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Marine plastic pollution in Morocco: state of the knowledge on origin, occurrence, fate, and management

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Abstract
Plastic pollution presents a major challenge facing stakeholders and decision-making worldwide. Plastics in the ocean damage biodiversity and marine ecosystem services that the blue economy relies upon. The present work analyses and reviews the literature on plastic pollution and the background knowledge about marine plastic pollution in Morocco. The economy of Morocco depends mainly on marine activities, including fisheries, tourism, and maritime trade. These sectors were identified as the main in-situ sources of plastics entering Moroccan coastal waters. The analysis results showed that the increasing abundance of plastics in such marine systems causes substantial economic loss to blue economy activities. In contrast, the lack of data on the plastic waste quantity entering Moroccan water is a limiting factor for assessing plastic pollution. This highlights the need for a risk assessment and more field investigations to value the weight impacts of marine activities generators of plastics on biodiversity and the economy. In addition, implementing laws and rules forbidding the disposal of plastic waste (PW) in public spaces, mainly beaches, and streets, is urgently needed. Raising awareness of plastic waste management and prioritizing improved waste collection, sorting, and management would boost Morocco's establishment and adoption of circular economy strategies. It is worth noting that while implementing the management projects and regulatory frameworks of plastic waste, considering their source and usage purpose is mandatory.

Keywords Plastic waste · Marine pollution · Waste management · Circular economy · Morocco

Introduction

Human activities development worldwide has put many pressures on Earth's ecosystems. Land-based resources were depleted while marine resources are currently under exploration in response to human needs growth. Since the industrial revolution, this growing tendency toward satisfying human demand has negatively and rapidly impacted the environment and accelerated the global climate change effects (Kasa 1973).

Until the 1970s, the ocean was considered a dumping site for different types of pollutants, including organic chemical wastes, metals, and radioactive and plastic waste (EPA 2022). Thus, minor concern was given to ocean pollution impacts (Mejjad et al. 2023). The London convention signed in 1972 against dumping waste in the ocean was the first legal measure taken to protect the marine environment (London Convention 1972). Since then, the interest in marine environmental protection and resource conservation has increased. Nevertheless, the world's ocean environment faces many challenges, mainly plastic pollution (Landrigan et al. 2020; Evans et al. 2019; Alava 2019).

From 1950 to 2015, the production of plastic increased from 2 million tons to 381 million tons per year (Geyer et al. 2017). This rapid growth of plastic production and consumption resulted in hazardous impacts on the marine environment and wildlife health (Beaumont et al. 2019). Indeed, many projects and scientific research have been conducted to evaluate and assess the effects of plastic on the marine environment and help in the remediation processes (Borrelle et al. 2017; Vince and

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Hardesty 2017; Lestari and Trihadiningrum 2019; Thushari and Senevirathna 2020; MacLeod et al. 2021; Çevik et al. 2022).

Plastic materials are thrown out without recycling, seriously threatening marine organisms and causing biodiversity loss, while it was reported that millions of animals are killed yearly because of plastic waste (Ocean Conference 2017). The plastics may reach the sea through wastewater discharges, rivers, stormwater runoff, or wind transport (Ryan et al. 2009). Recent studies have detected microplastic traces in surface water, sediment, deep water, and organisms (Chae and An 2018; Zhang and Liu 2018; Yu et al. 2021). Indeed, Jambeck et al (2015) stated that the world's ocean receives around 4.8–12.7 million metric tons (MT)/yr of plastic waste from land-based sources, mainly transported by wind or rivers.

Plastic pollution is less investigated in Morocco than chemical pollution, mainly in the marine environment. Plastic materials are broadly commonly used products in Morocco for different purposes, including industrial, domestic, fisheries, and agricultural activities. The primary use of plastics in Morocco is concentrated in the manufacturing sectors of, for example, fishing nets, pipes, and hoses used for sanitation, drinking water and irrigation, packaging, greenhouses films, and plastic materials used for construction and tires (UNEP). Plastic waste in Morocco was found to cause economic losses and presents public health threat as only 25% of generated plastic waste is recycled, as reported in the National Strategy for Waste Reduction and Recovery report (SNRVD 2019). This means that 75% of the plastic waste may reach the ocean mainly if disposed of in landfills or dumping sites close to rivers and oceans.

Noting that there is a lack of knowledge and field data about microplastic and its impacts on the socioeconomic sectors in Morocco, which was recently reported in a World Bank report addressing marine plastic pollution in Morocco (WorldBank 2022). Whereas the report mentioned above states that around 6.3 kg of improperly managed plastic waste enter the Moroccan Mediterranean water each day from each kilometer of the coastline which remains less high than the estimated quantity of mismanaged waste entering Tunisian water (9.5 kg per km).

It is worth noting that Morocco is committed to all regional and international agreements associated with plastic pollution. Besides, a number of legislative and operational measures at the national level have been taken to address the plastic pollution issue. Besides, SNRVD 2019 reported that the plastic recycling rate in Morocco is supposed to reach 50% by 2025 and 70% by 2030.

However, few studies investigated plastic pollution in the Moroccan coastal environment (Loulad et al. 2016; Alshawafi et al. 2017, 2018; Ben-Haddad et al. 2022a, 2022b; Abelouah et al. 2022). Ben-Haddad et al. (2022b) stated that Moroccan beaches, mainly those located in the central Atlantic, are severely affected by microplastics. Indeed, in 2016, Morocco was ranked as the 9th largest producer of plastic among African countries and faced many challenges linked to waste management (WWF 2019) while it engenders 0.69Mt of plastic waste yearly, of which 57% leaks into nature.

In this order, because of the increased interest in plastic pollution impacts on marine biodiversity and economic activities and the little attention given to the scientific research in this field in Morocco, we review and analyze the plastic pollution sources and fate, and we screen the background of knowledge about plastic pollution in Morocco. We also analyze the Moroccan position versus other countries in the marine plastic pollution field through a bibliometric analysis of related studies. In addition, this review defines and presents the key instruments and legal frameworks established for managing plastic waste in Morocco. Thus, this study provides a base reference to the studies related to marine plastic pollution and can also provide data for governmental institutions and agencies to formulate marine microplastic pollution assessment and control policies in the country.

Methods and material

Bibliographic review

In order to analyze the plastic pollution origin and fate in the Moroccan coastal zone, 110 scientific publications, policy reports, and books were reviewed, among which 22 publications were carried out in the Moroccan coastal zone. Documents were retrieved from various scientific databases, including Scopus, Dimensions, Web of Sciences, and Google Scholar. We only considered research carried out in English for scientific papers and technical reports and both in French and English for policy documents and reports (e.g., Decree). The keywords used to perform the research query are as follows: Plastic pollution, marine pollution, Plastic in Morocco, Plastic waste, domestic waste, medical waste, tourism waste, marine pollution, pellets, food business waste, single-use items, plastic types, waste management, circular economy.

Bibliometric analysis

In the present work, a bibliometric analysis was performed to understand the Moroccan research trend and position versus other countries in terms of scientific publications related to marine plastic pollution. In this order, data were exported from the dimensions online database (https://www.dimensions.ai/), where the keywords used for the first research query are "Marine" AND "Plastic" AND "Pollution." The keywords used for the second research query is "Plastic" AND "Marine" AND "Morocco." The exported data were filtered and then imported to Vosviewer (https://www.vosviewer.com/), a software tool for establishing and visualizing

bibliometric networks (van Eck and Waltman 2022). The research query was performed on October 9, 2022. The research query covered the scientific research carried out in the last 10 years (Fig. 1).

Results and discussions

Bibliometric analysis

The analysis of scientific publications carried out between 2013 and 2023 by country according to the dimensions' scientific database shows that the Moroccan scientific production-related research work in the field of marine plastic pollution is minor compared to other countries, with only 13 documents published in the latest 10 years (Fig. 2). The analysis highlighted the lack of research on marine plastic pollution and the absence of collaborations with Afro-Mediterranean scientific institutions. This analysis points out the need for developing projects and research work to investigate microplastic content, distribution, and effects on marine organisms and human health. Plastic debris can be ingested by fish by mistake for food as it acquires the smell of fish food because of their time residence in the ocean, and sometimes this debris picks up a covering of biological material (Savoca et al. 1860). Accordingly, plastic waste in the ocean must be a priority as the Moroccan economy depends largely on the marine and fisheries sectors and associated activities such as coastal tourism.

To analyze the publications score by country, we created a networking map based on bibliographic data retrieved from a scientific database, which permitted performing bibliographic coupling links (Wang and Huang 2021, Wang et al. 2021). In this order, bibliographic coupling analysis was used to identify the publication number associated with our search query per country. Countries with a number of publications inferior to 8 were excluded (Fig. 2A). The size of the circle in the networking map is indicated by the weight of the Total link strength (TLS) attribute, while each cluster is presented by a color representing a group of countries that are relatively strongly linked to each other with a high number of collaborations (Jan van Eck and Waltman 2022). The TLS signifies the collaboration amount of countries. In this sense, China, the USA, Germany, Italy, and India (Fig. 2B) display the most vigorous collaboration intensity in marine plastic pollution.

