Discover Environment

Review

An overview of the prevalence of micro- and nanoplastics in the Southern African development community: a potential risk to environmental and public health

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Received: 17 February 2025 / Accepted: 24 June 2025
Published online: 03 July 2025

Abstract
Rapid urbanisation, industrial development, and inadequate solid waste management systems, finances, and even legal frameworks have exacerbated Southern African Development Community (SADC) plastic waste and micro and nanoplastics (MNPs) proliferation, raising serious public health and ecological concerns. There is scant information on the occurrence of MNPs in the SADC, especially in rivers, streams, wetlands, and lakes which are vital as freshwater sources and food producers. This systematic review analyses the occurrence of MNPs within the water bodies of SADC. The literature, which included 84 published papers, was collected through the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology with additional literature (n = 39) that confirmed MNPs' presence in these ecosystems. Some prominent examples of water bodies that have shown the prevalence of MNPs are Namibia's Main River and South Africa's Crocodile and Vaal Rivers. Pollution caused by urban runoff and degradation of plastic waste stemming from industrial activities is critically damaging to the environment, particularly the soil, water, food web, and biodiversity of the region. Overall, there is a dearth of research directed towards investigating the occurrence of MNPs in SADC countries with most studies concentrating on bulk plastic waste, underscoring the need for public awareness and stricter regulations on plastic production and waste to mitigate MNP pollution.

Keywords Microplastic · Nanoplastics · Aquatic environments · SADC countries · Environmental risks · Human health · Regulatory frameworks

1 Introduction

Plastic production globally reached 400.3 million metric tons in 2022, a 1.6% increase from the previous year [1]. The production of thermoplastics is expected to reach 445.25 million metric tons by 2025, with annual production volumes expected to reach 590 million metric tons by 2050. Approximately 70% of daily plastic production originates from Africa, particularly Southern Africa, with SADC having the fourth-largest category of plastic imports [2]. Figure 1 shows plastic waste data in some SADC countries in (kt), with South Africa, DR Congo, and Tanzania generating over 1000 kt of plastic waste [6, 7], which enters waterways and ultimately reaches the coast [8].

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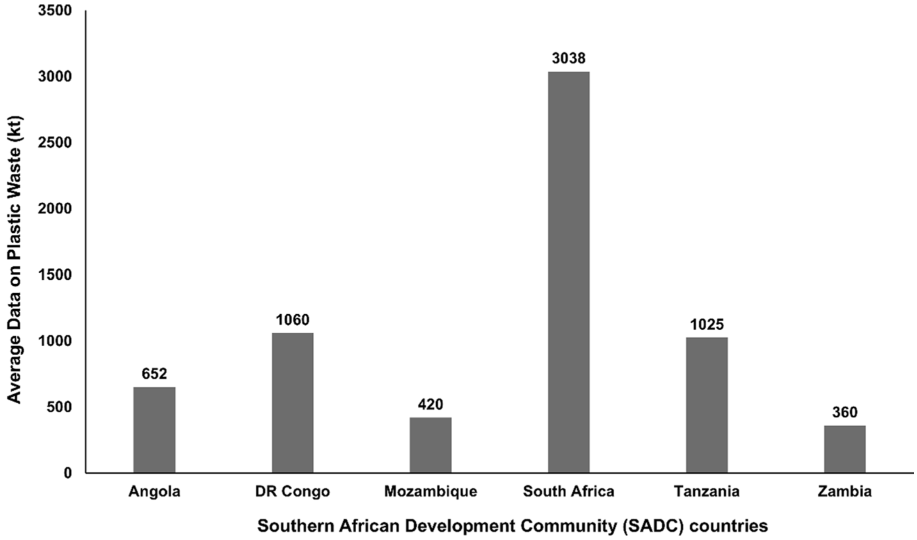

Fig. 1 Average data on plastic waste for some SADC countries per year in (kt), adapted from [7]

Africa, the second-largest of the world's continents both by surface area and population, is projected to experience rapid urban population growth (3.5 percent a year), growing middle class, and municipal solid waste (0.78 kg per the mean individual per day to 0.99 kg by 2025), with the increased usage of different plastics and therefore plastic pollution [3]. Some of these plastics may be transported from land into rivers. For example, in 2016, 19–23 million metric tons, accounting for 11% of global plastic waste, were recorded in riverine ecosystems [5]. While some plastics remain in the river system, others may be exported into the ocean [4, 72]. Africa's extensive coastline, with South Africa having the longest coastline in Southern Africa and shared river systems, contributes significantly to the transfer of plastic waste to the sea and deeper into the ocean [3, 9]. South Africa has a bigger economy and industrial base than other SADC countries, its greater production of plastic (especially for packaging and construction) reflects this. This is primarily due to a greater per capita consumption and dependency on plastic within these sectors [2].

Urbanisation, economic growth, and population growth have also led to increased plastic waste generation and the introduction of emerging contaminants, posing risks to the environment and animal and human health [10, 11]. These emerging contaminants are caused by anthropogenic activities, and they enter water systems from surface runoff, wastewater effluent, and industrial discharges [12]. Among these are MNPs, which are minuscule plastic particles that can result from the breakdown of larger plastic objects or may be produced at minuscule sizes for specific uses [13]. The issue of MNP pollution has received attention recently because MNPs pollute the air, land, and water and endanger human health and ecosystems, thus, they are classified as emerging pollutants because of their persistence and accumulation in the environment.

MNPs are widespread in South Africa's aquatic environments, especially in freshwater systems, and they can enter the food chain via several pathways, leading to bioaccumulation in the human body [14]. This review thus focuses on the occurrence of MNPs in the aquatic systems of the SADC and their associated risk.

2 Materials and methods

2.1 Literature collection

The study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards. Eighty-four (84) papers that were published in the chosen journals between 2017 and 2025 were reviewed using the PRISMA flowchart. Supplementary sources (n = 39) were also used to enhance and provide a comprehensive overview of the study. The study period was selected because, (1) Web of Science has 16,083 publications about microplastics, of which 4,056 were published between 2017 and 2024 [15], (2) the world's annual production of plastic waste increased from 180 million tonnes to around 400 million tonnes, with a significant portion of this increase occurring between 2017 and 2024 as per the OECD's Global Plastics Outlook report [16], and (3) there was a significant increase in human tissue MNP research, particularly focusing on possible health effects of MNPs in humans [17].

