International Journal of Multidisciplinary Research and Growth Evaluation.

Quantitative Assessment and Spatial Distribution of Plastic Waste Pollution in Madagascar (Case Study: Toliara)

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Article Info

ISSN (Online): 2582-7138
Impact Factor (RSIF): 7.98
Volume: 07
Issue: 01
Received: 09-11-2025
Accepted: 10-12-2025
Published: 11-01-2026
Page No: 343-348

Abstract

Plastic pollution represents a major challenge for coastal cities in the Global South. This study quantifies the production, accumulation, and spatial distribution of plastic waste in the urban municipality of Toliara (southwestern Madagascar). Field surveys were conducted over an area of 24, 000 m² during two working weeks, covering residential, commercial, port, and coastal neighborhoods. The waste was sorted by functional typology, weighed separately, and analyzed using a Geographic Information System (GIS).

The results indicate an average production of 50 g of plastic per capita per day, equivalent to approximately 10 tons per day for an estimated population of 200, 000 inhabitants, corresponding to nearly 3, 650 tons per year. Single-use plastics dominate, while pollution hotspots are mainly located around markets, commercial areas, and the port. The overall accumulation is estimated at about 1, 200 tons.

These results provide novel quantitative data and a scientific basis for improving sustainable plastic waste management in Toliara.

Keywords: Plastic Pollution, Coastal City, Plastic Waste, Spatial Analysis, GIS (Geographic Information System), Sustainable Waste Management

1. Introduction

In cities of the Global South, and particularly in Madagascar, plastic pollution constitutes a growing environmental problem, exacerbated by rapid urban growth, inadequate waste management infrastructure, increased use of single-use plastics, and a lack of environmental awareness, all of which promote the uncontrolled dispersal of plastic waste in urban and coastal environments. (Raharinirina, 2018) [14].

In Toliara, a coastal and port city in southwestern Madagascar, this pollution is driven by multiple sources, including households, markets, commercial activities, artisanal fishing, and marine inputs, thereby strongly exposing sensitive coastal ecosystems such as mangroves and coral reefs. (INSTAT Madagascar, 2025 ; Dewar & Yoder, 2016) [7, 2].

Plastic waste present in the municipality consists predominantly of single-use plastics, notably bags, packaging, and bottles, but also includes more durable plastics as well as a growing proportion of microplastics, whose dispersion in the environment and ingestion by fauna pose major environmental and public health risks (Loi, 2017; UNEP, 2021) [11, 13].

In response to this multidimensional challenge, the circular economy emerges as a central theoretical and operational framework, aiming to break away from the linear "produce–consume–discard" model in favor of strategies based on reduction, reuse, recycling, and valorization of plastics, while generating local economic opportunities and strengthening the resilience of vulnerable urban territories (Geissdoerfer *et al*., 2017) [4]. International experiences in Europe, Asia, and Africa show that sustainable plastic management relies on a combination of appropriate regulations, effective infrastructure, citizen participation, and technological innovation, offering relevant lessons for adapting management models to the specific context of Toliara.

In this context, in Toliara, plastic pollution results from the massive production of single-use plastics combined with insufficient collection and treatment infrastructure, leading to the accumulation of waste from households, markets and commercial activities, port operations, and artisanal fishing, as well as marine and atmospheric inputs. This situation makes a precise quantitative assessment and a spatial analysis of areas with high overall plastic concentration necessary (Jambeck *et al.*, 2015; Raharinirina, 2018; INSTAT Madagascar, 2025) [9, 14, 8].

Thus, the objective of this article is to quantify the production and accumulation of plastic waste in the urban municipality of Toliara, to identify its typology, and to analyze its spatial distribution, particularly in residential, commercial, and port neighborhoods, in order to provide a reliable quantitative and cartographic basis for improving plastic waste management.

The originality of this study lies in the empirical and context-specific quantification of plastic pollution in Toliara, providing novel data on the volumes, typology, and spatial distribution of plastic waste. It thereby fills a major gap in scientific data for coastal cities of the Global South and constitutes an essential decision-support tool for planning local waste management strategies (Jambeck *et al.*, 2015; INSTAT Madagascar, 2025) [9, 8]

2.Materials And Methods

2.1. General methodology

This study is based on a quantitative field approach combining systematic inventories, direct measurements, and spatial analysis. It aims to quantify the production, accumulation, typology, and spatial distribution of plastic waste in the urban municipality of Toliara, in accordance with methods commonly used for assessing plastic pollution in coastal urban environments (Jambeck *et al.*, 2015) [9].

