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*Review*

# Plastic Pollution from River to Ocean: A Comprehensive Review in Indian Scenario

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**Abstract:** Plastic poses a significant threat to the environment, polluting land, water, and air. It is a broad term encompassing a variety of polymers. In the form of microplastics and nanoplastics, it can induce toxicity in water bodies. Plastic debris not only physically pollutes freshwater, but also chemically, undergoing changes over time due to hydroclimatic effects. Rivers serve as conduits, transporting plastics from minor tributaries to major rivers and ultimately into the ocean, endangering marine life. India, as a developing country with the largest population and numerous rivers, generates a significant amount of plastic waste, a substantial portion of which finds its way into rivers, leading to alarming rates of plastic accumulation in the ocean. Previously, policymakers focused primarily on landfills for plastic waste, neglecting the pollution of water bodies. The consequences of this neglect are evident, with major rivers in the country severely affected by plastic waste, necessitating advanced, efficient, and sustainable solutions. This study aims to establish a comprehensive framework for managing plastic waste, understanding its transport mechanisms to the ocean, and recognizing the threats it poses to life. It also expounds on harmful plastic pollutants in water, globally adopted technologies, and emphasizes the need for further research and data collection in this field. The primary concluding point is to prevent plastics from entering waterways and to actively collect river and marine plastic pollution. Banning single-use plastics and implementing efficient collection methods are crucial in containing plastic pollution. Effluents from industries should not be overlooked, as they often contain harmful micro and nanoplastics with ecotoxicological effects. The innovative concept of the "4Rs" - Refuse, Reduce, Reuse, and Recycle - stands as the cornerstone for safeguarding the environment against plastic pollution.

Keywords: plastic pollution; microplastic; nano plastic; marine pollution; river pollution

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## 1. INTRODUCTION:

Plastic was invented by Leo Baekeland in 1907, proving to be a versatile material applicable in numerous industries. Over time, various plastic polymers were developed, leading to its widespread use. It has now become the most commonly used material in our daily lives. Concerns about plastic pollution arose as its production surged, and due to its non-biodegradable nature, the accumulation of plastic waste in landfills began to negatively impact soil fertility. Terrestrial pollution resulting from plastic waste became a significant issue, exacerbated when it started contaminating freshwater sources. The Ganga, a major river in the country, became heavily polluted with plastic debris, prompting policymakers to initiate costly cleaning projects that yielded some improvement. However, the pressing need for a centralized, comprehensive, efficient, and sustainable framework for the effective management of plastic waste has become evident. Plastic debris from rivers is transported to the ocean, posing a threat to aquatic life. Additionally, the presence of microplastics and nanoplastics in rivers is detrimental to the river ecosystem and is of anthropogenic origin.

The data reveals that although a substantial amount of plastic waste is generated, only a small portion of it is effectively and sustainably managed and properly disposed of on a global scale. From 1950 to 2015, approximately 8.3 billion metric tonnes (BMTs) of plastic were produced worldwide. Out of this, 80 percent, equivalent to 6.3 BMTs, was categorized as plastic waste. Among these 6.3 BMTs of waste, a mere 9 percent underwent recycling, 12 percent were subjected to incineration, and a staggering 79 percent were indiscriminately deposited in landfills, oceans, or other bodies of water.

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There exist two primary approaches to handling plastic waste. The first involves the recycling or re-processing of various types of plastic waste into secondary materials. The second method entails the incineration of plastic waste. Nevertheless, incineration proves to be costly and environmentally detrimental if not executed with the appropriate equipment. (NITI AAYOG-UNDP HANDBOOK ON SUSTAINABLE URBAN PLASTIC WASTE MANAGEMENT, 2021). Plastics have permeated the environment and have garnered significant attention in academic discourse. Extensive studies have concentrated on analytical methodologies, sources, quantities, transportation, longevity, degradation of plastics in the environment, as well as the potential threats they pose to natural habitats, wildlife, and even human health. Nonetheless, the essential characteristics of plastic pollution, crucial for comprehending this burgeoning issue, have remained elusive thus far (Li et al., 2021). While plastic waste has been a concern for environmentalists for decades, microplastics have recently emerged as a significant pollutant. Currently, there are limited studies on microplastics in India. There is a critical need to fill the knowledge gap in our understanding of plastic pollution to gain a comprehensive insight into microplastics, including their sources, pathways, and broader impacts on the environment and human health. (Sarkar et al., 2007). Widespread plastic pollution affects both terrestrial and aquatic ecosystems. The presence of plastic waste in the environment poses significant concerns for all living organisms. This surge in plastic production and its buildup in natural settings is happening at an unprecedented pace, largely due to indiscriminate use, insufficient recycling, and the disposal of plastic in landfills (Kumar et al., 2021).