The study utilised six popular electronic bibliographic databases: Google Scholar, Web of Science, Scopus, EBSCO-host, JSTOR, and PubMed, along with grey literature from various sources, newspapers, newsletters, and government gazettes. Keywords like "Microplastic* or Nanoplastic* or Plastic particles, Polyvinyl chloride microplastic*, Polyethylene microplastic*, Polyamide microplastic*, Polypropylene microplastic*, Polystyrene microplastic*, "Southern Africa", "SADC region", "Environmental risks", "Health risks, and "Plastics law" were used.

2.2 Literature screening: inclusion and exclusion criteria

Two hundred and five (205) identified records were exported to the EndNote 21 reference manager software to eliminate duplicates. Fifteen (15) duplicates were eliminated, leaving 190 records for screening. Fifty-five (55) duplicates were further eliminated during screening because crucial information contained in them was inaccessible, leaving 135 records. Out of the 135 records that were sought for retrieval, 46 were not retrieved, and 89 were assessed for eligibility. Of the 89 records, 5 were further removed due to a lack of clarity and irrelevance. The remaining 84 publications that specifically investigated the prevalence of MNPs in aquatic environments were included in this study. Despite the study's focus on the SADC, there weren't many publications about the region.

Figure 2a depicts articles that have been identified (205) and used (84) per year from 2017 to 2025, using Google Scholar, EBSCOhost, Web of Science, PubMed, JSTOR, and Scopus. Figure 2b shows the PRISMA flowchart indicating the search procedure for identifying and selecting articles.

3 Discussion

3.1 Microplastics and nanoplastics: characteristics and potential toxicity

Microplastics (MPs) are plastic particles smaller than 5 mm, while nanoplastics (NPs) are even smaller, usually between 1 nm and 1 µm, and both these types of plastics come in a variety of shapes, sizes, colours, and polymer types [13]. Figure 3 below shows a graphical description of the sources of MPs and NPs, including the processes involved in their formation. Recognising MNPs entails being aware of their types, sources, pathways to the environment, and their exposure to humans and ecosystems. This is required to develop management strategies to lessen their impact on the plastic waste-environment/ecosystem-human nexus.

A combination of forces (e.g., wave action, wind, mechanical abrasion, and exposure to sunlight) breaks plastics into MPs and NPs. Sunlight induces photodegradation that makes plastics brittle, leading to MPs through UV radiation. Thermal degradation also occurs at elevated temperatures in diverse environments, including landfills. Other microorganisms and chemical processes, such as oxidation, can slowly degrade plastics, thus contributing to MNP formation [28, 34, 112]. These small particles pose severe ecological risks due to their environmental persistence and potential impact on wildlife and human health [28].

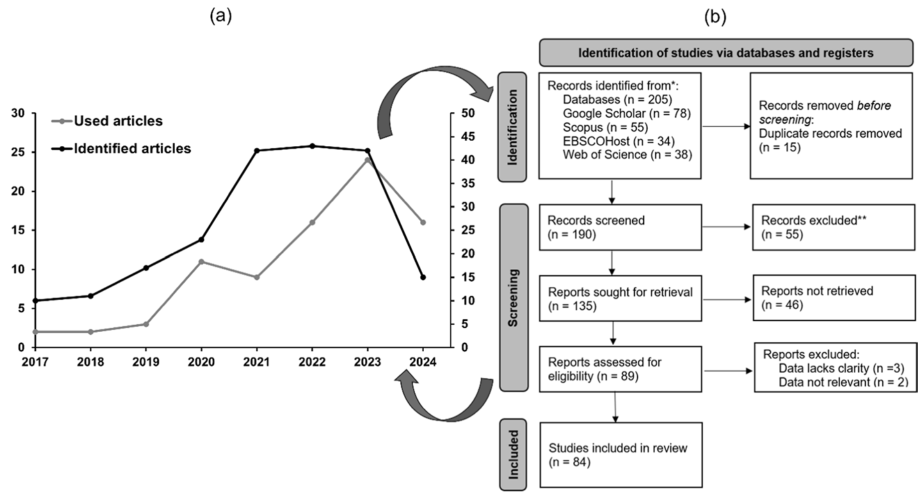

Fig. 2 **a**, **b** Procedures for selecting studies from the five largest databases according to PRISMA guidelines from 2017 to 2025 as used in this study

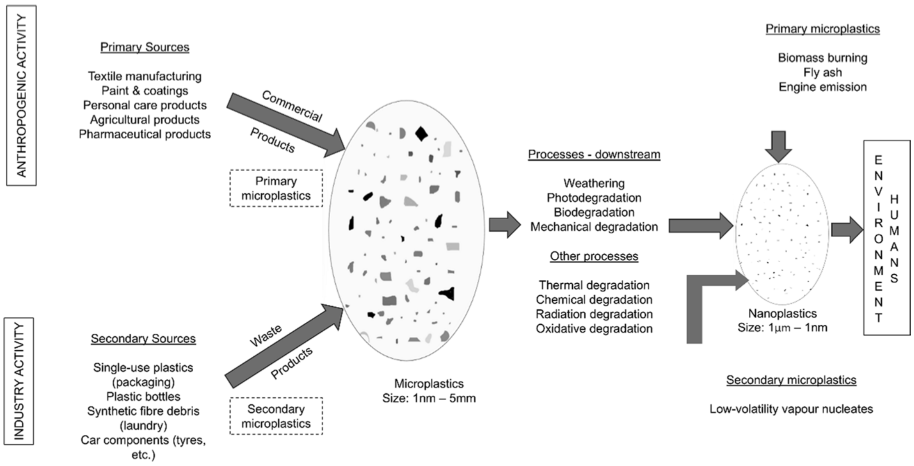

Fig. 3 Fragmentation of plastics into microplastics and nanoplastics

3.1.1 Microplastics

MPs are synthetic polymers with a diameter of ≤ 5 mm. The term "microplastics", according to Lambert et al. [18], encompasses a wide range of particle sizes, shapes, and polymer types. The size and shape of MPs can vary significantly, which influences their behaviour in the environment. Consequently, the chemical and physical characteristics of MPs will differ from those of the microbeads that are commonly used in ecotoxicity testing.

MPs have unique properties and exist in different forms, such as fibres, films, fragments, and microbeads [115]. Moreover, due to their small size, they can easily be ingested by marine organisms, resulting in bioaccumulation in the food chain [19]. Because each type of MP has its own unique set of chemical properties, they share commonalities at an environmental level. MPs can adsorb several toxic pollutants, such as organic compounds and heavy metals, present in the environment because of their comparatively high ratio of surface area to volume relative to larger plastic debris [20]. This adsorption of other pollutants can make them more toxic when some marine organisms feed on them. MPs not only take up and absorb other pollutants but also pose different ecological risks like chemical contamination and disturbance of ecosystem functions [21, 22]. MPs are relatively stable in the environment but are subject to further degradation processes that produce smaller particles, called NPs [23].