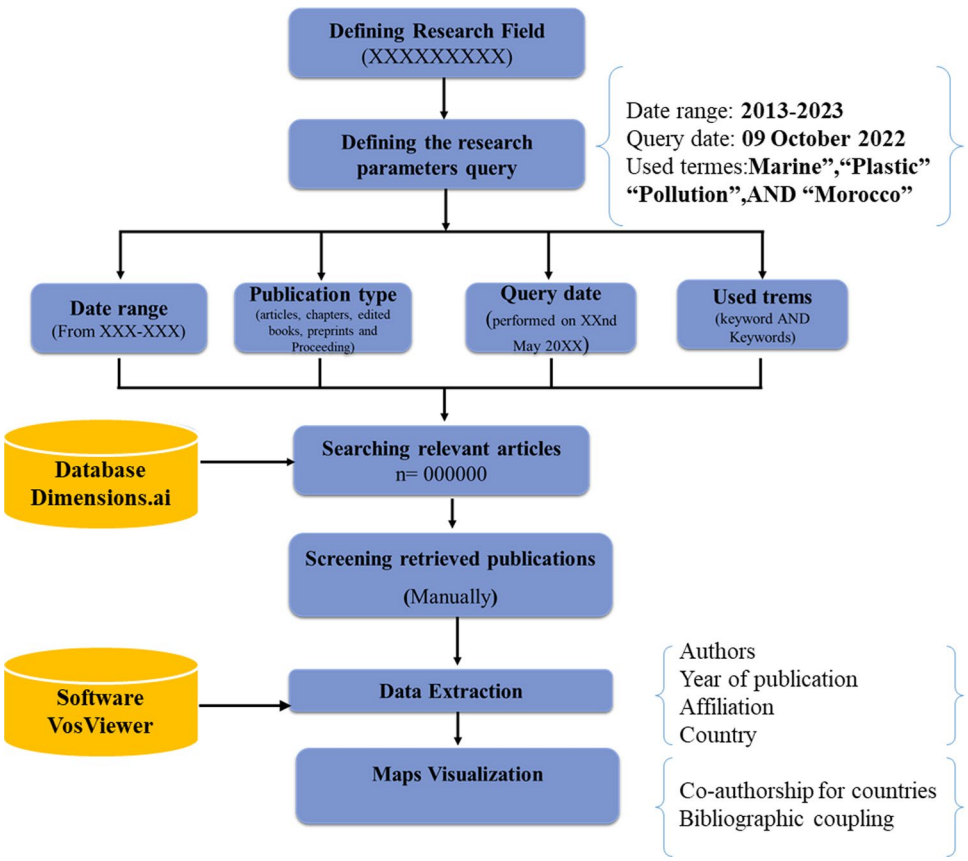


Fig. 1 Flowchart showing the map visualization procedures through VOSviewer software

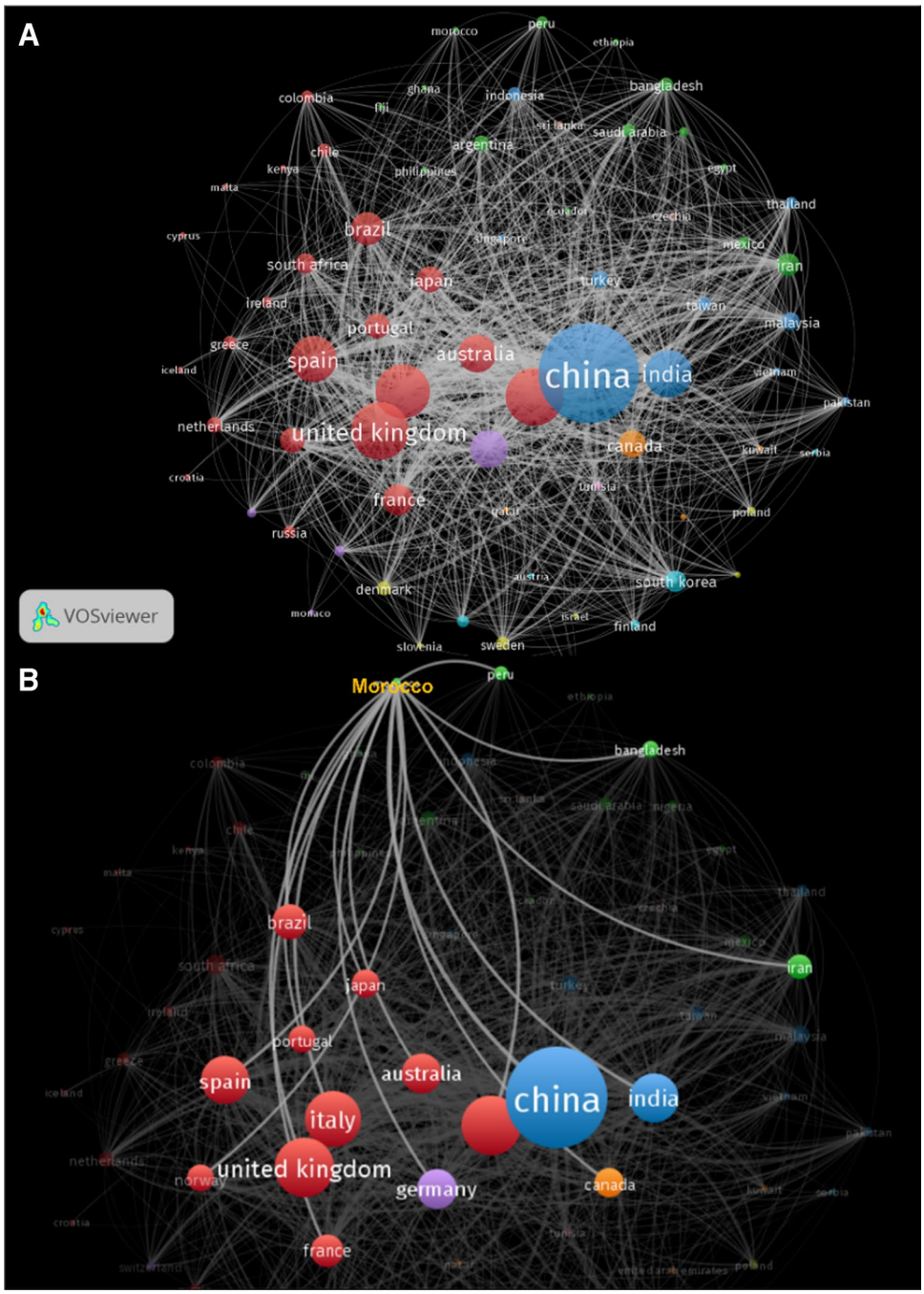


Fig. 2 **A** Bibliographic coupling analysis of the countries' scientific production based on document weight; **B** the fragment of overlay networking map shows the countries Morocco is collaborating with within the field of marine plastic pollution

Plastic pollution in Morocco: sources and fate

Marine plastic waste: an overview

Plastics play an essential role in community life and the economy. Plastics provide many societal benefits and are used by humans for different purposes as they constitute the raw material for various products of high importance, such as hygiene, medical facilities, and equipment (Andrady and Neal 2009). Approximately 400 million tons of plastic are manufactured yearly (Boucher and Friot 2017), while nearly 14 million tons end up in the sea yearly (IUCN 2021). Plastics have been detected along the coastlines of every continent, mainly in densely populated areas and tourist destinations.

However, the multiuse, malpractices, and mismanagement of plastics-related waste have led to a global plastic pollution crisis. Indeed, the management system of such waste is unable to remediate and control the growth of

plastic waste as the world is fabricating twice as much plastic waste as two decades ago (OECD 2022).

Plastics are used for different purposes, and the associated waste can have different sources, including industrial and domestic activities and medical and pharmaceutical products (Fig. 3).

Domestic wastes (single-use items)

Domestic waste may include different types, such as iron, paper, and plastic. The quantity and composition of generated waste may change according to the lifestyle and nature of consumed products. Besides, the consumption rate also depends on the population's living standards in each city. Indeed, several studies linked average population income to the quantity of generated waste (Bandara et al. 2007; Qu et al. 2009; Kamran et al. 2015; Grazhdani 2016; Adzawla et al. 2019; Dahchour and Hajjaji 2020; Immurana et al. 2022).

Similarly, in Morocco, the quantity and nature of generated waste vary according to socioeconomic factors, including population number, lifestyle, and living standards (Dahchour and Hajjaji 2020). As shown in Fig. 4, the high volume of plastic waste is mainly detected in the region with a high population (> 3 million). The region of Casablanca-Settat is known for the concentration of the main Moroccan industrial activities with a dense population (6,861,739 Hab recorded in 2014), followed by Rabat-Salé-Kénitra, Marrakech-Safi, and Fès-Meknes (HCP 2018). Accordingly, the distribution and volume of waste are mainly related to the number of population and living standards. According to the WorldBank (2022), the assessment of marine pollution in Morocco showed that Casablanca is a Priority "Hotspot Area," Tanger, Tetouan, and Kenitra are classified as "Hotspots," and Nador, Rabat-Salé, Mohammedia, El Jadida, Safi, Agadir, and Sidi Ifni are identified as "Sensitive Areas."