The proliferation of plastic pollution poses a significant threat to natural ecosystems, human health, and artistic appreciation in both developed and developing nations. It has become a pressing global issue, as rivers serve as conduits for the transportation of plastics originating from terrestrial environments due to human activities (Chibundo Chukwuma et al., 2021). Birds and fish exhibit a susceptibility to ingesting microplastics. All the examined chemicals, encompassing both adsorbed micropollutants and contained additives, were discovered to surpass the detection limit, frequently even the quantification limit. It is imperative to validate and quantify the sources along with their respective contributions, while also conducting in-depth research into the ecotoxicological effects. Several questions still linger, such as the transport and ultimate fate of plastic particles in the environment (Faure et al., 2015).

Plastic pollution is a global issue. However, in contrast to marine environments, our comprehension of the distribution and impacts of plastics in other ecosystems remains rudimentary. In this review, we delve into the transportation and repercussions of plastics in terrestrial, freshwater, and marine environments (Windsor et al., 2019). Present attempts to quantify plastic emissions in rivers are hampered by a scarcity of field observations. One of the primary challenges lies in the absence of uniform measurement techniques, which hinders the ability to compare rivers across different locations and time frames. Recent studies, however, have indicated that straightforward visual assessments offer a reliable initial assessment of plastic transport, both in terms of quantity, spatiotemporal distribution, and composition for floating and superficially suspended plastics.

## 2. UNDERSTANDING PLASTICS AND Its TYPE

Plastic is a man-made material derived from hydrocarbons, allowing for the formation of objects in nearly any conceivable shape or size. By refining crude oil, various petrochemicals are acquired, providing the foundation for producing plastics. Owing to its advantageous properties, plastics have supplanted weightier and pricier materials like glass, steel, and aluminum. In packaging, the adoption of plastic has led to significantly improved food preservation, reducing waste and expanding both shelf life and transportation options (van Emmerik et al., 2022). Figure 1 shows the different types of plastics forms and their example.

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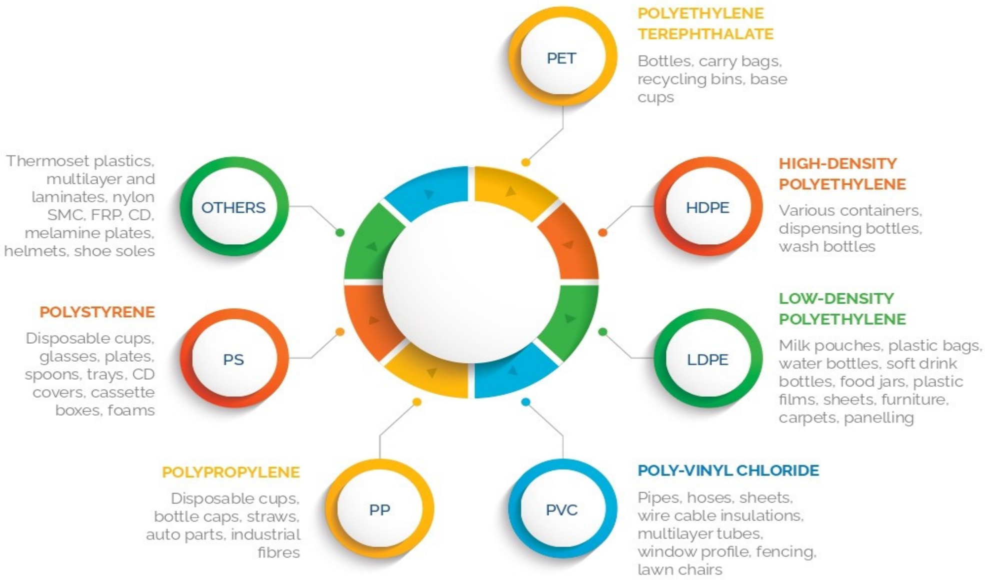


**Figure 1.** Source: (NITI AAYOG-UNDP HANDBOOK ON SUSTAINABLE URBAN PLASTIC WASTE MANAGEMENT, 2021.)

Various types of plastics have been invented and widely utilized. The Central Pollution Control Board (CPCB) has classified them and outlined their numerous applications in the "Guidelines for Disposal of Plastic Waste, 2017." These categories include Polyethylene Terephthalate, High-Density Polyethylene, Low-Density Polyethylene, Poly-Vinyl Chloride, Polypropylene, Polystyrene, and others.