3.1.2 Nanoplastics

NPs range in size from 0.001 to 0.1 µm, making them even smaller than MPs, and their special physio-chemical properties raise concerns about their behaviour in ecosystems. NPs are smaller, so they have a greater surface area-to-volume ratio compared to similar MPs. This makes them more likely to interact with other pollutants and become more toxic. NPs are also more reactive in water, but their toxicity is not well understood [24–26]. This could enable them to absorb higher concentrations of other hazardous substances, such as persistent organic pollutants (POPs) or heavy metals. Since particles adsorb heavy metals, including POPs, biomagnification up the food chain is likely with increased toxicity at higher trophic levels, culminating in alterations of DNA in animals and humans alike, leading to undesirable mutations including other disorders [27].

There are also concerns about inflammation and oxidative stress because of exposure to NPs since they can more readily penetrate biological membranes than MPs due to their small size, potentially enabling them to cross barriers like cellular membranes in marine organisms, and the blood–brain barrier in humans. NPs are resistant to degradation, just like MPs, but because of their smaller size, they are more mobile within the ecosystems, which increases the likelihood of widespread distribution in soil, water, and air [28].

3.2 Classification of microplastics and nanoplastics

MNPs have been classified into primary and secondary MNPs by Nguyen et al. [29]. Qaiser et al. [22] described primary MPs as a class of manufactured plastics (commercial products) that are as tiny as resin pellets. Karbalaei et al. [30] described primary MPs as tiny plastic beads produced purposefully for commercial products and are commonly used in cleaners, cosmetics, and agricultural, pharmaceutical, and explosive technology products. Additionally, they may serve as carriers for medications in clinical settings [29]. Ali et al. [31] confirmed that primary MPs arise during manufacturing or are added to cleaning and personal care products.

Secondary MPs result from the fragmentation of bigger plastic objects through natural elements and other environmental stressors [32]. The organic material breakdown through microorganisms in biodegradation results in simpler compounds. The rate of biodegradation depends on plastic type and environmental conditions, together with microbial communities and MNP formation [33]. Apart from fragmentation, MNPs can also stem from the destruction or the improper disposal of plastic films, household waste, atmospheric deposition, and vehicle emissions [35], whereby MPs up to some 2.5 μm can float in the air.

Primary NPs (1–100 nm in diameter) are those emitted into the atmosphere from human activity, such as biomass/coal burning and motor vehicle emissions [36, 37]. They are released into the atmosphere already in particulate form. As such, direct human contact via dermal contact and inhalation is unavoidable. Hypothetically, these NPs can be easily absorbed into the bloodstream of animals and humans upon inhalation. In humans, the development of lung ailments will thus be profound [38].

On the contrary, low-volatility and nucleates from gaseous precursors can form secondary NPs through reactions such as photooxidation. These NPs are largely volatile organic compounds (VOCs) that condense in the atmosphere. The debate exists on whether gaseous oxides are the major source of NPs. Industrial and anthropogenic activities contribute to these emissions, affecting atmospheric conditions, cloud formation, and rainfall patterns. Moreover, these NPs pose risks to human health, potentially damaging the respiratory system and increasing cancer risks [39].

From a SADC context regarding primary and secondary MNPs, with South Africa (69%, 2023) and Angola (68%, 2024), respectively, having residents in urban areas and cities, the possibility of primary and secondary MNPs and inhalation is likely [40, 41]. This is evidenced by increased clinical cases of asthma in these countries' cities, perhaps because of smog [42]. Smog, a typical byproduct of primary/secondary NPs, has shown increased levels in South African and Angolan cities.

3.3 Microplastic and nanoplastic polymer type and structure

Various types of plastic polymers differ in their behaviours regarding bioaccumulation, toxicity, and degradation in ecosystems [20]. Polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), and polystyrene (PS) are the most common plastics that constitute MNPs. PE is often used for bottles, bags, and packaging materials, whereas PP is often used for textiles, car parts, and food containers. PS is a polymer used in disposable utensils, insulation, and foam packing [43]. PVC is a plastic found in medical equipment, flooring, and pipes. Of the most prevalent polymers, polyethylene terephthalate (PET), PVC, and polyamide (PA) will sink, while PP, PS, and PE will float [44]. Figure 4 illustrates the chemical structures of the most prevalent plastics.

The strength, flexibility, and transparency of these plastics and their resistance to heat and chemicals are significantly influenced by the polymer structure [45]. Whereas branched polymers, like low-density polyethylene (LDPE), carry branches for a softer material, linear polymers, like PE, are more elastic but weaker. Cross-linked polymers are less flexible but more mechanically strong. Crystalline polymers have stronger atomic bonds that result in a higher melting point, as well as rigidity, whereas amorphous polymers have weaker bonds that allow them to be more flexible and transparent, but they also degrade more easily.

Environmental conditions, such as acidity, can expedite the collapse of both types, and so amorphous materials tend to be more prone to that. Polystyrene (PS), Polymethyl methacrylate (PMMA), and Polycarbonate (PC) are amorphous plastics, while polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) are crystalline plastics [46]. The polymeric structure and monomer type affect the way polymers interact with biological systems, their potential health hazards, and their environmental behaviour [47].