Seven to 9 million tonnes of domestic solid waste are generated yearly in Morocco, mainly composed of water, paper, metals, and plastics (Hafidi 2014; Dahchour and Hajjaji 2020). The temporal evolution of plastic waste in Morocco shows a steady increase with the time of generated related waste (Table 1), wherein in 1960, plastics presented only 0.3% of the total generated municipal solid waste (Ministry of Environment in Hafidi 2014). The continuous growth of the population with the change of lifestyle, lack of awareness, and mismanagement of plastic items would contribute to producing more plastic waste ending up in the ocean. It should be noted that the estimated amount of plastic leakage to the marine environment in Morocco is 75 KT/year (World Bank 2022).

In this sense, implementing frameworks and policies to decrease the population's dependency on plastics while managing the related waste in aquatic ecosystems is an urgent need. Although, while establishing management projects, rules, and policies, each region's socioeconomic factors and location must be considered for effective management and risk assessment. Besides, increasing the population's awareness toward adequately managing their waste is essential to boost the adaptation of the waste recycling concept, mainly plastic. This would help achieve the 2025 objective aiming at reaching a rate of 50% of plastic recycling in Morocco. Noting that the

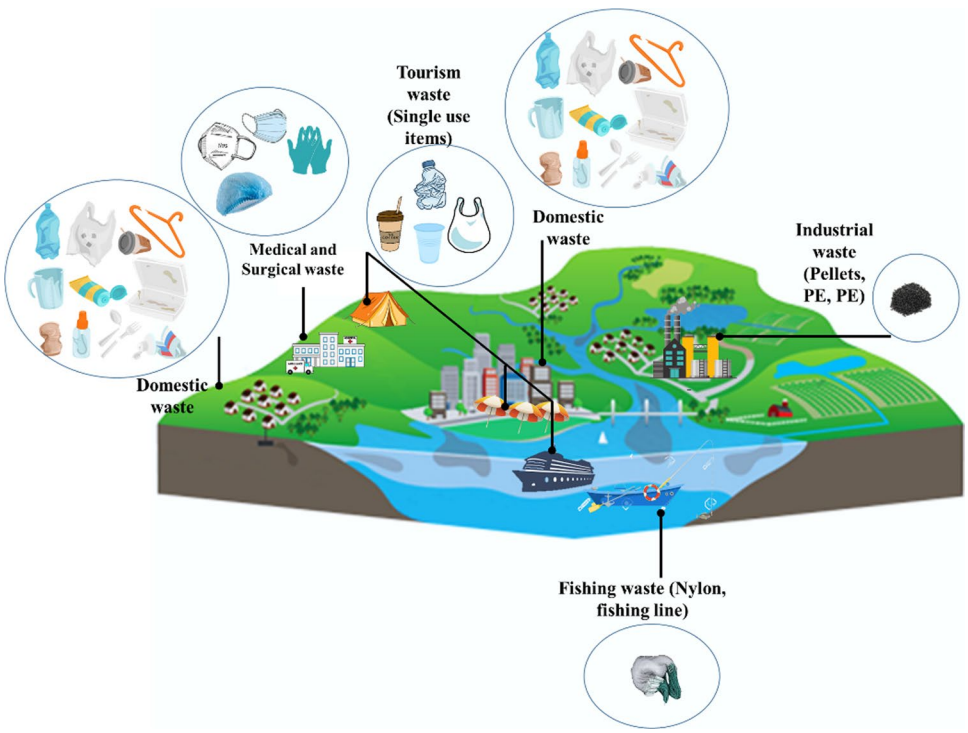


Fig. 3 Main activities that generate plastic waste in Moroccan waters

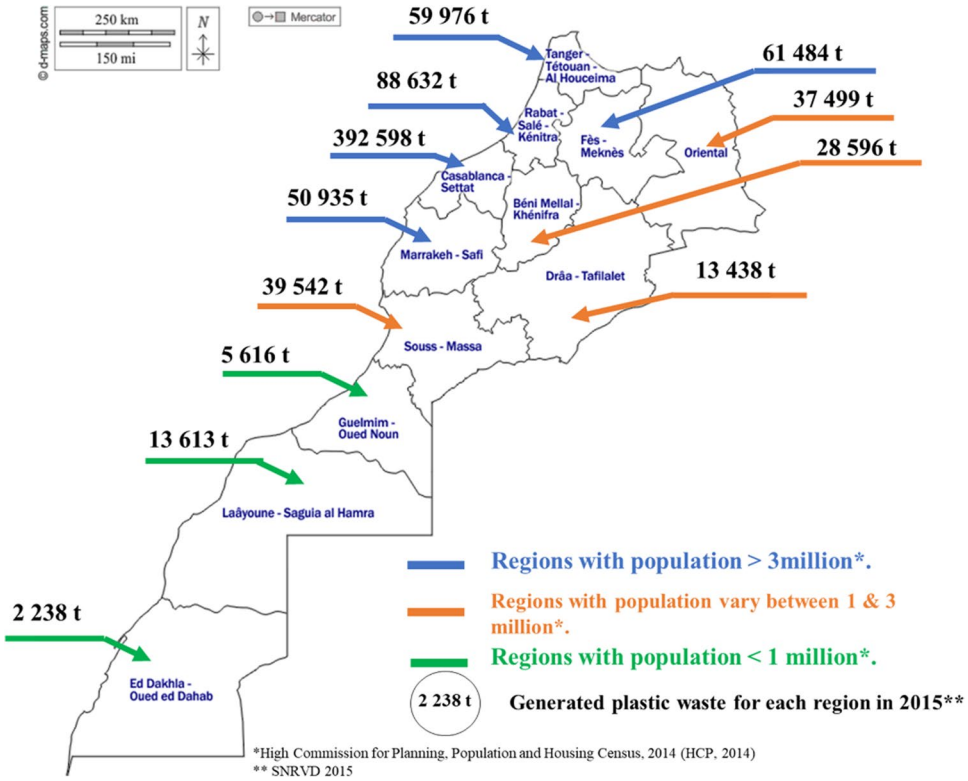


Fig. 4 Volume of plastic waste generated in 2015 by the 12 Moroccan regions versus the population number by region in 2014; *Hafidi 2014; ** SNRVD 2019

procedure of collecting and sorting out plastic waste is challenging in Morocco, thus providing functional and efficient solid waste management facilities in the Moroccan urban areas remains the most crucial step toward attaining the objectives mentioned above for 2025 and 2030 (SNRVD 2019).

Tourism

Tourism is the main sector generator of single-use plastic items waste, while it suffers from improper disposal and mismanagement of this waste, which ends up on coastlines, affecting tourist activities and harming life underwater (Gjyli et al. 2020; Chu et al. 2020). Indeed, several studies linked the plastic waste increase to tourism activities, principally in tourism hotspots of coastal zones (Windsor et al. 2019; Vargas et al. 2020; Thushari and Senevirathna 2020; Welden 2020; Maione 2021; Mejjad et al. 2022a). In the Mediterranean sea, UNEP indicated that marine litter is mainly linked to summer tourism (UNEP 2009). In this sense, studies have evaluated the seasonal evolution of plastic waste on the beach during summer tourism and found that plastic items volume is higher during the summer compared to other seasons (Pervez et al. 2020; Gómez et al. 2020; Zhang et al. 2022). Indeed, Ariza et al. (2008) reported that 13% of collected litter and waste from the Lloret Centre beach during summer tourism on the Catalan coast was discarded and left on the sand by visitors.

Noting also that tourism acts as a motor engine of a country's economy where many other activities benefit from tourism activities during the summer period (Fig. 5), such as local fish sales, transportation, and other commercial activities increase, meaning more waste and plastics would be thrown out in bins, streets, and beaches.