While much attention has been focused on the behavior of microplastics in marine environments, there has been relatively little consideration given to nanoplastics in freshwater systems. It has been observed that nanoplastic particles undergo rapid changes in their surface charge, shifting from positive to negative, and form small heteroaggregates at low concentrations. When the isoelectric point is reached, an increase in nanoplastic particle concentration leads to the formation of larger heteroaggregates, underscoring the significance of neutralizing the surface charge of nanoplastics (Guerranti et al., 2020).

Plastic pollution can be categorized based on size variations into Megaplastic, Macroplastic, Mesoplastic, and Microplastic (in both primary and secondary forms) as shown in Figure 2 Megaplastic, macroplastic, and mesoplastic constitute bulk plastic debris, whereas primary and secondary microplastics are minute pollutants observed at a microscopic scale, with sizes ranging from 1–6 mm or less than 1 mm. larger debris can also undergo processes, both physical and biological, leading to the formation of microplastics.

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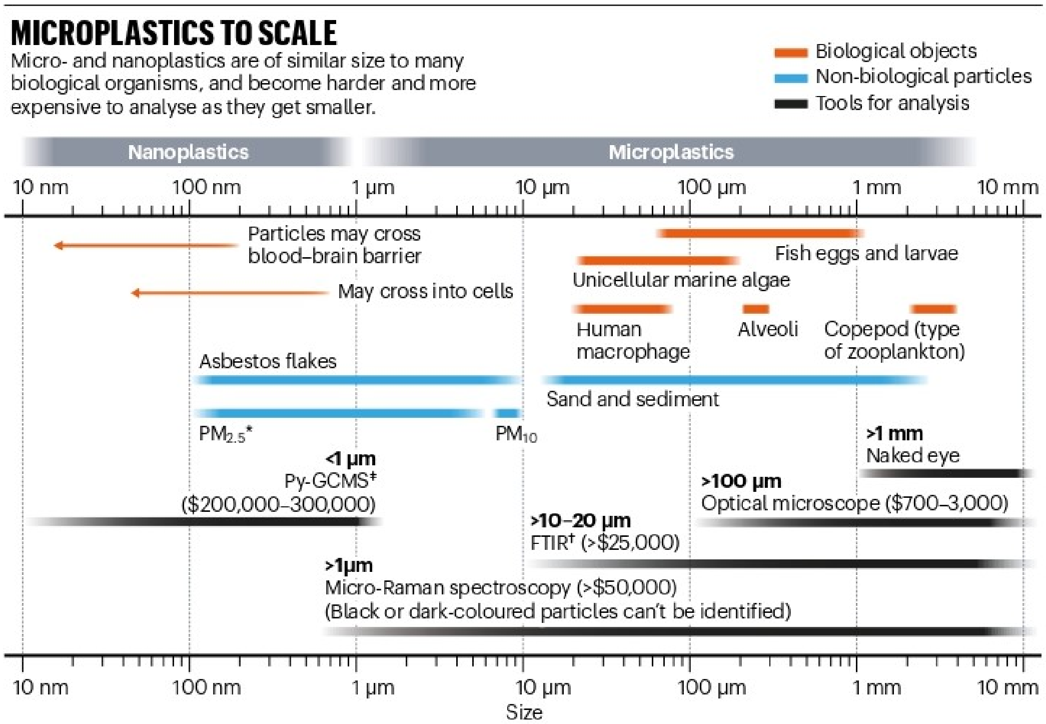