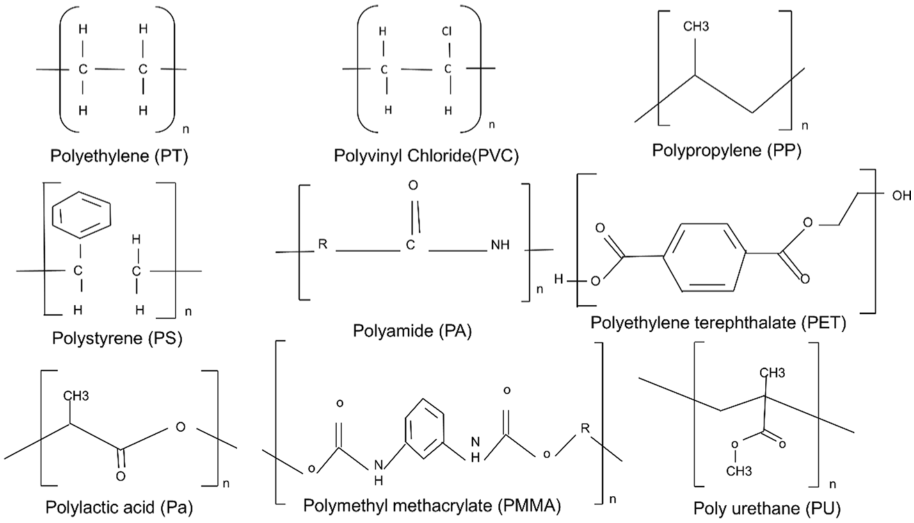

Fig. 4 Plastic types and chemical structure of their monomers

3.4 Transportation and fate of microplastics and nanoplastics

MNPs are transported in the environment via atmospheric or aquatic currents, including rainfall, surface runoff, and ocean circulation, depending on their weight and density. This transportation may be over great distances with their fate depending on factors such as shape, density, and size, and environmental conditions like salinity and temperature [113]. Some fragments of plastic will sink while others will float depending on their density, thus mobility. Heavier particles may sink into sediments or to the ocean bed, whereas lighter ones may float on the surface of the water [48]. POP and MNP sinks include oceans (the largest), rivers, lakes, and groundwater. Given their size, oceans are expected to absorb most MNPs, with coral reefs serving as a significant sink as MNPs integrate into their skeletal structures. This leads to low MNP concentrations at the ocean surface [52–54].

Additionally, MNPs are transported from land to water via ocean circulation, and from land to land [49]. The wind carries the smaller and lighter MNPs, while the denser aggregates tend to settle in the pedosphere. High-intensity rainfall can transfer MPs from urban areas and farmland to surface waters via surface run-off. Indeed, small plastic particles are increasingly entering soils as a result of agricultural practices, including using plastic mulches for crop development and sewage sludge for soil amendment, which also potentially contributes to runoff contamination [21, 50, 114]. Additionally, MPs from tyre wear enter surface waters through stormwater runoff during rainy seasons [51]. All these transportation pathways apply to NPs also.

Figure 5 depicts the routes of MNPs, from manufacturing facilities, industries, and homes to water bodies like rivers and oceans. It also shows the linkages between aquatic environments and land-based activities.

The distribution of primary and secondary MNPs is illustrated in Fig. 6, showing that synthetic textiles, car tyres, and city dust contribute 87%, while road markings, marine coatings, personal care products, and plastic pellets make up

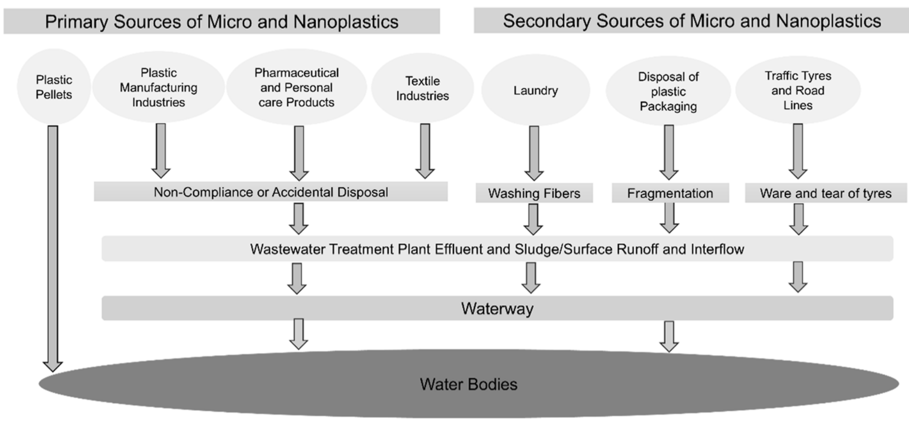

Fig. 5 Primary and secondary sources of microplastics and nanoplastics—pathways to waterbodies

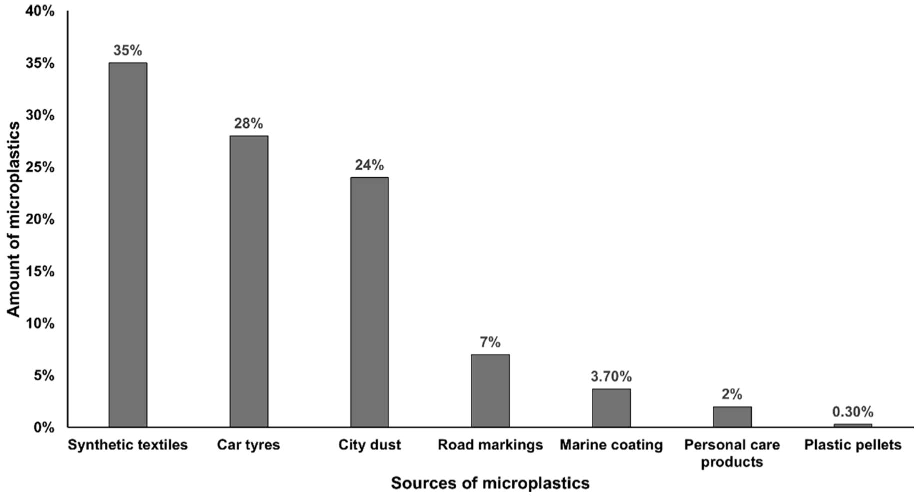

Fig. 6 The distribution of sources of primary/secondary MPs and NPs in the ocean [55]

13%. According to Fig. 6, synthetic textiles are the primary source of MNPs in the SADC, largely due to the fast fashion industry's rise, which has led to increased polyester clothing consumption. This influx leads to decreased clothing prices, with a large amount ending in waste treatment or informal dumps [116]. Motor vehicle users, as an outcome of economic growth, contribute to MNPs, with South Africa allegedly converting 72.7% of new tyre sales into waste between 2016 and 2022. Gauteng, Western Cape, KwaZulu-Natal, and Mpumalanga generated 74% of national waste tyres [117].

3.5 Toxicology and bioaccumulation of microplastics and nanoplastics

The physicochemical characteristics of MNPs, including their shape, size, surface characteristics, and polymer type, have a significant influence on the toxicological outcomes related to MNP exposure [33]. MNPs can prevent growth and development in organisms, substantially increasing the death rate. Furthermore, oxidative photodegradation of these plastic debris may result in the formation and subsequent release of some harmful VOCs, such as benzene and acrolein [56, 57].

