic accumulation, with polyethylene as the main polymer type and fibers as the most dominant shapes [153]. This establishes a baseline for subsequent water and sediment monitoring and evaluation in South African freshwater systems.

### 5.2. Land and agricultural conservation

Environmental scientists at the University of New England recently reported the presence of microplastics in protected environments used for annual trail running events and recreational hiking, similar to microplastics in marine protected areas [154]. Reports indicate that agroecosystems receive between 1.15 and 2.41 million tons of plastic waste each year, progressively generating microplastics that significantly impact land ecosystems and activities [146]. Microplastics from mulching cause soil pollution and act as pollutant vectors, altering soil flora and fauna characteristics. Furthermore, microplastics impact the enzymatic activities of soil, soil microbes, and plant growth.

In Africa, two naturally occurring mangrove forests on a small island in Mauritius are overrun by pieces and films of microplastics (diameter range of 800–1000μm and 1000–2000μm), reflecting the near proximity of human settlement and anthropogenic activities [155]. Through an awareness of the level of microplastic contamination and information for future development of management methods on a local and regional scale, such investigations serve as the foundation for the conservation of mangroves. As a result, the Republic of Mauritius suggests a comprehensive strategy to address microplastic contamination through the use of recycling technology, a circular economy, life cycle analysis, and plastic waste regulation [156]. Aligning with reports from diverse countries across the globe, the aggressive use of personal protective equipment associated with the COVID-19 pandemic is linked to the massive accumulation of microplastics in several land ecosystems, as observed along the coastline of Agadir in Morocco [157]. This reflects the effect of beachgoers and personal protective equipment items as a novel and growing source of microplastics, posing a potential threat of entanglement, ingestion, and/or infection among apex predators and substrate to invasive species colonization. Further experimental investigations are recommended to provide more insight into understanding how sediment loading with microplastics predicts biological uptake for land conservation. Most African countries have not yet taken into account the assessment of plastic ingestion by terrestrial animals, including ruminants, poultry, and birds, among others [152]. Only a few studies have looked at how microplastic particles affect soil parameters, and there is a knowledge gap regarding the toxicity of microplastic particles in biological systems. Additionally, a variety of authors from around the world used various measurement units to report the levels of microplastics and macroplastics in water, sediment, and biota, underscoring the necessity of standardizing units to allow comparisons between concentrations and compartments for a broad assessment of risk.

### 5.3. Air conservation

Decades ago, there were relatively no studies on microplastics in the air, while water and land were more commonly reported. A six-month investigation in recreational trails in Reserves and National Parks found that the average atmospheric deposition of microplastics per day was 17.4 MPs $m^{-2}$, dominated by fibers comprising 84 % of microplastics [154]. Notable sources of microplastics in the air include urban dust, simulated textiles, abrasive powders, and erosion of rubber tires [146], owing to their lightweight, size, shape, and distribution. Microplastics in the atmosphere include polyethylene terephthalate, polyester, polyethylene, poly(N-methyl acrylamide), polyacrylonitrile, rayon, epoxy resin, and ethylene vinyl acetate, occurring as granules, foams, fragments, fibers, and films. Microplastics are ubiquitous with a wide area of transportation and distribution, although knowledge about the health implications of aerosolized microplastic particles remains elusive. The presence and levels of microplastic particles in the air in most African countries are yet to be investigated [152].

### 5.4. Role of community-led initiatives in Africa for promoting sustainable resource use

Advocating for healthy environments is a matter of justice as the toxicity of plastics and microplastic pollution impact the health of communities. Oftentimes, individuals are unable to safeguard themselves through individual actions alone. Hence, collective efforts through community-led initiatives can be termed more effective and impactful. Ghana, Kenya, Mozambique, Nigeria, and South Africa were named winners of the African environment photo essay contest "Vibrations – a social media campaign" aimed at supporting community-led environmental improvement and education initiatives [158]. The core objectives of the projects initiated include the following:

- Efforts to combat pollution,
- Efforts to create environmentally conscious school curricula,
- Utilization of clean energy sources, and
- Awareness campaign about environmental justice with respect to local communities.