**Figure 2.** SOURCE (TOOLS AND COSTS): (Primpke et al., 2020.)

## 3. ANTROPOGENICITY OF PLASTIC

**Challenges concerning plastic waste**

Plastic waste exerts manifold implications on both the environment and human health. When discarded in landfills, plastic waste infiltrates the soil and nearby water sources, resulting in pollution of both land and water, eventually permeating the food chain. Moreover, unregulated incineration of waste, including plastics, leads to air pollution. Furthermore, obstructed plastic waste within sewage systems exacerbates pollution of rivers and groundwater. The ingestion of plastic-contaminated food and water can lead to severe health consequences, including genetic disorders and damage to the endocrine system. The United States Environmental Protection Agency underscores that all plastic waste ever generated remains on Earth today, underscoring the crucial need for sustainable management of plastic waste (NITI AAYOG-UNDP HANDBOOK ON SUSTAINABLE URBAN PLASTIC WASTE MANAGEMENT, 2021)

**ENVIRONMENTAL IMPACT** Single-use plastics are believed to take thousands of years to decompose. This leads to contamination of soil and water, posing hazards for both land and aquatic wildlife. In certain instances, the presence of single-use plastics in water or food has resulted in the incorporation of plastics into the human body, giving rise to potential health issues.

**HEALTH AND SOCIAL IMPACT** Instances of open burning of plastic waste led to air pollution. In some developing countries, plastic is burned for cooking or heating purposes, resulting in health issues for vulnerable groups such as women, children, and the elderly. Littering in open spaces such as parks leads to welfare losses, which account for an indirect social cost of plastic pollution.

**ECONOMIC IMPACT** The presence of plastic litter is aesthetically unpleasing and bears the potential to adversely affect the GDP of nations relying on tourism. Plastic pollution in the oceans exerts economic repercussions on industries such as tourism, shipping, and fishing. Implementing sustainable plastic waste management practices can transform plastic from being considered 'waste' into a 'renewable resource'. The economic toll of plastic pollution on marine ecosystems amounts to approximately $13 billion per year.(NITI AAYOG-UNDP HANDBOOK ON SUSTAINABLE URBAN PLASTIC WASTE MANAGEMENT, 2021)

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Plastic pollution constitutes a significant anthropogenic problem in coastal and marine ecosystems worldwide. The continuous and unprecedented accumulation of plastic pollutants in aquatic ecosystems, sourced from human activities, directly and indirectly disrupts the structure, functions, and subsequently, the services and values of these ecosystems. Both land-based and sea-based origins serve as the primary contributors of these contaminants, entering the ocean in various ways. Microplastics, being similar in size to food particles commonly consumed by most marine and coastal organisms at lower trophic levels, are highly prone to accumulation in such biota through ingestion, leading to detrimental impacts. Additionally, microplastics can also concentrate in higher trophic level organisms, including humans, through food chains and webs (Thushari & Senevirathna, 2020) The ongoing ecological risk posed by plastic pollution is projected to persist in the future. This is due to anticipated rises in plastic production, coupled with the notable persistence of plastic particles and the deterioration of current plastic pollution. These factors will lead to elevated concentrations of micro- and nanoplastics worldwide (Windsor et al., 2019).

## 4. PLASTIC POLLUTION FROM RIVER TO OCEAN

The Ganges River releases an alarming 315 tons of plastic waste daily, an amount equivalent to the weight of 79 elephants. A recent study reveals that over 663 species face adverse effects due to marine debris, with 11% of them solely attributable to microplastic ingestion. Despite the Ganga's deep cultural and spiritual significance, it stands as one of the most polluted rivers globally, owing to the continuous discharge of both industrial and sewage waste by over 1100 industrial units and numerous towns along its banks. A recent report from the Central Pollution Control Board has declared that the Ganga's water is unsuitable for bathing, let alone for direct consumption. When we compare the concentration of microplastics in the Ganges to similar studies conducted on other rivers worldwide, such as the Rhine in Europe, the Patapsco, Magothy, and Rhode in North America, and the Elqui, Maipo, Biobio, and Maule in South America, the Ganga exhibits significantly higher levels of microplastic pollution. This is notable even in the face of higher per capita plastic consumption in European states, as well as North and South America, in comparison to India.(Sarkar et al., 2007).

Rivers are acknowledged for their vital role in carrying land-based plastic waste to the world's oceans. However, riverine ecosystems themselves are also directly impacted by plastic pollution. To more accurately measure the global transport of plastic pollution and to efficiently mitigate its sources and associated risks, it is imperative to possess a comprehensive understanding of the origins, transport, fate, and impacts of plastic debris in rivers (van Emmerik et al., 2022) The ocean represents the ultimate destination for land-based microplastic sources. However, when compared to marine environments, the occurrence and effects of microplastics in freshwater ecosystems remain largely uncharted (Guerranti et al., 2020).