Studies reveal that one of the primary mechanisms by which MNPs exert toxicity at the cellular level is through oxidative stress. Studies conducted in vitro have shown that exposure to MNPs can cause inflammatory reactions, cytotoxicity, and genotoxicity in a variety of cell types [31, 58]. Mammalian models have also demonstrated similar toxic effects in in vivo studies, indicating that MNPs may harm organ systems and general health in humans and animals [59]. Thus, their bioaccumulation in individual living organisms and their biomagnification through the food chain is undesirable.

Recent biomonitoring studies reveal the presence of MNPs in human samples like blood, urine, faeces, and placental tissues, indicating exposure through pathways such as inhalation and ingestion [33]. Notably, studies have shown that human organs such as the kidneys, liver, and brain, contain significant quantities of MNPs. The results imply that the most common polymer in these tissues is polyethylene. The increasing levels of bioaccumulated MNPs in these tissues raise concerns about chronic diseases and long-term health impacts for humans, animals, and sensitive ecological systems. Since MNPs can transport distinct biotic communities to new environments. The transportation of organisms and, subsequently, exotoxins linked to them by hydrological and meteorological processes is an emerging issue of serious concern [60].

3.6 Microplastics and nanoplastics in the SADC

Between 80 and 90 percent of plastic waste (excluding littered waste) in Africa is improperly handled and disposed of, which pollutes the continent's rivers and oceans and is expected to rise by 2025. Table 1 shows sector and application hotspots that were identified for plastic leaks by the World Wildlife Fund (WWF), namely Mozambique, South Africa, and Tanzania, all being part of the SADC.

In another study by Jambeck et al. [9], South Africa, Nigeria, and Egypt were identified as the continent's top contributors to plastic leaks. These nations were among the top 20 coastal nations in the world that contributed to

Table 1 Plastic leakage hotspots

Country	Sector Hotspots			Application Hotspots				
	Textile	Packaging	Automotive Tyres	PET Bottles	Other bottles (non-drinking)	Bags	Lids and caps	Nappies
Mozambique	0.7 kt	12.9 kt	–	–	–	4.9 kt	–	1.6 kt
South Africa	–	63 kt	9 kt	13 kt	–	–	–	3 kt
Tanzania	18 kt	2.6 kt	–	–	7.7 kt	4.6 kt	–	–

marine plastic pollution. These plastics break down into MNPs. Overall, freshwater ecosystems and water quality are under threat from MNPs [61].

Globally, MNPs have been detected in oceans, rivers, air, and sediments [62, 63]. Furthermore, studies have shown that marine organisms like fish, molluscs, and crustaceans ingest MNPs, which can enter the food chain when these organisms consume MNPs, and subsequently, larger predators consume the contaminated organisms culminating in biomagnification. For example, in the upper Vaal River, South Africa, fish species such as African catfish (*Clarias gariepinus*) have been reported to contain MNPs [64]. This is expected, as a study conducted in the Vaal River revealed the presence of MNPs with an average size of 0.055 mm (mean 0.68 ± 0.64 particles/cubic meter) and a large quantity of smaller MNPs below 1 mm in the river's surface water [65, 66].

Since river water is a source of drinking tap water, a study conducted in three suburbs of the Gauteng Province of South Africa (Tembisa, Braamfontein, and Silver Lakes) revealed that Tembisa had MNP concentrations of 4–20 particles/L (mean 13 ± 4.9), Braamfontein 9–31 particles/L (mean 18 ± 6.2), and Silver Lakes 4.7–16 particles/L (mean 11 ± 4.0), indicating contamination [67]. Furthermore, an examination of major drinking water suppliers, including Johannesburg, Mabopane, Ga-Rankuwa, and Pelindaba, revealed insufficient evidence that treatment processes reduced MNPs. Concentrations were 0.26–0.88 particles/L in distribution networks, 0.56–0.9 in immediate treatment, and 0.24–1.47 in source water, predominantly consisting of fibres and plastic fragments [68].

Seasonality also plays a role in the prevalence of MNPs, whereby these emerging pollutants were determined to be abundant in surface water during the cool-dry season (mean 1058 particles per m3) and high in sediment during the hot-dry season (mean 568 particles per kg dwt) in the Crocodile River (South Africa) sediment. Because of the old wastewater treatment plant (WWTP) infrastructure which is not maintained, effluent from such WWTP was attributed as a primary source of MNPs in receiving rivers [69]. Another similar study conducted in Plankenburg River, Western Cape, South Africa, revealed that all sites had varying seasonal distributions of MNPs in the surface water samples. However, the MNP occurrence was lowest in the Autumn samples (1.52 ± 2.54 MNP/L) and highest in the Spring samples (5.13 ± 6.62 MNP/L). In Spring, sediment samples showed MNPs of 1587.50 ± 599.32 MNP/kg. Fibres were the most prevalent type (shape) of MNPs, with PE being the predominant polymer type [70].

Figure 7a–c shows secondary MNP sources (waste products) pollution in the Black River and Salt River, Cape Town, which included diapers, bags, bottles, tyres, etc. Exemplarily, tyre-derived MNPs contribute 28% to the overall concentration of MNPs in aquatic environments, as shown in Fig. 6. These tyres enter river systems with other secondary MNP sources, degrade, and break up into MNPs, increasing the strain on aquatic ecosystems and endangering aquatic life and human health. Aquatic ecosystems are at risk of MNP pollution, which has diverse impacts on marine organisms and can disturb the delicate balance of these ecosystems, thus altering the delicate balance of life under the oceans by infiltrating the very foundation of marine ecosystems [71].

In low-income countries, advanced recycling equipment is non-existent, leading to large amounts of plastics being burned by the side of the road before washing into and polluting rivers. This is a source of primary and secondary MNPs and it is in contrast with developed countries, where some plastics are recycled [73]. According to the Environmental Protection Agency (EPA), only 7% of the tonnes of plastic waste generated globally each year are recycled [74]. Furthermore, the most prevalent plastic recycling processes used in developed countries are downcycling, chemical recycling, or incineration; these processes do not reduce the risk of MNP environmental contamination but may produce hazardous substances from the plastic end-products [75].