While these projects highlight the transformative community-driven potentials towards fostering continued conversations and environmental sustainability in Africa, it also encourage meaningful action through policy changes and collaborations throughout the African continent and beyond. Therefore, notable plastic and microplastic projects based on countries are illustrated in Fig. 8 alongside further strengthening factors.

## 6. Conclusion and future outlook

Although, there are several challenges arising from plastic pollution in our environment today, however, these challenges could be mitigated if proper measures are taken. These may involve innovative ideas and approaches aimed at proper plastic waste management.

### 6.1. Management and disposal of waste

In developed countries, the implementation of a waste disposal culture in which waste, especially household waste, is separated into different categories such as organic, plastic metal and paper has facilitated proper waste management. This has facilitated easy waste collection and management. This approach is yet to be dominant in many African countries. This system of waste management also ensures appropriate waste collection. Implementation of such a system will facilitate the reduction of improper disposal of plastic waste, thereby reducing the circulation of microplastics in the environment. The effectiveness of this approach involves government policy and initiation of measures for collection and strict laws against improper waste disposal such that defaulters will be penalized. Also, improper waste management such as burning of waste (plastics) further resulting in environmental pollution with noxious gases/fumes from combustion could be mitigated by this approach. Furthermore, incineration of plastics is an approach to control microplastic pollution, however, necessary precautions should be taken as some plastics may not be good candidates for this process and non-combustible plastic waste matter should not be included in such process to prevent the incidence of explosion.

### 6.2. Recycling and upcycling of plastic waste

The process of recycling ensures the generation of new products from plastic waste by complete destruction of its previous form while upcycling is the creation of new products/outcomes from plastic waste without necessarily destroying its current form but by modifying it. Following proper disposal of plastic waste, this waste could be collected