Microplastic pollution has been discovered to be prevalent in freshwater ecosystems globally. Global models predict that river networks are significant and still growing contributors to marine plastic waste. While earlier research has primarily focused on pinpointing potential sources of plastic pollution in freshwater ecosystems, such as wastewater treatment plants, storm sewers, and urban areas, and linking them to observed microplastic pollution patterns in river corridors, little is understood about the conditions under which these potential pollution sources become activated and connected to surface waters. Additionally, there is limited knowledge about how the fluvial transport of various micro- and nanoplastic size fractions influences the spatial distribution of plastics along river networks, encompassing long-term deposition, storage, and potential resuspension (Krause et al., n.d.). Mismanaged plastic waste often finds its way into the ocean through rivers and city drains, where it accumulates in coastal sediments, ocean gyres, and even the deep sea. This poses a serious threat to marine life and, ultimately, may circle back to humans through the food chain. Private initiatives focused on retrieving plastic from water bodies have garnered widespread attention, particularly in the media. However, achieving a substantial reduction in plastic debris in the ocean necessitates the implementation of measures either at rivers or through a combination of river barriers and cleanup devices. Furthermore, we demonstrate that the incineration and production of plastic exert a significant, long-term impact on the global atmospheric carbon budget. In light of this, we assert that a concerted effort to decrease plastic emissions coupled with bolstered collection methods represents the only viable solution for ridding the ocean of plastic waste (Hohn et al., 2020). Aquatic organisms have been shown to ingest microplastics (MPs), although the extended consequences of ongoing exposure remain less comprehensively studied. Anticipated technological advancements and shifts in demographics are poised to impact the varieties of MPs and their concentrations in the environment. Therefore, it will be crucial to formulate strategies for alleviating the introduction of synthetic polymers into freshwater ecosystems (Wagner & Lambert, n.d.). The quantity of debris from each river correlates with the population residing within the river's catchment area and the ratio of mismanaged plastic waste (MPW) in the respective country to which the river belongs. Typically, the debris is carried to the coast near the river's point of origin (Seo & Park, 2020). Under tranquil flow conditions, advective fluxes exhibited a magnitude two times greater than lateral and vertical fluxes. In turbulent conditions, heightened particle exchange within the cross-section led to a three to tenfold surge in lateral and vertical plastic fluxes. The influence of turbulence on plastic particles was contingent on factors such as size, shape, and composition (Green & Johnson, 2020).

Based on the most recent model-based estimates, a significant portion of riverine plastics is released in Asia. Nevertheless, the precise global riverine plastic emission remains uncertain, primarily due to a severe shortage of observations. Field-based studies are scarce and predominantly concentrated on rivers in Europe and North America, employing widely differing data collection techniques (van Calcar & van Emmerik, 2019). The average concentrations of MPs, as well as their shapes and polymer compositions, in river bank sediments align with those found in their respective riverine counterparts. The only exception lies in the case of fibers, which may be susceptible to being washed further offshore. Consequently, sediments along the shoreline near river mouths could serve as valuable indicators of MP pollution levels in rivers (Constant et al., 2020). The plastic transport at the most downstream location was, on average, ten times higher during high flow periods than during low flow periods. This indicates a strong correlation between plastic transport and river discharge as well as flow velocity. Furthermore, plastic transport exhibited a notable increase along the length of the river, potentially associated with factors such as population density, human behavior, riverbank infrastructure, and industrial zones situated along the river (van Calcar & van Emmerik, 2019).

**Methods used in previous studies to measure Plastic waste**

Employing a Lagrangian particle tracking model, we examined the trajectory and coastal aggregation of waste from ten rivers flowing into the sea surrounding the Korean Peninsula. The quantity of waste originating from each river was determined based on the population within the catchment area and the MPW ratio (Seo & Park, 2020), utilizing a straightforward technique for mapping macroplastic hotspots in urban regions. By means of visual assessments, both the quantity and composition of plastic can be promptly ascertained. Monitoring water systems in urban city centers can be accomplished within a matter of hours (Ippolito, 2022). To identify plastic leakage from land-based sources to the ocean, we utilized variables associated with plastic accumulation in a specific region. Several maps were created, concentrating on geo-environmental factors, and public-use data was geocoded within an ArcGIS environment. This process was modeled for Anambra state through the application of geospatial technology. The risk map was formulated by amalgamating various thematic variables, including plastic waste density within the study area, slope, a classified land-use map, drainage density, and proximity to the drainage network in the study area (Chibundo Chukwuma et al., 2021).