Table 1 Temporal evolution of generated plastic waste in Morocco (1960–2015) (in mass percent (%)). *Hafidi 2014; ** SNRVD 2019

Year	1960*	1990*	2000*	2015**
Generated plastic waste	0.3%	2 to 3%	6 to 8%	10%

Restaurants and food business Ordering food for takeaway or delivery has become popular and is growing vast, especially with technological information development, mainly the Internet, making easy food and services ordering (Triyuni et al. 2021). Such services come with significant quantities of single-use packaging (e.g., plastic bags and sacks, food containers, microbeads, cutlery, straws, and polystyrene). These disposal materials contribute 60–95% of marine plastic pollution (Walker et al. 2006) and generate about 20 MT of plastic pollution (Sorrentino 2022). Indeed, tourists may snack in tourist and historical spaces, streets, and beaches, consequently contributing to more litter. Also, these growing online services in the latest years, especially with the COVID-19 pandemic, would encourage tourists to order their food via the Internet and save time for enjoying their destinations. In Morocco, the

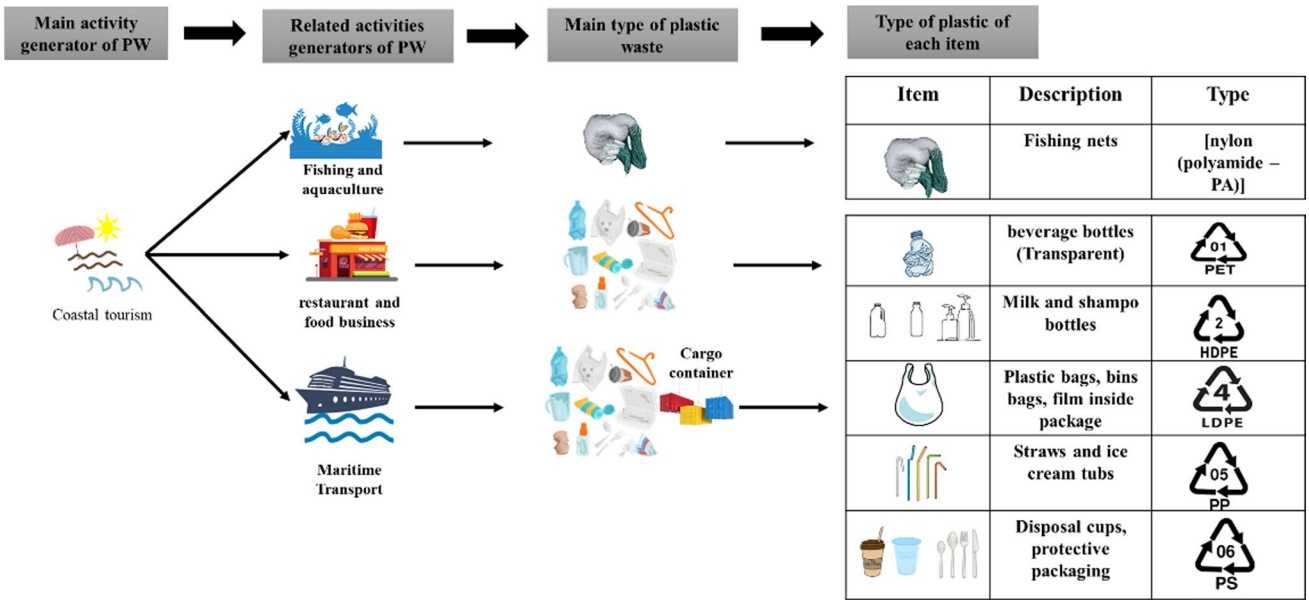


Fig. 5 Main activities related to coastal tourism generator of plastic waste in the marine environment

food services market is rising at 4–6% yearly and was valued at $3.1 billion in 2017 (USDA 2018). The food services style for the Quick Service Restaurants category (e.g., ice cream, burger, fish) in Morocco showed by 2017 that 38% of customers took away their food, and 91% takeaway was recorded for the street stalls/kiosks category (USDA 2018). Given the high numbers of those categories (3385 quick service restaurants and 31,525 street stalls/kiosks) (USDA 2018) and the growing tendency for food takeaway, such services would generate significant quantities of single-use packaging, mainly plastic bags, food containers, cups, cutlery, and straws.

Maritime transport Maritime transport/shipping (cargo, recreational and military navigation) activities could contribute to marine plastic pollution when the plastic items are mismanaged and discarded directly into the ocean. Indeed, shipping is considered the main contributor to plastic pollution as ships related waste is used to be dumped in the sea (Hagen 1990; Chalhoub 2022). According to surveys, up to 4518 kg/km of plastic was logged on the Alaskan beach, and an important quantity of plastic litter was found on Svalbard beach, originating mainly from ships, including beverage bottles, packaging, toothbrushes, spoons, and cigarette butts (Bergmann et al. 2017). Besides, according to research carried out in July 2017 by the World Shipping Council (WSC), thousands of containers are lost yearly in the sea. Noting that plastics are the most common materials used for producing various products across almost all sectors; thus, they are loaded in containers to be transported by ships to their destinations (Jo 2020; Abeynayaka 2021). Given the global growth of world trade through ship containers, the lost containers constitute a serious environmental problem. Indeed, the estimated average of plastic losses due to ship containers lost may reach up to 10 000 MT per year (Galafassi et al. 2019).

It is worth noting that Morocco's largest ports are located in Tangier and Casablanca, which are reported as hotspot areas due to demographic pressures, mismanagement, and illegal waste dumping (WWF 2019). Thus, the maritime transport sector in Morocco is also under pressure from plastic leaking into the sea and then vulnerable, for example, to collisions with plastic waste, vehicle damage, delays, and maintenance costs. According to the World Wide Fund For Nature, around $4.6 million is lost yearly because of plastic pollution in maritime trade (WWF 2019).

Fishing As shown in Fig. 5, tourism promotes fishing and aquaculture, maritime transportation, and commercial activities where different plastic products are used, such as fishing nets for catching fish in response to human demand for seafood. These nets are made from nylon [(polyamide—PA)], a non-decomposed type of plastic (Kühn and van Franeker 2020). Once lost or discarded in the ocean, fishing nets become ghost nets because they injure and kill marine animals. This is because animals could be entangled in abandoned fishing nets, blocking them from moving freely, needed sunlight, and causing their death (Wilcox et al. 2015; Azevedo-Santos et al. 2021). The affected animals are fish, birds, reptiles, and mammals (Stelfox et al. 2016; Adelir-Alves et al. 2016; Lima et al. 2019; Azevedo-Santos et al. 2021).

A study carried out on the Moroccan Central Atlantic coast by Maaghloud et al. (2020) revealed the occurrence of

microplastics in the stomach of three different pelagic fish species, mainly those sampled between Cape Cantin and Sidi Ifni. Given that WorldBank (2022) has identified Sidi Ifni as a sensitive area for marine pollution, which explains the findings of Maaghloud et al. (2020). The extensive fishing activities in this area, mainly artisanal fishing, are identified as the possible source of the significant detected microplastic concentrations in fish samples collected from the north part of TanTan. Indeed, Houssa et al. (2021) reported that fishing activities practiced on the Moroccan Atlantic coast were found to be the source of 94% of artificial polymers (fishing nets and plastic). Besides, it was stated that the impact of plastic pollution on fisheries in Morocco was estimated as a loss of $ 8 million (€ 7 mill).

However, the lack of knowledge and field data about plastic waste from ocean-based activities, such as lost and discarded fishing nets and waste released from shipping, does not allow quantifying the volume of generated waste from related activities. Accordingly, building gaps concerning plastic pollution and impacts on both biodiversity and socioeconomic sectors in Morocco is an urgent need, mainly since the sustainable growth of the Moroccan economy relies upon the blue economy, which depends on marine ecosystem services.

The blue economy, including coastal tourism, maritime transport, and fisheries, is crucial to the Moroccan economy. However, plastic pollution resulting from mentioned economic sectors costs Morocco around $26 M annually (WWF 2019). According to WWF, in 2016, nearly 30KT of waste was leaked into Moroccan waters. About 18% (5.3kT) of waste was leaked into the Mediterranean, while 87% into the Atlantic Ocean, housing the densely populated cities including Casablanca, Kenitra, and Rabat, reported as hotspot areas.

Coastal tourism plays an essential social and economic role as it provides job opportunities and increases touristic Moroccan cities' population local income (Mejjad et al. 2021b). Besides, Morocco was ranked as the first most visited African country in 2019, with 13 million tourists (Worlddata 2020). As a result, it was estimated that around 18kt of waste, including plastic, is generated yearly by tourists across the country (WWF 2019), costing a loss of 13.6 M $ annually. Figure 6 shows pictures taken in July 2022 in Mriziga and Tamaris Beaches in Casablanca and M'dieq in the north part of Morocco. The pictures show discarded waste by visitors, mainly plastic packaging food. It should be noted that Casablanca is recognized as a priority hotspot city because it hosts various economic activities with a high population density while Tetouan-Fneidq and Mdieq are the most visited cities during the summer period, where tourists from all Moroccan cities prefer to spend their summer holidays on Morocco's Mediterranean beaches.

Plastic is just a tool invented to simplify our lifestyle, so humans are responsible for these tools' management. In this sense, the fight must be against human behavior toward managing their waste and, precisely, plastic which heavily influences the environment and ocean as a final receptor of all kinds of waste affecting marine organisms and putting at risk human health.