2.2. Study area

The study area corresponds to the urban municipality of Toliara, characterized by rapid population growth, a diversity of economic activities (commerce, artisanal fishing, services), and immediate proximity to the coastline. The study covers residential, commercial, port, and coastal neighborhoods in order to account for the diversity of potential sources of plastic waste.

2.3. Sampling and field inventories

The study covered 12 representative neighborhoods of the urban municipality of Toliara.

In total, 36 sampling points were defined (three points per neighborhood), including streets, markets, commercial areas, port infrastructures, and coastal zones.

The inventories involved approximately 120 households, selected using a systematic approach along collection routes.

2.4. Collection of Plastic Waste

Plastic waste was collected manually over predefined surfaces corresponding to the main urban spaces (primary and secondary streets, markets, commercial areas, the port, and beaches).

The collection campaigns were conducted over a continuous period of two working weeks in order to limit temporal variations related to daily activities.

2.5. Sorting and typology of plastic waste

The collected waste was sorted according to a functional classification based on use, including plastic bags, plastic bottles, food packaging, fishing nets and ropes, as well as containers and other plastics used for industrial purposes. Classification by resin type (PET, HDPE, LDPE, etc.) was not applied. This lack of resin-based sorting is considered a methodological limitation of the study (UNEP, 2021) [13}.

2.6. Weighing and estimation of quantities

Weighing was carried out using a portable electronic scale with a precision of 0.01 kg.

The waste was weighed in a dry state immediately after collection in order to limit the influence of moisture. Weighing operations were performed daily at the end of each collection session (GESAMP, 2019) [5].

2.7. Estimation of daily and annual production

The estimation of daily and annual production is based on field data and demographic statistics from INSTAT Madagascar. Extrapolations were performed considering an estimated margin of error of ±10%, related to spatial and temporal variations in plastic waste generation (INSTAT Madagascar, 2025) [8].

2.8. Spatial analysis and mapping

Spatial analysis was carried out using QGIS software (version 3.34-LTR).

Cartographic base layers were derived from OpenStreetMap data and municipal administrative boundaries. The geolocation of collection points was performed using a smartphone-integrated GPS, with an average accuracy ranging between 5 and 10 meters.

2.9. Analytical indicators

The indicators selected for the analysis include the surface density of plastic waste, daily and annual per capita production, the functional typology of plastic waste, as well as its spatial distribution according to different types of urban areas. These indicators form the basis of the analyses presented in the Results section.

3.Results

3.1. Overall quantification of plastic pollution in the urban municipality of Toliara

The collection campaigns and statistical extrapolations indicate that plastic pollution in the urban municipality of Toliara reaches high levels. The average production of plastic waste is estimated at 50 g per capita per day, corresponding to approximately 10 tons of plastics generated daily for an urban population of about 200, 000 inhabitants. On an annual scale, this production represents nearly 3, 650 tons of plastic waste.

These volumes exert significant pressure on existing waste collection and management infrastructure, whose capacity remains insufficient to absorb all generated flows (Jambeck *et al.*, 2015) [9].

The collected waste was classified by type (plastic bags, bottles, food packaging, fishing nets and ropes, containers, and plastics for industrial use) and weighed separately, allowing for a reliable quantification of the different fractions.

Table 1: Overall Results of the collection Campaigns

Plastic category	Collected weight (kg)	Main observations
Plastic bags	480	Very common in markets and main streets
Plastic bottles	210	Higher concentrations near commercial and tourist areas
Food packaging	250	Mainly found around restaurants and neighborhood shops
Fishing nets and ropes	180	Originating from artisanal fishing areas (Ambohitsabo, Ankiembe, Mahavatse, Anketrake)
Containers and other industrial-use plastics	80	Used for storage or transport; present near ports and workshops
Total	1, 200	Collected over an area of 24, 000 m²

***Source*:** Author, 2025

The overall results show that each inhabitant generates an average of 18.25 kg of plastic per year, that the municipality's daily production is close to 10 tons, and that the collected data make it possible both to compare pollution levels between neighborhoods, to identify the main sources linked to economic activities, and to provide a solid quantitative basis for the development of a circular economy model adapted to Toliara (Geissdoerfer *et al.*, 2017; Ellen MacArthur Foundation, 2016) [4, 3].

Table 2: Summary of the main plastic pollution indicators in the urban municipality of Toliara

Indicator	Estimated value	Interpretation
Average plastic production per inhabitant	50 g/day	Level comparable to low-industrialized coastal cities; high use of bags and packaging.
Estimated population	200, 000 inhabitants	Basis for calculating total volumes.
Total daily production	≈ 10 tons/day	Significant burden on collection, sorting, and recycling infrastructure.
Estimated annual production	≈ 3, 650 tons/year	Massive accumulation in the absence of effective management.
Most polluted neighborhoods	Tanambao, Bazar Be, Scama, Mahavatse, Sanfily, Ambohitsabo, Ankiembe	Areas with intense commercial activity and artisanal fishing.
Dominant plastic types	PE (45%), PET (25%), PP (20%)	Useful for guiding recycling strategies.
Average density of collected waste	1, 200 kg over 24, 000 m²	≈ 50 g/m², indicating high concentrations in coastal and commercial areas.