River flows in SADC are decreasing because of several factors, including climate change. Many of these rivers provide transportable, potable fresh water. As a result, nearby urban development and anthropogenic activities have a major influence on the region's river health. Information regarding the frequency of MNPs in the region's

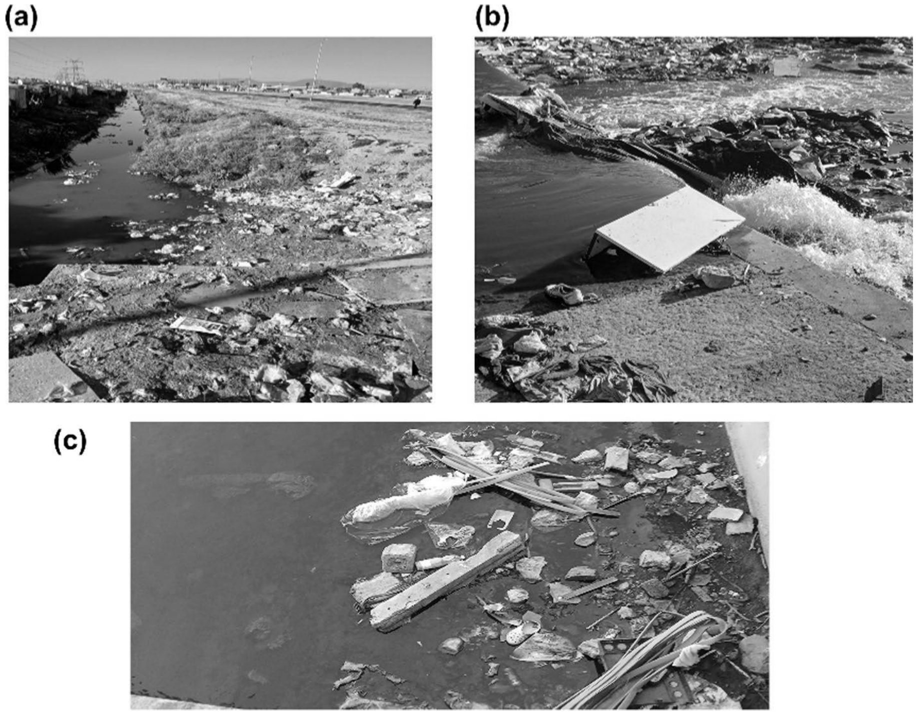

Fig. 7 Plastic pollution in the Black River (**a** and **b**) and the Salt River (**c**), Cape Town, Western Cape, South Africa: Image: Babalwa Gqomfa

rivers appears to be scarce. Water availability is a national security concern for the majority of nations, hence it is a strategic blunder in the long term not to address MNP contamination of rivers as a source of fresh water [118, 119].

3.6.1 Microplastics and nanoplastics on some of the SADC coastline

MNPs are a growing environmental concern on the coastline of SADC. Countries that have coastlines in this region are South Africa, Namibia, Angola, Mozambique, Madagascar, Mauritius, and Comoros. These countries have coasts that run along the Mozambique Channel, the Atlantic Ocean, and the Indian Ocean, with South Africa leading the fishing activity, which is comparatively high compared to international standards. Some popular fish being caught are Sardines (*Sardina pilchardus*), Cape hake (*Merluccius merluccius*), Rock lobster *(Jasus edwardsii*), and Tunas (*Thunnini*). Kingklip (*Genypterus capensis*) and Snoek (*Thyrsites atun*) constitute the rest of the basket [76]. Because of such fishing activity, MNP prevalence might contaminate the fish, culminating in MNP-contaminated fish being eaten by humans.

The presence of palladium-doped polystyrene NPs in Cape Agulhas, South Africa, was observed in the carcasses of rainbow trout, specifically within the muscle, bone, and connective tissues [120]. Additionally, measurable quantities were detected in various organs, including the intestine, liver, gallbladder, kidney, and gills, raising significant health concerns due to the potential implications for human dietary intake. MPs were identified in seven different fish species (n = 105), which included *Trachurus capensis*, *Merluccius capensis*, *Merluccius paradoxus*, *Etrumeus whiteheadi*, *Scomber japonicus*, *Chelidonichthys capensis*, and *Argyrozona argyrozona*. A substantial majority of the sampled fish (86.67%) contained MPs, with the predominant form being fibres [77].

MNPs are caused by industrial processes, textile fibre shedding, and the breakdown of debris [78]. Southern Africa's distinct geographical and ecological features also contribute to the distribution and accumulation of MNPs. MNPs are transported over great distances by the currents of the Atlantic and Indian Ocean [28]. While diverse topography affects runoff processes and rainfall patterns, major rivers like the Zambezi, Limpopo, and Orange Rivers carry MNPs from inland areas to coastal areas [121]. See Table 2 for some of the SADC regional coastlines that have been affected by MNP pollution. Observingly, there is scant literature on MNP contamination of the coastlines within the SADC region—an area needing further research.

Table 2 Microplastics and nanoplastics on some of the SADC region's coasts/oceans

Country	Amount of MNPs and analysis method	Dominant polymer	References
South Africa, Durban Harbour	Surface water samples contained up to 80.72 MP m^{-3} and sediments had 1.76 MP g^{-1}. Analysis using Horiba LabRAM HR Raman spectrometer	PE, PP, and PET	[79]
South Africa, Simon's Town	Sediment (38 ± 2 MP/kg) water (0.37 ± 0.06 MP/L). Analysis using FTIR	Nylon, PET, cotton	[80]
Tanzania, Dar es Salaam, and Zanzibar coasts	641 MPs across all sites, 84% (Beach) and 16% (seabed sediments). Analysis using Micro-FTIR	PE and PET	[81]
Northern Mozambique and Tanzania	meso- and micro-litre (8567 ± 19,684 items·km^{-2}, 44 ± 195 g km^{-2}) and microfibres (2.4 ± 2.6 fibres·L^{-1}) are pervasive pollutants. Analysis using LUMOS stand-alone micro-FTIR microscope (Bruker Optik GmbH)	Not Specified	[82]

3.6.2 Prevalence of microplastics and nanoplastics in SADC waterbodies and food sources

Various studies have shown the presence of MNPs in the SADC region's waterbodies. For instance, a study conducted in the Okavango River, Botswana, revealed that the Okavango Panhandle's surface sediments were contaminated with MNPs [83]. MNP concentrations varied from 1075.7 to 1756.3 particles/kg sediment. The main constituents of the MNPs were PVC, PP, PE, PS, and PET [83]. Another study examined MNP distribution in Madagascar's Ikopa River and its impact on fish species, indicating significant increases in MNP concentration during the wet season (from 138.6 ± 9.0 to 222.0 ± 24.5 particles per m3), with higher contamination rates observed in the Nile Tilapia (*Oreochromis niloticus*) and Gambusia. The most common polymer, accounting for 62.3 ± 5.13% of the total polymers sampled, was polyethylene-co-vinyl acetate (PEVA) [84]. One of Madagascar's main fish species is the Nile tilapia, which is essential for providing the local population with a sustainable source of protein.