## 5. TECHNICAL MODEL FOR PLASTIC WASTE RECYCLING AND MANAGEMENT

To effectively manage plastic waste and prevent its entry into freshwater systems, a comprehensive framework is proposed. This framework centers around a decentralized dry waste management model, prioritizing Proper Waste Management (PWM) practices and recycling efforts. Authorized agencies or contractors are responsible for the door-to-door collection of municipal solid waste from various sources, such as households, condominiums, institutions, and commercial buildings. Subsequently, this waste is transported to decentralized dry waste centers or transfer

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stations under the jurisdiction of Urban Local Bodies (ULBs). At these transfer points, the waste is then forwarded to Material Recovery Facilities (MRFs). Upon arrival at the MRF, the incoming waste is meticulously segregated into two main categories: dry and wet waste. The wet waste undergoes processing and is subsequently directed towards composting and biogas generation. Any remaining residue is appropriately disposed of in designated landfills. The dry waste, including plastics, undergoes further categorization. Recyclable materials are sent for recycling processes, while non-recyclables are managed through appropriate end-of-life cycle treatments. For a visual representation of this process, please refer to the accompanying in Figure 3 (NITI AAYOG-UNDP HANDBOOK ON SUSTAINABLE URBAN PLASTIC WASTE MANAGEMENT, 2021).

A framework has been formulated to assist water and waste managers in the selection of appropriate devices. This framework emphasizes the importance of conducting a comprehensive watershed assessment, gaining an understanding of site-specific conditions, obtaining community support, and establishing a long-term maintenance plan. While plastic pollution capture devices can mitigate the flow of plastic waste from freshwater sources, it is equally imperative to manage plastic waste at its origin in order to ultimately cleanse our oceans and waterways an example can be seen in Figure 4. We classify these devices based on their physical components, which include booms, watercraft vehicles, and receptacles. Our findings suggest that devices employing two or more of these components may have greater efficacy in capturing plastic debris (Helinski et al., 2021).

The achievement was realized through the compilation of baseline data on marine plastic disposal from the mainland. This was done by thoroughly contextualizing data generated by remote sensing technology and conducting spatial analysis. The study encompassed various parameters, including plastic waste generation, land cover, population distribution, and identification of human activities. These parameters were subsequently utilized to create the Plastic Waste Disposal Index. This index illustrates the movement of waste from the mainland, flowing through the river, and ultimately accumulating in the estuary. The distribution of plastic waste is determined through a calculation involving a weighting method and an overlap analysis between land and coastal areas (Sakti et al., 2021).

Although commendable, the current capacity and widespread implementation of these initiatives to collect plastic pollution are limited when compared to their potential and the extensive nature of the plastic pollution problem. Similarly, only a few technologies endeavor to prevent plastic pollution leakage, and those that do have limited scope. A comprehensive approach is required, one that integrates technology, policymaking, and advocacy to thwart the progression of plastic pollution and the ensuing harm to aquatic ecosystems and human health (Schmaltz et al., 2020).