Medical and pharmaceutical waste (MPW)

The development of plastics in the early 1950s allowed the advancement in the creation of medical tools and devices (Ksiazki 2013; Czuba 2014). This facilitated the healthcare industry's growth and consequently led to population health development (Czuba 2014). Thus, the invention of

Fig. 6 Plastics items discarded on beaches of **A** Mriziga, Casablanca (July 27, 2022); (**B**) Tamaris Casablanca (July 30, 2022); **C** M'dieq (July 31, 2022)

plastic permitted the provision of drugs and treatments such as penicillin and insulin to a wide variety of populations, not only privileged classes of society and/or the wealthy. Accordingly, the availability of clean, sterile, and good-quality products at affordable prices enabled the rise of the number of hospitals where the sick and injured could obtain adequate medical treatment. In addition, plastic is the raw material of personnel protective equipment (PPE) such as gloves and facemasks used to protect against dangerous diseases and viruses (e.g., COVID-19; Wang et al. 2022a; Mejjad et al. 2021c).

Figure 7 shows different categories of waste released from the medical industry. Various equipment, tools, and devices are made of plastic, mainly PPE (surgical caps and masks, shoe covers, body suits, and gloves). Drug packaging is almost fabricated from plastics, such as tubes, jars, bottles, and tablets. These types of medical equipment and devices are single-use fabric. Indeed, these pieces of equipment could be hazardous and infected, mainly PPE, which requires disposing of them after the first use in particular bags to prevent further infection or contamination. Five types of medical garbage bags and containers are dedicated to medical waste, and five colors were defined for each category of generated waste. The blue is dedicated to infected plastic waste, while the other colors are for other types of medical waste, such as chemical waste, sharps, and solid waste.

Medical and pharmaceutical waste is reported as one of the biggest challenges worldwide will face in the future, mainly after the COVID-19 era (Wang et al. 2022b; Gill et al. 2022; Mejjad et al. 2022b). According to 2013 data, around 21,000 tons/yr of medical waste is generated by 143 public and 443 private hospitals in Morocco, of which 28% (6000 tons) is infectious waste (ESCWA 2015). The mismanagement of this waste may harm human health, mainly health workers and sanitary workers. Besides, the improper disposal of this kind of waste presents a danger to the environment and biodiversity if it ends up in aquatic ecosystems. Indeed, syringes, insulin needles, and blood bags were washed up on the New Jersey coastline, the USA, in 1987 and caused a US$ 1 billion loss to the local tourism industry (Valle-Levinson 1991; Chryssa 2006). Similarly, in Clifton beach, Karachi, Pakistan, it was reported by the media that the shoreline beach is covered by waste, including hazardous medical waste such as blood vials and syringes (Drury 2019).

Thus, MPW can reach the coastlines if they are improperly managed. According to ESCWA (2015) (Economic and Social Commission for Western Asia) report, several Moroccan hospitals are equipped with incinerators, but most of these do not work or are obsolete. Indeed, studies carried out on medical waste management in some Moroccan hospitals highlighted the need to adopt novel strategies for medical waste management (MWM) (El Morhit et al. 2021). A lack of awareness in terms of medical waste management and regulation among the medical staff and the unavailability of health technicians and material resources are the main issues related to MWM at the RHC Regional Hospital in Tangier based on an observational study carried out in 2017 by El Morhit et al. (2021). In contrast, Mbarki et al. (2013) indicated that the medical waste management conditions in the Souss-Massa-Daraâ region's hospitals are better than in other Moroccan regions, while they recommended the integration of medical staff in training related to MWM for correct handling and processing of MW. Another

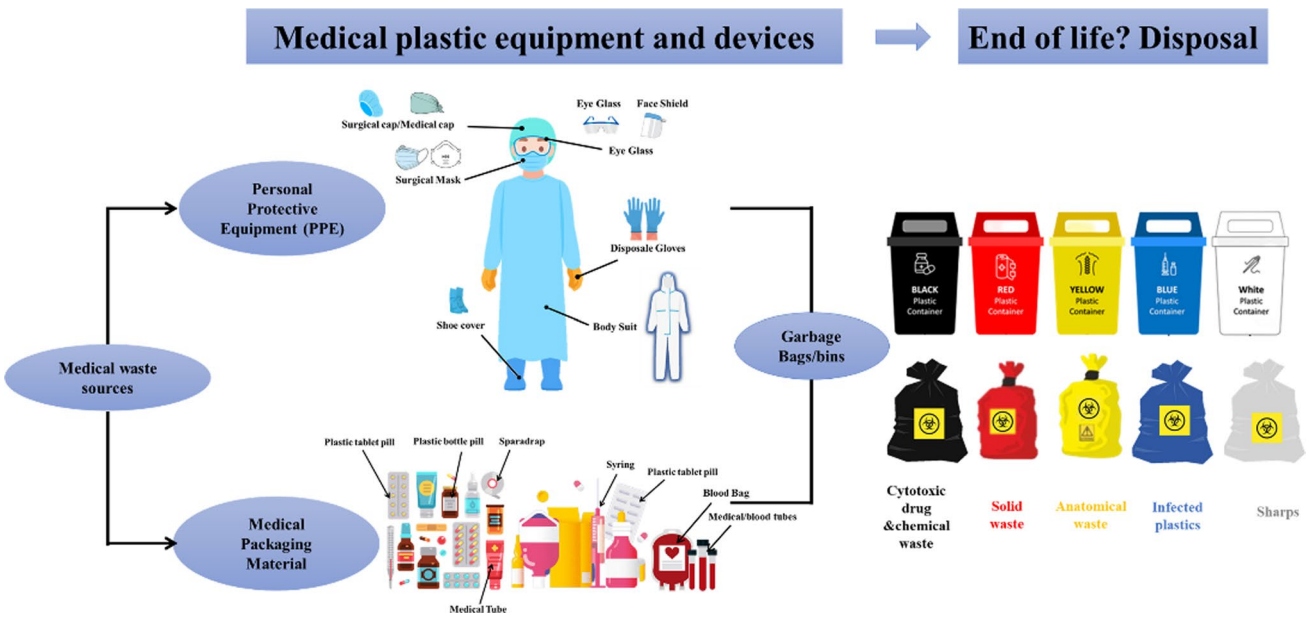


Fig. 7 Medical and pharmaceutical plastic equipment and devices sources and fate

investigation in Beni Mellal city showed that medical and pharmaceutical wastes are discharged and mixed with domestic waste (Msaad et al. 2020). Indeed, it was estimated that most of the MPW in Morocco is stored in public landfills (Mejjad et al. 2021a; UNECE 2014), which may severely impact human health and the environment. In this sense, the control and management of medical and pharmaceutical-related wastes must be taken as a priority, mainly the management tools, equipment, training, and capacity skills building of medical staff regarding MWM, particularly because this waste can harm human health, the environment, and end up in aquatic ecosystems.

Industrial activities (pellets)

Virgin plastic pellets, beads, nurdles, or preproduction pellets are essential for plastic production. They can be made of various plastics such as polyethylene, polystyrene, polypropylene, and a range of additives (e.g., benzotriazole UV stabilizers (BUVs)) mixed into the plastic to produce pellets of diverse densities. They are manufactured and transported worldwide to industrial units, melting and molding into different plastic products (Karlsson et al. 2018; Tunnell et al. 2020). They are included within the microplastic group. They are similar to lentils in terms of shape and size (with a diameter of 2–5 mm) (Corcoran et al. 2020). These pellets can easily end up in a coastal environment because of spills during the production chain (transport and storage) (Fig. 8). The pellets can be transported by train, ship, or truck to the facility where the final products are made from virgin material. Pellets can then be lost or spilled during all phases of the production chain (Karlsson et al. 2021). If these preproduction pellets are spilled on land, rain, and runoff can transport them to rivers, lakes, and coastal areas (Fig. 8) (Karlsson et al. 2021).

Millions of pellets have been found on beaches around the world since the 1940s (Jambeck et al. 2015), and it is estimated that approximately 230,000 tons of plastic pellets enter the environment worldwide each year (Sherrington 2016). Indeed, in many studies, plastic pellets were recorded washing up on beaches (e.g., Carpenter and Smith 1972; Carpenter et al. 1972; Gregory 1977; Mato et al. 2001; Costa et al. 2010; Karapanagioti et al. 2011; Bittencourt et al. 2015; Rodrigues et al. 2019; Corcoran et al. 2020; da Silva Ferreira et al. 2021). These pellets are spilled or lost accidentally and ingested by hundreds of species (Kühn and Rebolledo 2015) from all trophic levels (Eriksson and Burton 2003), mainly by turtles, bird species, and fish (Kühn and Rebolledo 2015).