Source: Author, 2025

3.2. Results of field collections and plastic waste density

Direct collections carried out over a total area of 24, 000 m², distributed across several representative neighborhoods, made it possible to recover 1, 200 kg of plastic waste, corresponding to an average density of approximately 50 g/m².

Comparative analysis by type of area highlights marked contrasts:

• residential areas show densities ranging between 2.5 and 3 kg per 100 m²;

• commercial and port areas reach significantly higher densities, between 5 and 7 kg per 100 m².

These results reflect a higher concentration of plastic waste in sectors characterized by intense economic activity and high human presence.

The municipality as a whole thus accumulates approximately 1, 200 tons of plastics, corresponding to an average of 10 tons per day, confirming the magnitude of plastic pollution in Toliara.

3.3. Typology of identified plastic waste

Analysis of the composition of the collected waste highlights a typology dominated by commonly used plastics. Polyethylene (PE) plastic bags constitute the largest fraction, representing approximately 40–50% of the collected plastic waste. Plastic bottles (PET) account for nearly 25%, while food packaging and polypropylene (PP) containers represent about 20%.

Fishing nets, ropes, and specific plastics account for approximately 10–15% of the total, with a marked concentration in coastal and port areas, reflecting the influence of artisanal fishing activities (GESAMP, 2021) [6].

Table 3: Typology and spatial distribution of plastics

Major findings	Observed elements	Environmental and operational issues	Implications for management / circular economy
Predominance of plastic bags and bottles	High presence in streets, markets, commercial areas, and urban neighborhoods	Main sources of visible waste and microplastics; obstruction of infrastructure; diffuse pollution	Priority for sorting, selective collection, and recycling; potential to significantly reduce total urban waste volume
Accumulation of fishing nets and coastal plastics	Concentration in ports, beaches, landing sites, and fishing villages	High risks to marine biodiversity: entanglement, ingestion, fragmentation into microplastics	Implementation of sector-specific actions for fisheries: net recovery, valorization, and awareness programs for fishers
Strategic contribution of GIS	Identification of areas with high accumulation and pollution "hotspots"	Enables better understanding of spatial dynamics and waste flows	Supports planning of a contextualized circular economy model; focuses efforts on priority areas and the most problematic categories

Source: Author, 2025

3.4. Physicochemical characterization and degradation state of plastics

Laboratory analyses carried out on representative samples show that polyethylene (PE) is the dominant polymer (≈ 45%), followed by PET (≈ 25%) and PP (≈ 20%). Smaller proportions of PVC and industrial-use plastics were also identified (Andrady, 2011).

Plastics exposed in the environment exhibit an advanced state of degradation. More than 60% of the samples show clear signs of oxidation linked to prolonged exposure to sunlight, wind, and marine salt. In coastal areas, this degradation results in fragmentation leading to an estimated production of between 120 and 180 microplastic particles per m².