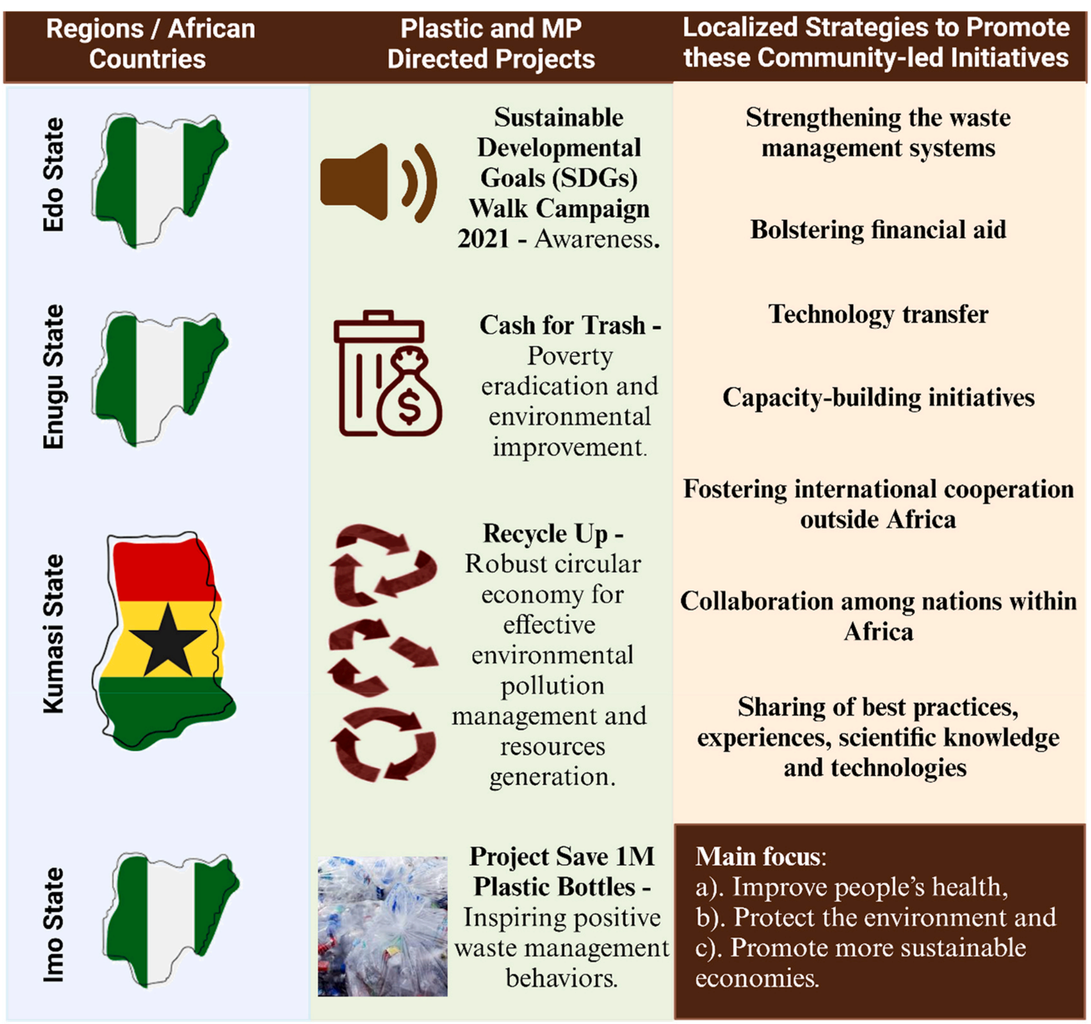


**Fig. 8.** Successful grassroots efforts and their potential impact channeled towards localized solutions for addressing microplastic pollution and aiding environmental sustainability.

for recycling/upcycling usability. In developed countries, the introduction of technological machines known as reversing vending machines, as a means to facilitate the collection of reusable plastic waste with monetary compensation has enhanced proper waste disposal. Although this is just gaining recognition in a few African countries, the introduction of such a system especially in the big cities of many African countries will not only ensure proper management/disposal of plastic waste but could also be a source of job creation and income generation for plastic waste scavengers. Companies involved in plastic waste recycling should contribute through awareness as this plastic waste could be recycled into different products such as tables, chairs, shoes, etc. Innovation in upcycling is also gaining much attention. Following proper disposal and collection, plastics can be employed in the construction of perimeter fencing, planting in agriculture, and raising seedlings as well as other household uses.

The introduction of circular economy i.e., recycling of waste materials, involves all stakeholders both public and private, but most importantly, the government must pioneer/encourage the concept of "cradle to cradle" rather than "cradle to grave" as this will create a different perspective to plastic wastes to be seen as raw materials, thus, generating income and facilitating a safer environment, rather than improper plastic wastes disposal such and burning and the popular throw-away culture/landfill deposition [159], which is not only harmful to the environment but to human as well. Unfortunately, the concept of circular economy in many African countries is not new but has struggled to thrive due to issues revolving around politics, investments, and technology. The technological transformation on a large scale required for recycling plastic waste is lacking especially due to limited technical know-how and financial capacity to establish such industry at a commercial scale; this has facilitated the increasing generation of plastic waste in most African countries. One step forward involves funding this transformation to a point where plastic waste could be viewed as a resource for income generation on a large scale.