These plastic pellets have been shown to carry additives, adsorb and release environmental contaminants (e.g., persistent organic pollutants (POPs)) (Mato et al. 2001; Ogata et al. 2009; Koelmans et al. 2016). In this sense, plastic pellets samples were collected from various beaches in 23 countries, including Morocco, and were analyzed for 13 polychlorinated biphenyls (PCBs) and ten benzotriazole UV stabilizers (BUVs). The obtained results showed that these pellets contain toxic chemicals, which may contribute to spreading these chemicals on beaches (Karlsson et al. 2021). Even though African countries are not major producers of plastics nor chemicals, the recorded concentrations of toxic chemicals were high. Indeed the total BUVs, were

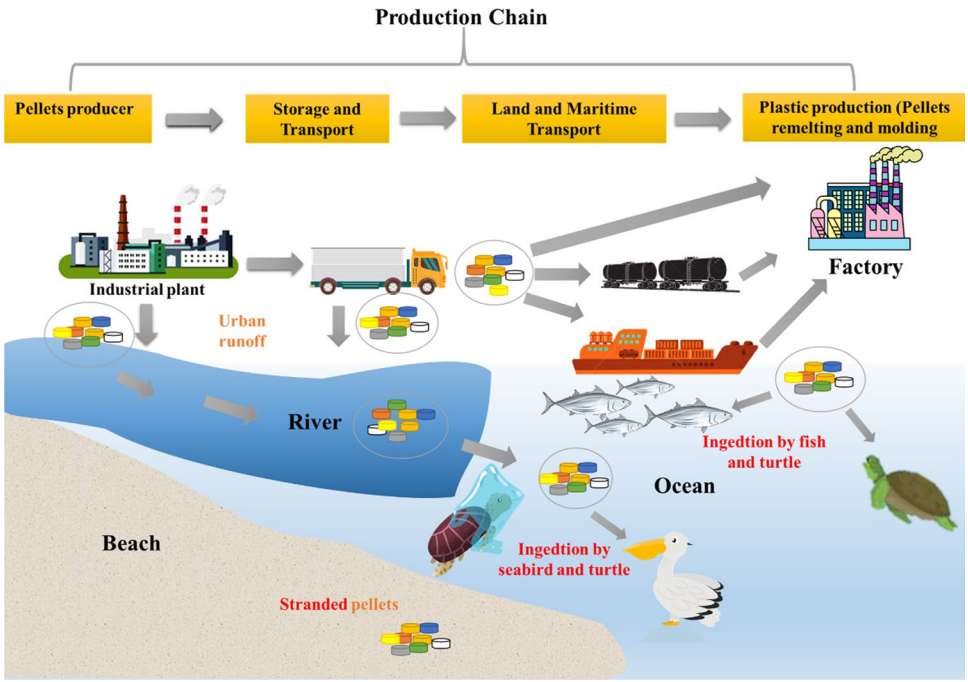


Fig. 8 Plastic pellets way to the ocean

reported high in Guy Ville beach (Morocco) subsamples, while for PCBs, the recorded concentrations fluctuated from moderately to highly polluted (Karlsson et al. 2021). Thus, there is an urgent need to assess and quantify the plastic pellets lost and released from industrial facilities to understand better the interaction between the pellets, beach environment and biota. Besides, a regulatory framework at a national level needs to be implemented to mitigate and prevent accidental spells and loss of pellets during the production chain.

Plastic pollution management in Morocco

Institutional framework

Governmental, public, and private institutions ensure the management and governance of marine and coastal zones in Morocco for both Mediterranean and Atlantic (World Bank 2022). The main stakeholders are mapped in Fig. 9. Ministries departments such as the Department of Sustainable Development of the Ministry of Energy Transition and Suitable Development, the Department of Ports, the Department of Marine Fisheries, and the Royal Navy are in charge of the coastal planning, control, operation, investigation, and regulation (see WorldBank 2022). The Ministry of Industry and Commerce, the Moroccan Federation of Plastics, and the Plastics and Rubber Technical Centre are in charge of the plastics industry, including planning, regulation, and green economy. Besides, universities, National Institute for Fisheries Research, and other stakeholders ensure marine debris research, monitoring, and surveillance.

Legal and regulatory framework

In order to reduce marine plastic pollution, Morocco has legislated a series of legal instruments, mainly Law 77–15 of December 7, 2015, also known as the "zero Mika" law, which banned the manufacture, export, import, marketing,

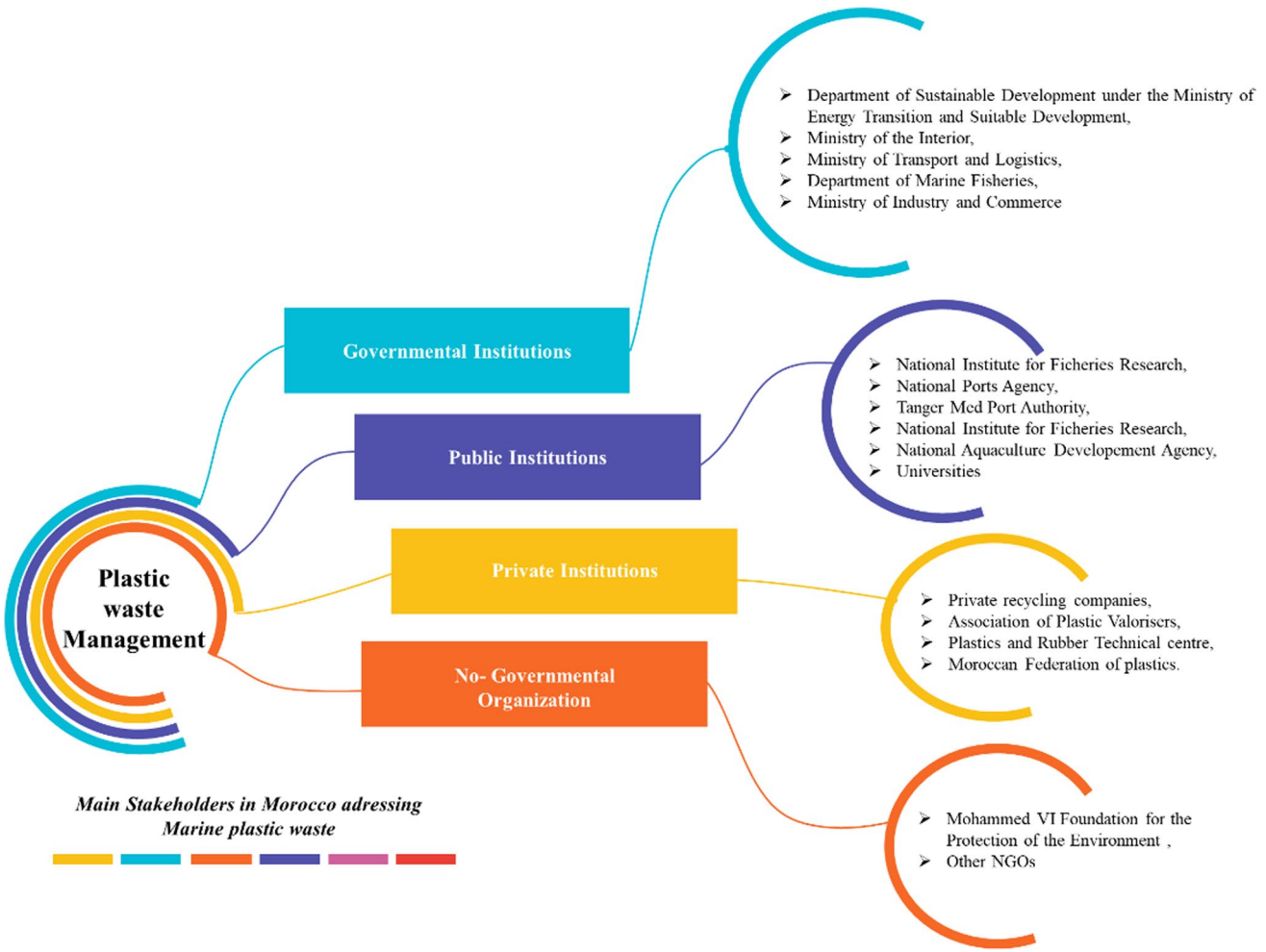


Fig. 9 Map shows the main stakeholders responsible for managing Moroccan marine plastic waste

and use of plastic bags, mainly black bags. Law 22–10 reports the use of degradable and biodegradable plastic bags and encourages the use of all alternatives to plastics. As a result, a decrease in generated waste in Morocco was noted in 2016, where the recorded volume of plastic waste in 2016 was 570,102 tons, while the amount of plastic waste in 2010 was 863,555 tons (World Population Review 2022).

Ecotax is another essential instrument in Morocco. Article 12 of the 2013 Finance Act established a 1.5% tax on plastics material sale, manufacturing, and import. This tax rate was reviewed in 2016 and set at 1% ad valorem to attain a recycling rate of 22% by 2022. This set Ecotax was planned for eligible projects under the operational manual, comprising downstream sorting facilities, pilot projects, feasibility studies, and outreach activities (WorldBank 2022), which would contribute to a significant decrease in plastic pollution and mitigation of its impacts on both terrestrial and marine ecosystems. The key legal instruments set for marine plastic pollution management in Morocco are shown in Table 2.

Other actions, initiatives, and programs were prepared and implemented to fight against marine plastic pollution. These programs aim at preventing and reducing marine plastic pollution, including:

- The National Coastal Plan (PNL) (2020) aims to protect and preserve the marine environment while ensuring economic growth.
- Bathing Water Quality Monitoring Program: for Bathing water quality monitoring and assessment.
- Beach Sand Quality Monitoring Program.
- The National Household Waste Program (PNDM) (2008): for household waste collection improvement and management.
- National Strategy for Waste Reduction and Recovery (SNRVD) promotes the circular economy and improves the performance of the "sorting –recycling –recovery" sector. SNRVD has set targets for the recycling rate to reach 50% of plastic recycling by 2025 and 70% by 2030 (SNRVD 2019).