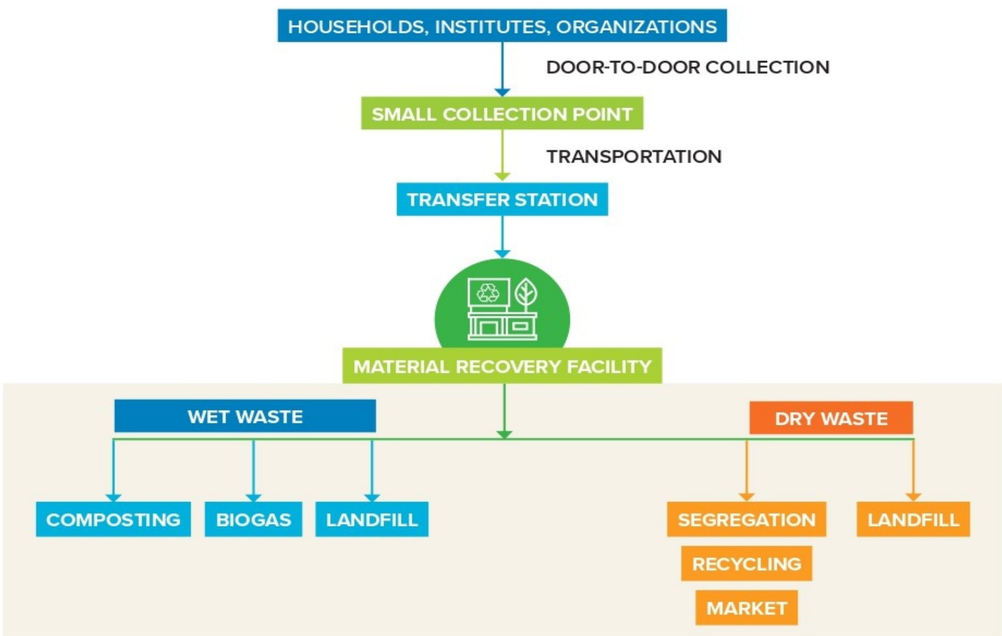

**Figure 3.** (NITI AAYOG-UNDP HANDBOOK ON SUSTAINABLE URBAN PLASTIC WASTE MANAGEMENT, 2021).

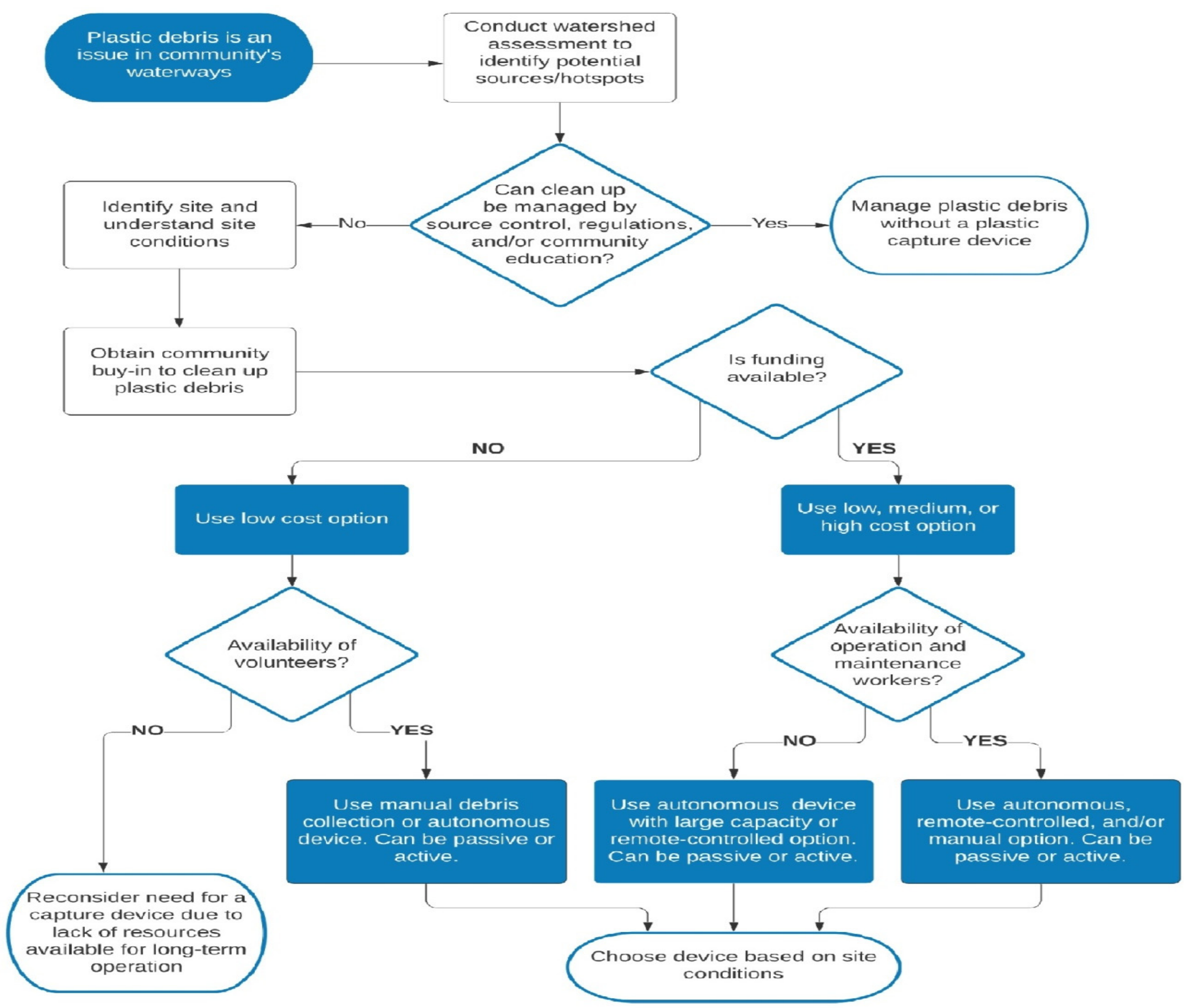


**Figure 4.** Source; (Boucher & Billard, n.d..)

## 6. FUTURE RESEARCH

Understanding the movement of plastic within hydrological catchments constitutes a crucial stride in discerning the dynamics from origin to deposition of plastics within natural systems. This review underscores that evaluations at the catchment scale are predominantly theoretical at present. However, they offer a framework to guide future inquiries, rooted in hypotheses derived from theoretical models. The logical progression involves augmenting existing studies with extensive field-based and experimental datasets, thereby advancing a comprehensive body of research that scrutinizes the transport and impact of plastic pollution at the catchment scale. Thus far, empirical studies have concentrated on specific ecosystems, furnishing an examination of plastic dispersion and interactions between plastics and organisms. The assessment at the catchment scale represents a pivotal next phase in research, particularly in substantiating the management of plastic sources with a more informed perspective. The subsequent sections outline several key developments necessary to facilitate the progression of catchment-scale investigations (Windsor et al., 2019). A comprehensive examination of plastic pollution in the environment is essential. While recent studies have primarily concentrated on microplastic pollution in marine systems, we recommend that macroplastic and nanoplastic pollution should also be given more consideration. This is particularly important because microplastics, especially nanoplastics, have been extensively investigated (Li et al., 2021)

## 7. CONCLUSION

Plastic pollution has emerged as a significant challenge in our modern era, posing a threat not only to terrestrial ecosystems but also to aquatic environments. Mismanaged plastic waste often finds its way into freshwater systems such as rivers, where it is transported. This leads to its transformation into more hazardous forms, including microplastics and nanoplastics, which originate from various industries and have proven to be highly detrimental. The entry of nanoplastics into drinking water sources and their potential impact on human health