According to a South African study, three commercially significant small pelagic fish species—South African sardine, West Coast round herring, and European anchovies—were found to contain MNPs. Additionally, MNPs were more prevalent in *Sardinops sagax* (Southern African pilchard) than in *Etrumeus whiteheadi* (South African round herring) and *Engraulis encrasicolus* (Cape anchovy). A large number (80%) of items consumed by these species were microfibres [85]. This further attests that synthetic fibre contributes a large proportion of fibres as MNPs in the ocean (see Fig. 6).

In Mauritius, an island geographically considered part of Africa and located in the Indian Ocean off the southeast coast of Africa, Ragoobur et al. [86] observed in four estuaries that fibres were the most abundant, with MNPs of sizes 24-250 µm in surface water and 500-1500 µm in sediment. Cotton polyamide-type MNPs were predominant in both surface water (33%) and sediment (44%), followed by PE (28%) and PP (22%), respectively. A similar study conducted by Faulstich et al. [87] in Namibia's Iishana system, a system in which tilapia (*Oreochromis andersonii*) species are abundant, revealed a higher concentration of MNPs than perennial or ephemeral systems in Namibia's major river catchments. Common polymer types were also PE and PP, with fractions measuring between 0.3 and 0.5 mm.

3.6.3 Community initiatives to reduce plastic waste pollution in the SADC

Community education plays a vital role in addressing plastic waste pollution by increasing awareness of the environmental risks of MNPs and their impact on human health. Dealing with these difficulties involves a diverse strategy that includes raising awareness, promoting behavioural changes, allocating resources, developing infrastructure, integrating policies, and innovating technologically [122]. Global efforts like the New Plastic Economy Global Commitments and the Alliance to End Plastic Waste were established to motivate members of the worldwide plastics sector to pledge to decrease plastic waste pollution in the oceans. Although these initiatives are praiseworthy, they do not adequately tackle the specific obstacles encountered in SADC concerning waste management infrastructure, education, and awareness. International best practices must serve as the foundation for solutions that are specific to the SADC regional context and that aim to alter human behaviour in the process [88].

For example, Lesotho is becoming a leader in plastic waste management within SADC, highlighted by initiatives like Pheha Plastic, which recycles plastic into floor tiles while educating communities on converting plastic waste into tradeable goods [89]. A Plastic Waste Management Project launched by UNDP and Lesotho Correctional Services in June 2021 supports female prisoners in plastic recycling [90]. Similarly, women in Botswana form an integral waste value chain, serving as street sweepers, informal plastic waste collectors, and community recycling leaders. Specifically, they can promote the collection and recycling of waste and reduce the environmental pollution caused by plastics [123].

Furthermore, Madagascar, a SADC country vulnerable to environmental harm, faces rising concerns over plastic waste pollution. Since 2022, the Plastic Tide Turners Challenge Project has engaged over 4500 youth in understanding environmental issues, particularly plastic waste [91]. Good plastic usage practices have been emphasised. Concurrently, PREYO (Plastic Recycling and Youth Empowerment) TZ in Tanzania addresses plastic collection, focusing on PET, HDPE, and PP waste, particularly PET. The project has successfully collected around 6000 tons of plastic, including 3000 tons of HDPE. These efforts have garnered global recognition, including the Green African Global Climatic Ambassador award, and supported about 200 waste pickers through fair compensation [92].

3.6.4 Plastic-related legislation and regulations in the SADC

In November 2020, 16 countries, including Eswatini, Lesotho, Angola, Madagascar, Botswana, Comoros, Congo, Mozambique, Namibia, Zimbabwe, South Africa, Malawi, Mauritius, Tanzania, Zambia, and Seychelles, formed part of the Southern African region [93]. Figure 8 shows the map of the Southern African Development Community member states.

SADC nations are developing regulations to levy or ban plastic bags to increase awareness about plastic waste pollution. However, implementation varies [94]. The SADC 16 countries have all issued a plastic bag reduction policy. Reducing or eliminating single-use plastics may greatly reduce environmental waste and toxicity [95]. In many SADC states, ineffective tax systems undermine the efficient enforcement of bans. Successful models, such as Rwanda, Tanzania, and Kenya, feature effective national and regional policies for minimizing plastic waste [96]. Infrastructure challenges in Lesotho include the absence of regulated disposal sites and unauthorized dumping, creating a situation in which 25% of municipal waste is collected and where no waste management laws exist. A Waste Management Information System was launched in 2022, advocating for a dedicated waste management division and regulatory frameworks [3]. Lesotho's Legal Notice No. 88 of 2022 prohibits the import, production, sale, or use of plastic bags under 25 to 35 microns thick, as well as thin plastic bags [97]. Funds collected by the Lesotho Revenue Authority from the plastic levy will go towards pollution prevention and environmental education projects. Mozambique's Decree No. 16/2015 and Environment Protection Regulations 2020, aim to reduce the use of plastic bags and promote biodegradable options, as well as set compliance measures [98]. As of March 1, 2021, Mozambique prohibited plastic bags and single-use plastics like utensils and straws.

In Eswatini, the Eswatini Accelerator Lab launched the Phatsa Sakho Nawe campaign under the "Clean Eswatini Campaign" of the Prime Minister's Office. The campaign is a continuation of earlier efforts by the Eswatini Environment Authority including the imposition of a single-use plastic bag levy which was put on hold in 2017 due to community push-back [99].

In South Africa, while there isn't a dedicated environmental law for packaging and plastic waste, steps are being taken to tackle these concerns. The 2022 National Environmental Management Laws Amendment Act (NEMLA Act), effective from June 30, 2023, enhances the legal framework. Key legislation tackling plastic waste includes the National Environmental Management Waste Act (No. 59 of 2008) and the National Environmental Management Act (No. 107 of 1998) [100]. Furthermore, the Environment Conservation Act (No. 73 of 1989) governs waste management processes and limits certain single-use plastic bags. South Africa is also advocating for a global plastics pollution convention, addressing the entire plastic life cycle [100–102].