In addition, to prevent and reduce plastic waste, other flagship initiatives have been established as part of joint actions by the Ministry of the Interior, the Ministry of Industry and Commerce, the Department of Environment, and the Mohamed VI Foundation for the Protection of the Environment. Also, civil society has been dynamic and active in increasing awareness.

Table 2 The key legal instrument for marine plastic pollution management in Morocco (WorldBank, 2022)

Year	Law or Decree	Description
2006	Law No 28–00	Law No. 28–00 on Waste Management aims to lay the foundations of a waste management policy
	Law No. 54–05	According to Article 1, this law applies to contracts for the delegated public services management and facilities concluded by local authorities or their groupings and public establishments
2008	Decree No. 2–07-253	Decree n° 2–07-253 (July 18, 2008), on the waste classification and establishment of the list of hazardous wastes, provides an inventory and classification of waste
2009	Law No. 99–12	The framework law No. 99–12 on the National Charter for the Environment and Sustainable Development defines, in article 8, the updating of the legislative framework concerning waste, including the promotion of waste recovery procedures and the integration of EPR (extended producer responsibility) principles
2010	Law No. 22–10	Law No. 22–10 on the usage of degradable or biodegradable plastic bags and sacks bans the manufacture of non-biodegradable or non-degradable plastic bags and sacks for the local market, their import, distribution, holding for sale, offering for sale, and sale
2012	Decree No. 2–12-172	Decree No. 2–12-172 sets the technical and procedural requirements for the disposal and recovery processes of waste by incineration
2015	Law No. 77–15	Law No. 77–15 or Zero Mika Law supplemented Law No. 22–10 to stipulate the prohibition on the production, import, export, marketing, and use of bags made of plastic
	Law No. 81–12	This law sets the basic rules for the improvement, protection, enhancement, preservation, and conservation of the coastline
2016	Law No. 113–14	This organic law stipulates municipal establishment and management of public services, facilities, and equipment necessary to collect, transport, treat, and recover domestic waste
2018	Decree No. 2–17-587	Decree No. 2.17.587 (December 10, 2018) set the terms and conditions for waste import, export, and transit
2019	Law No. 13–101	Relating to pleasure boating, differentiating the applicability of plastics laws from those applicable to commercial or fishing vessels, completing the Moroccan maritime legislation previously based on the Maritime Code of Commerce
2020	Law 57–18	Amends and supplements Law No. 77–15; Dahir no. 126.19.1 also further amends Law 57–18 with new definitions, reporting requirements planned to control manufacturers' activities, and a more precise definition of agents' enforcement and inspection roles

Solutions and mitigations

Plastic debris in the ocean has different provenances. At the same time, the amount, type, and toxicity of the released debris vary depending on its origin and use purpose. In this sense, implementing the management projects and policies, and regulatory frameworks must consider their source and usage purpose. In addition, the study and analysis of the origin and fate of plastic waste revealed the need for a separate assessment of each sector generator of plastic waste.

For medical waste, it was pointed out that the lack of education and awareness among medical staff and the absence of facilities and equipment remain the main issues contributing to the mismanagement of MPW (Fig. 10). Regarding the plastic waste released from coastal tourism activities, it is mainly related to human behavior toward managing their waste. Therefore, increasing awareness among citizens would boost the mitigation of plastic disposal phenomena in public spaces and the beach sand. Providing urban and rural areas with recycling bins would encourage citizens to select and separate their household waste. This would help improve waste management in Morocco and oblige visitors to respect and act differently toward waste disposal, including plastics. A visitor is a guest acting according to the country's citizens' behavior, comportments, waste facilities, and equipment availability. Thus, in the absence of waste facilities and official recycling systems, in residential areas, gardens, parks, tourist areas, and beaches, the management and mitigation of plastic waste would remain complicated. For economical and industrial plastic waste, it is essential to promote scientific research in this area and to encourage and promote partnerships and cooperation between academic, public, and private institutions to address the impact of plastic waste on sustainable growth in the environmental and socioeconomic sectors. This would help provide more functional and efficient management measures based on private actors' expertise and knowledge, resources and capacity enforcement, and academicians' scientific findings