remain poorly understood. Furthermore, the consumption of microplastics by aquatic life leads to toxicity, contributing to the extinction of many species. Landfills designated for plastic waste occupy substantial amounts of land, and due to the non-biodegradable nature of plastic, they can significantly decrease land fertility. The incineration of plastic waste further exacerbates the problem by causing air pollution, introducing harmful microplastic compounds into our respiratory systems. Given that plastic is deeply ingrained in our modern way of life, completely discontinuing its use is not a feasible solution. Therefore, our primary objective is to identify sustainable strategies for managing plastic waste efficiently. This review offers a comprehensive examination of the ecological, environmental, and socio-economic dimensions of plastic pollution, with a focus on both river and marine environments. This review suggests banning the single use plastic and promoting the 4R's concept of Refuse, reusing, reducing and recycling, a simple key to control plastic pollution.

I. The management of plastic pollution on land should involve an efficient decentralized dry waste management model, encompassing door-to-door collection and recycling of plastic waste. This approach is essential to prevent plastic from reaching our waterways.

II. Implementing river and beach cleaning initiatives, deploying plastic debris capturing devices at the river's terminus, utilizing booms, watercraft vehicles, and receptacles can effectively combat plastic pollution in riverine and marine ecosystems.

III. There is a pressing requirement for further research in this field, accompanied by the necessity to establish unified standards. More precise data regarding plastic waste in rivers can be obtained through advanced methods employed by the Surface Water Management Department.

IV. Furthermore, it is imperative to monitor industrial effluents closely, as they often contain ecotoxic microplastics and nanoplastics, which pose significant environmental hazards.

This review represents a significant advancement in the field of Plastic Pollution and Management, offering a fresh perspective for future studies. It not only expands the scope of research but also provides a comparative framework for its application in upcoming studies.

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