Zambia has also introduced laws such as Statutory Instrument No. 65 of 2018, the Environmental Management Act (Act. 12 of 2011), and the Environmental Management (Extended Producer Responsibility) Regulations of 2018. In 2018, the Zambian government banned the use of packaging materials, such as plastic bags, and the waste they carry. There are no restrictions in this country on the enforcement of this prohibition, either [103]. The Plastic Packaging and Plastic

Fig. 8 Map of the Southern African Development Community (SADC) member states: Image: Babalwa Gqomfa

Bottles Regulation 2010 (S.I.) No. 98 of 2010 was implemented in Zimbabwe, making it illegal to manufacture, distribute, or import plastic packaging, irrespective of whether biodegradable or not, with a wall thickness of less than 30 µm, except for plastic bags designed to package bread [104]. Also, no ink may be used to print on plastic or plastic bottles unless it and the printing in question meet mandatory requirements. Additionally, unless the ink and the printing meet mandatory requirements, no ink may be used to print on plastic or plastic bottles.

In Mauritius, the government introduced Gazette No. 81 of 6 August 2015 (Government Notice No. 153 of 2015), and the Environment Protection Act Regulations were made by the Minister under Section 96 of the Environment Protection Act [105]. Furthermore, Mauritius passed Government Notice No. 153 Notice in 2015 that regulates the usage of plastic with respect to their management to encourage sound environmental sustainability. These actions range from banning single-use plastics such as straws and bags and promoting recycling to using biodegradable alternatives [105].

In 2017, Seychelles adopted Statutory Instruments No. 37 of 2017, and No. 38 of 2017 [106]. The use of plastic bags, plastic utensils, and PS boxes was restricted to their sale, Importation, production, and distribution. It provided for a maximum fine of SCR 20,000 (USD 1460) for violations in March 2019 and a maximum jail term of one year—or both.

3.6.5 Global plastic treaty: SADC involvement

Plastic pollution globally could triple by 2040 based on the current rate unless action is taken immediately. Country-driven initiatives and voluntary measures have not been effective in stopping plastic waste pollution. Eighty-eight percent (88%) of the 20 million metric tons of plastic that leaked into the environment worldwide in 2019 were MNPs, with single-use products like shopping bags, bottles, caps, cups, and straws being responsible for the global plastic pollution issue [107]. Furthermore, with 9.3 million metric tons of primary source NP emissions per year, India leads the world in plastic emissions, followed by China [108, 109].

Given that plastic pollution is a global issue, a plastics treaty is necessary to address harmful subsidies, eliminate hazardous chemicals, and implement strict national plans with robust reporting. The United Nations Environmental Assembly has adopted such a treaty in Nairobi, with 175 nations committed to implementing it by 2025. This treaty aims to inspire national initiatives and promote high standards for plastic consumption [110]. Several African countries, including Tanzania, South Africa, Zambia, and others, have pledged support. The treaty's potential to reduce plastic pollution hinges on effective enforcement, international cooperation, public engagement, trade impacts, and strong national commitments. Although negotiations are ongoing, previous talks in Busan, South Korea, failed to reach an agreement, with a new session planned for 2025 [111].

4 Research gaps and future directions

MNP pollution is a critical global issue requiring coordinated, multisectoral efforts. Future management of MNP pollution requires innovative solutions, legal frameworks, and community participation. Research on MNP pollution is growing, yet research gaps remain that hinder understanding, specifically:

❖ The difficulty in detecting and identifying hotspots as existing methods are tailored for larger particles.
❖ There is limited research on the toxicity of NPs, particularly their effects on marine life and potential risks to human health.
❖ Moreover, the behaviour of MNPs in various environments remains poorly understood, necessitating further exploration of their degradation processes and interactions with other pollutants.
❖ The lack of a unified international standard for measuring MNPs in different matrices complicates regulatory efforts and the standardisation of the process.
❖ Current regulatory frameworks often do not adequately tackle MNP pollution due to insufficient data on risks and effects, highlighting the urgent need for research to inform regulatory policies.

Addressing the gaps in understanding MNPs requires the following:

❖ The development of advanced analytical methods is vital for detecting and quantifying MNPs using a unified international standard.
❖ Understanding the ecological impacts of MNPs is essential for assessing biodiversity and ecosystem health impacts.

❖ Industry organisations in SADC countries should advocate for standards, education, and training to ensure compliance with regulations. At this stage, there is no single industry organisation tasked with plastic waste pollution, although the SADC Business Council (SADC BC) is trying to develop initiatives to support plastic waste recycling.
❖ An integrated approach combining reduction strategies, sustainable alternatives, enhanced recycling, legislative support, community engagement, and technological innovation is critical to combat plastic waste pollution effectively.

5 Conclusion

The prevalence of MNPs in the aquatic environments of the SADC region constitutes a significant challenge with far-reaching implications for both the environment and human health. MNPs, categorised both as primary and secondary depending on their source, are emerging plastic waste contaminants found in various water bodies and habitats, with the potential to affect the biological systems of organisms, animals, and humans alike due to their smaller size and toxicity.

Within the SADC region, MNPs were found in animal parts. For example, the majority of palladium-doped polystyrene MNPs in rainbow trout were found in their carcass (muscle, bone, and sinew), with quantifiable amounts found in the intestine, liver, gallbladder, kidney, gill, and carcass of the fish, thus posing health concerns as these animals are part of human diets. MNPs were discovered in samples of horse mackerel (Trachurus capensis), hake/shallow-water hake (Merluccius capensis), deep-water Cape hake (Merluccius paradoxus), round herring (Etrumeus whiteheadi), chub mackerel (Scomber japonicus), gurnard (Chelidonichthys capensis) and carpenter seabream/silverfish (Argyrozona argyrozona) among others.

Most fish were found to have MNPs, with most being fibres and PE. Similarly, MNPs were also detected in drinking water, river water, and sediment, with the highest concentration in surface water observed during the cool-dry season. MNPs were also found on the coastline of SADC countries, with hotspots identified in different countries, i.e., (1) in South Africa, Durban Harbor, (2) Tanzania, Dar es Salaam and Zanzibar, and (3) in northern Mozambique. It is, therefore, important for SADC countries to legislate against plastic waste pollution, albeit with a direct mention of MNP abatement.

Author contributions Babalwa Gqomfa: Conceptualization, Methodology, Writing—Original draft preparation, Visualization, Investigation •Chidi Boredi: Supervision, Writing—Review & Editing, Resources •Seteno Karabo Ntwampe: Supervision, Visualization, Writing—Review & Editing, Resources •Cynthia Dlangamandla: Supervision, Writing—Review & Editing •Thabang Maphanga: Supervision, Writing—Review & Editing.

Funding The author declares that no funds or grants were received during the preparation of this manuscript.

Data availability No datasets were generated or analysed during the current study.

Code availability This work did not make use coding.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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