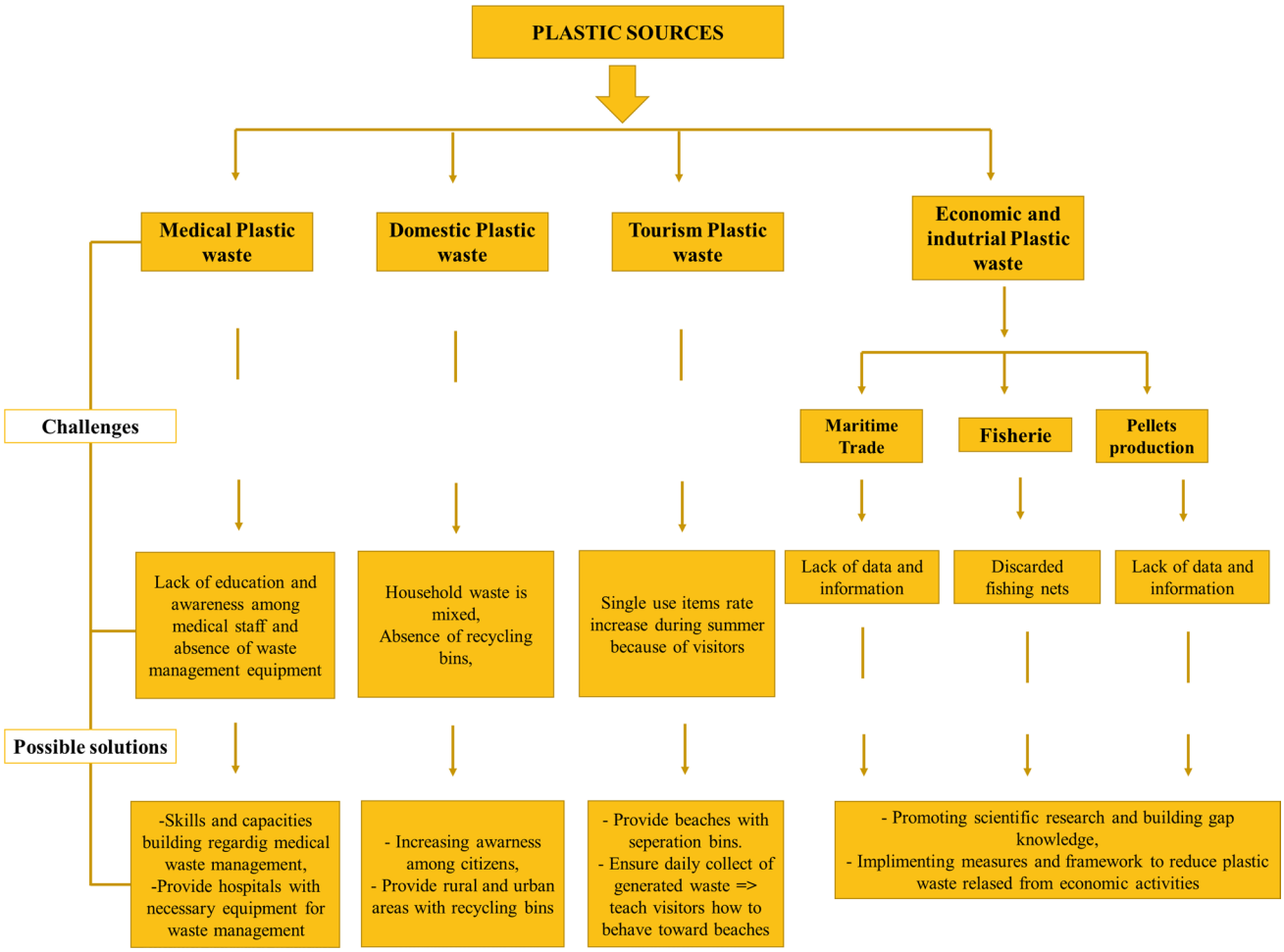


Fig. 10 Main challenges and solutions for plastic waste management in Morocco

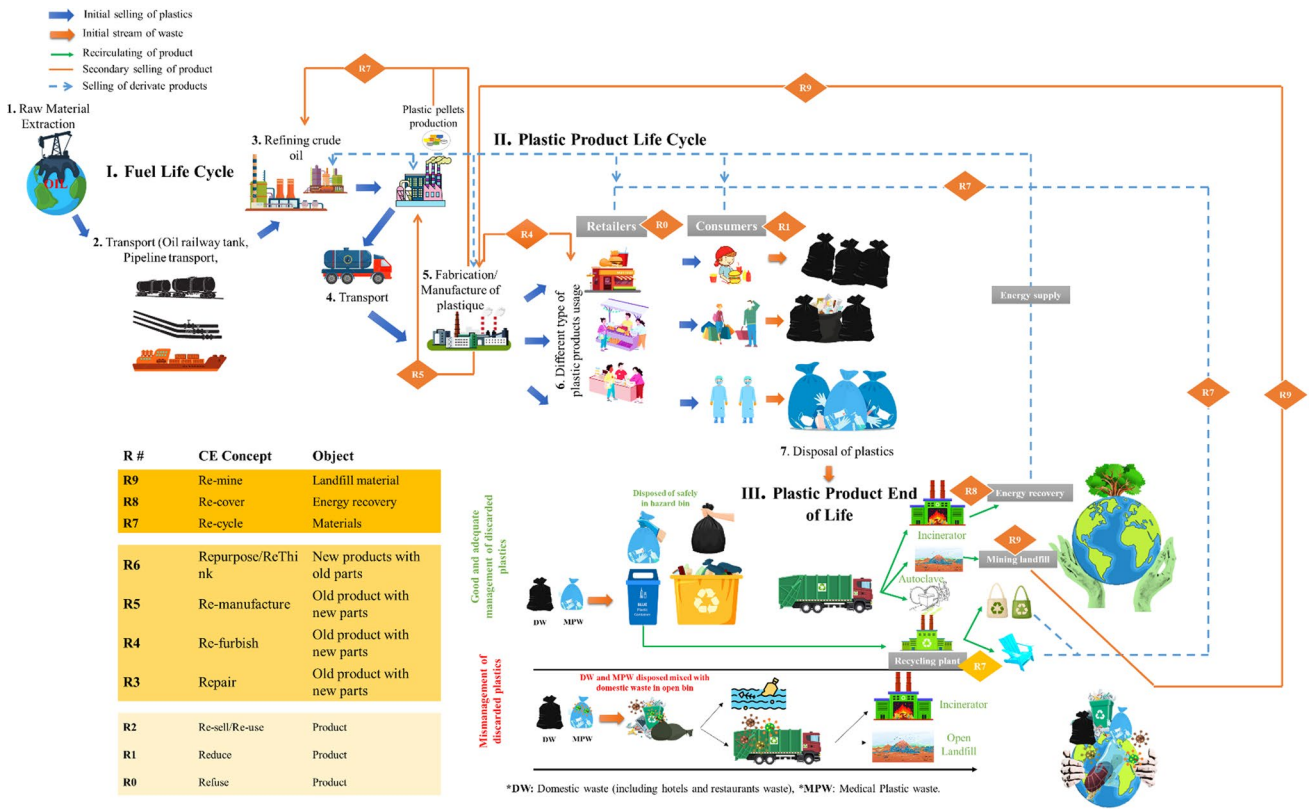
and knowledge. Indeed, building such a knowledge network would provide harmonized solutions and perspectives from the whole plastic value chain from the research and exploration to the end of life of plastic, thus fostering the transition to the circular economy for plastic.

Accordingly, assessing and monitoring plastic waste quantity generated by each sector is indispensable for valuing the amount of plastic waste entering Moroccan coastal waters and implementing frameworks related to marine plastic waste control and management. Indeed, scientific research in the field of marine plastic pollution in Morocco remains in its early stages, which implies promoting and encouraging the integration of scientific researchers in plastic waste mitigation and management projects.

Adopting green economic approaches and circularities strategies to face plastic waste growth enables reducing natural resource consumption and decreasing waste production (Potting et al. 2017). These circularities strategies aim at controlling the consumption and use rate while encouraging the reuse and recycling of waste. For the effective adoption and application of these strategies in Morocco, it is indispensable first to raise awareness among citizens about the importance of waste separation and install an official recycling system which is necessary for boosting and advancing the adoption of circular economy (CE) strategies. Noting that > 60% of Moroccan waste is mismanaged, while 57% of plastic waste leaks into nature (WWF 2019). In addition, the Moroccan Federation of Plastics Processing, 2016 (in Akkouri et al. 2020) reported that from 1 million tons of generated plastics yearly, around 20 to 30% is recovered, while the overall recycling rate is below 10%. Accordingly, the adaptation of CE requires prioritizing improving waste management quality and capacity.

Plastic items and tools cannot be repaired or re-sealed (e.g., plastic shoes, plastic foodstuff); however, some plastic products can be reused according to the type of used plastics, such as bottles, cups, spoons, and forks. Instead, if properly disposed of and managed, the released waste can be recovered and/or recycled into new products.

Figure 11 shows a mapping of CE ten Rs linked to the life cycle of plastic. The three first strategies (R0 Refuse, R1 Reduce, R2 Reuse/Re-sell) are related to consumers (commercial and/or non-commercial), all actors that can extend the plastic product life span. Thus, refusing plastic bags and food packaging by consumers in marketing stores and restaurants while utilizing alternative and multiuse of related items would reduce dependency on plastic. The fourth strategy "R3 Repair'' means extending the product lifetime (King et al. 2006) by making it good as it is new (Srivastava 2008), which can not be adopted for plastics (mainly single-use



R #	CE Concept	Object
R9	Re-mine	Landfill material
R8	Re-cover	Energy recovery
R7	Re-cycle	Materials
R6	Repurpose/ReThink	New products with old parts
R5	Re-manufacture	Old product with new parts
R4	Re-furbish	Old product with new parts
R3	Repair	Old product with new parts
R2	Re-sell/Re-use	Product
R1	Reduce	Product
R0	Refuse	Product

Fig. 11 Mapping of circular economy ten Rs linked to the life cycle of plastic (designed by N. Mejjad)

items); instead, producing and manufacturing high-quality and eco-friendly plastic products would extend their lifetime. The following concepts, R4, R5, and R6, are refurbish, remanufacture, and repurpose/ rethink, respectively, which are mainly related to business activities and indirectly linked to consumers (Reike et al. 2018). R7, R8, and R9 concern the plastic end of life, more precisely, plastic waste management, mainly plastic waste recycling, for example, into eco-friendly products, energy recovery, and landfill mining.

Analyzing the CE strategies mapping (Fig. 11) shows us that the success of circular economy concepts relies first upon adequate management and collection of plastic waste, suggesting considering improving waste collection and management capacities is crucial for an efficient adoption and application of CE concepts in Morocco leading to a sustainable society, economy, and environment.

Conclusions and recommendations

The present study reviewed the plastic pollution sources in Moroccan coastal waters and the main activities generators of plastics. At the same time, it gives an overview of the plastic pollution background of knowledge in Morocco.

The analytical study highlights the Moroccan latest achievement in the fight against plastic, where the volume of the generated waste significantly decreased between 2010 and 2016. The awareness increase about plastic pollution, the Ecotaxes, the law of "zero Mika," and the call for banning no recyclable bags and forbidding their use played an important role in decreasing plastic waste in 2016. However, managing domestic and municipal waste remains the main challenge facing projects related to protecting coastlines from plastics.

Besides, we noted an existing knowledge gap about plastic waste sources where there is a lack of data which made the impact valuation on biota and socioeconomic sectors unidentified. Thus, building gaps related to plastic waste generation in Morocco is a pressing need. In this sense, implementing management projects, strategies, policies, and regulatory frameworks must consider the plastic source and usage purposes. Besides, the carried analysis and investigation of plastic waste showed a need for separately assessing each sector generator of plastic waste.

It is also worth noting that the control and management of medical and pharmaceutical wastes must be taken as a priority, mainly the management tools and equipment, training, and capacity skills building of medical staff regarding MWM, particularly because this waste can harm the human health, the environment, and end up in aquatic ecosystems.

In addition, there is an urgent need to assess and quantify the plastic pellets lost and released from industrial facilities to better understand their origin, as they can also be transported by ocean currents once lost in the marine environment. Besides, a regulatory framework at a national level needs to be implemented to mitigate and prevent accidental spells and loss of pellets during chain production.

Accelerating the establishment of an official recycling system is among the priority, but the process can be complicated unless data related to plastic waste is available. In this sense, a risk assessment and further field investigations to value the weight impacts of activities generators of plastics on biodiversity and the economy are indispensable for better quantifying and analyzing plastic pollution in Moroccan waters.

Also, building a knowledge network exchange between different spheres of actors (academic, private, and public institutions) for tackling the plastic waste impacts would allow for providing harmonized solutions and perspectives from the whole plastic value chain from the research and exploration to the end of life of the plastic and thus fostering the transition to the circular economy for the plastic.

Indeed, CE strategies mapping analysis indicated that the success of circular economy concepts in Morocco relies upon adequate management and collection of plastic waste, suggesting that it must be considered first improving waste collection and management capacities for an efficient adoption and application of CE concepts leading to a sustainable society, economy, and environment.

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Author contribution NM: investigation, visualization, writing—original draft, writing—review and editing. AL, AF, O. EH.: validation, conceptualization, supervision, writing—review and editing.

Data availability The datasets generated and analyzed during the present study are available from the corresponding author on request.

Declarations

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Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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