### 6.3. Pyrolysis

The process of pyrolysis involves the degradation of solid or liquid or the conversion of same including heating at high temperature to generate smaller molecules that are volatile in the absence of oxygen for combustion. This process requires a high temperature ranging between 500 °C – 800 °C or more. Several materials can be subjected to the process of pyrolysis, however, the use of waste plastics as the material for pyrolysis is being used to generate fuel. Waste plastics for such processes must be free of contaminants which may result in hazardous outbursts. The production of such fuel could be used to power engines and automobiles. Although, certain challenges such as the quality of materials used which may affect the end product exist with the use of this process for plastic waste, nevertheless, it has been well improved in developed countries. However, in many developing countries especially in Africa, considering the high volume of plastic waste, the process of plastic waste pyrolysis is yet to gain significance commercially as it is expensive to set up a commercially suitable plant. Therefore, the need for more research leading to innovative approaches to further simplify this process might be a crucial step towards the eradication of microplastic and the creation of jobs and income for workers in such industries.

### 6.4. Biological degradation of plastics

This is a process whereby microorganisms are employed to facilitate the degradation of plastics. Such microorganisms produce enzymes that are capable of biodegradation of natural and synthetic plastic materials. However, for the success of this process, the combination of certain factors such as the type of plastic material i.e., the functional group, molecular weight, and the right temperature is of great importance. Fungi are essential microorganisms that feed on plastic materials by releasing enzymes such as cutinase, lipase, proteases, and others; examples of such fungi include *Aspergillus flavus*, *Penicillium griseolfulvum*, *agaricus bisprus*, and others as extensively reviewed by [109]. This process is yet to gain recognition on the African continent, therefore necessitating the need for research to explore several microorganisms, especially from plants that show potential for the degradation of both synthetic and natural plastics, thereby contributing to the elimination of microplastic pollution that could constitute negative socio-ecological effect to humans, animals and the environment at large. In addition, the degradation of MPs by ozone has been unveiled to impact the physical and chemical structure of MPs, as well as the quality of treated water. This process can increase the conformational changes in the physical and chemical constituents of MPs by 1–27 % when oxidized using hydrogen peroxide and also allow for the elution of phthalic acid esters and plasticizers [160].

### 6.5. Production of bioplastics

The negative effect of improper plastic degradation has led to the spread of micro and nano plastics not only affecting the aquatic ecosystems but also the human ecosystem. The need to transition from the use of materials that could harm living organisms to environmentally friendly materials has necessitated the evaluation of biodegradable materials for the production of plastics. Biodegradable plastics otherwise known as bioplastics are produced from bio-base materials such as corn, starch, rice, and others; also, from biowaste such as potato peels including plant materials as the primary feedstock. The application of plants and relevant microbes known to generate polymers as well as other materials high in cellulose have been explored for the production of bioplastics. Studies of materials and processes for the production of bioplastics are fast gaining attention in Europe, although, a greater percentage of its plastic production is derived from fossil fuel. Africa on the other hand is still aiming to explore this approach. Considering the different materials that could be explored for the production of bioplastics, the continent of Africa stands a great chance to benefit from this industry, however, the success of this process requires funding for research purposes as well as a concrete framework to serve a guiding principle for its implementation. Today, materials such as bamboo is being exploited in the production of bioplastic with China being the highest producer of bamboo. In Africa, countries like Nigeria with high production of bamboo could also develop this sector with the aim of bioplastic production.

Conclusively, the mitigation of microplastics especially on the African continent requires a multi-faceted approach rather than a one-directional approach. Therefore, the success of eliminating or at least minimizing the risk of microplastic pollution requires an all-inclusive approach involving individuals from the household level to the government level. The development of research ideas and policies to facilitate this success must be examined holistically, thereby not just solving the challenges of microplastic pollution but also enhancing job creation and income generation leading to the overall economic growth of such developing countries. In addition, governments all around the world especially in developed countries have launched a variety of campaigns to change consumer behavior over the use of plastic bags, primarily in the form of laws or levies. The purportedly harmful effects of plastic bags on the environment have been the main impetus for these campaigns. This initiative, if explored properly on the African continent will not only reduce the overall generation of plastic waste but could also be a source of revenue generation that could be channeled into the development of biodegradable plastic production.

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## Declaration of Competing Interest

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

## Data Availability

No data was used for the research described in the article.

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