Source: Author, 2025

Fig 1: Soil degradation following the accumulation of plastic waste in Anketsaky

3.5. Spatial distribution and identification of pollution hotspots

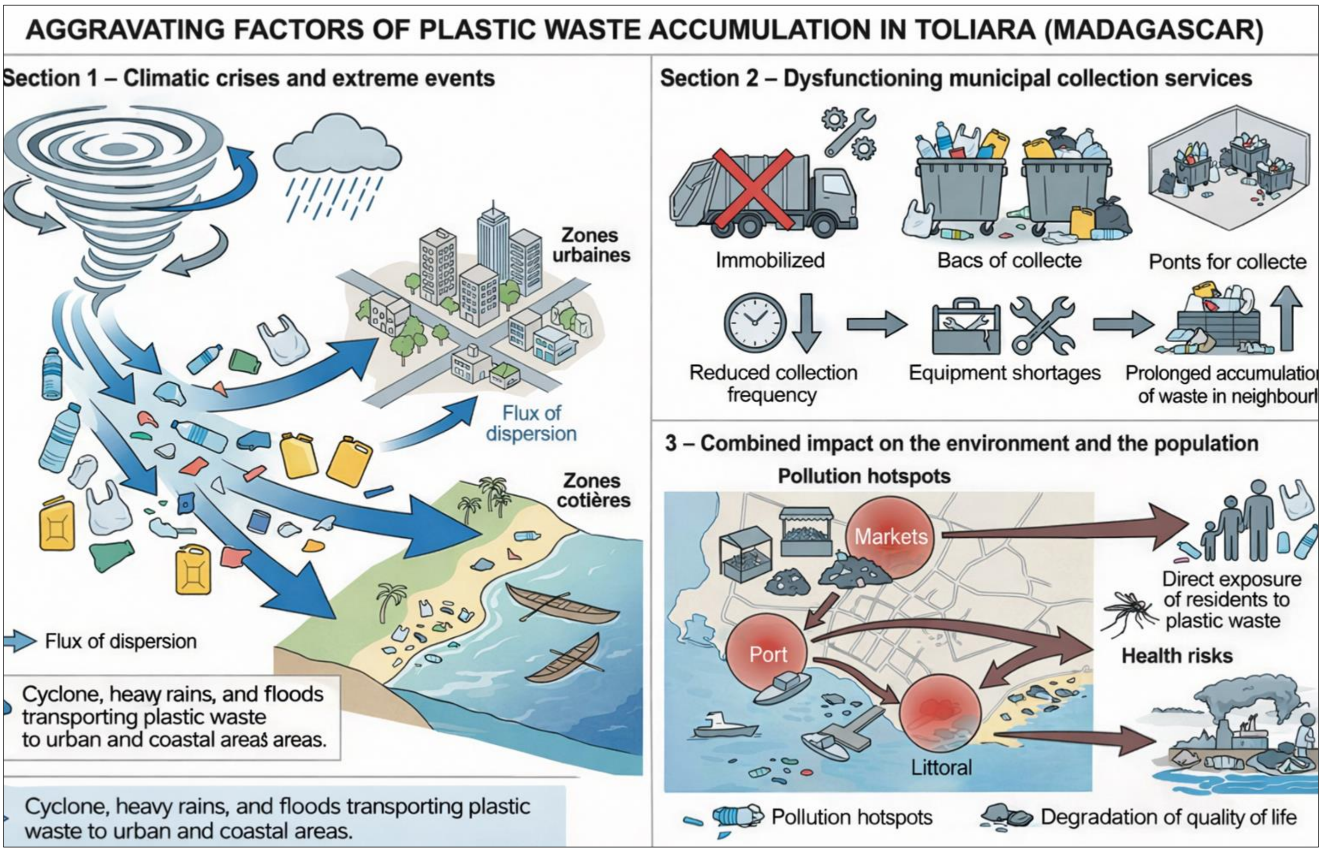
The spatial analysis carried out using GIS reveals a heterogeneous distribution of plastic waste across the entire municipal territory. Commercial areas, central markets, and port sectors appear as the main plastic pollution hotspots. The neighborhoods of Tanambao, Bazar Be, SCAMA, and the port areas show the highest levels of accumulation, while peripheral neighborhoods display more diffuse pollution, although certain coastal zones also concentrate significant volumes due to the combined effects of prevailing winds and tides.

3.6. Overall accumulation of plastic waste in urban and coastal spaces

A significant proportion of the plastics produced is not collected regularly, leading to an overall accumulation estimated at approximately 1, 200 tons across the entire urban municipality. The most visible accumulations are observed in streets and public spaces, drainage channels, as well as on beaches and coastal areas. This persistent accumulation increases the risks of flooding, degradation of marine ecosystems, and public health nuisances for urban populations (Kiare *et al*., 2020) [10].

3.7. Factors influencing the production and dispersion of plastic waste

The production and dispersion of plastic waste in Toliara are strongly influenced by population density, economic activities (markets, commerce, port activities, and artisanal fishing), irregular municipal waste collection, and climatic conditions, particularly prevailing winds and intense rainfall. Combined impact on the environment and the population The combination of these factors promotes the formation of pollution hotspots, especially near markets, the port, and coastal zones. Populations are directly exposed to unsanitary environments, increasing health risks and degrading quality of life. The obstruction of drainage systems by plastics also heightens the vulnerability of neighborhoods to flooding.



Source: Author, 2025

Fig 2: Illustration of the aggravating factors of plastic pollution

4. Discussion

The results show that the urban municipality of Toliara is facing a high level of plastic pollution, characterized by an average production of approximately 50 g of plastic per capita per day, corresponding to nearly 10 tons generated daily at the municipal scale. These values reflect less an exceptional overproduction than a structural imbalance between the flows of plastic waste generated and the actual capacity for collection and management, leading to an overall accumulation estimated at about 1, 200 tons in urban and coastal areas (Jambeck *et al*., 2015) [9].

The typology observed in the field highlights a predominance of single-use plastics, particularly polyethylene bags and PET bottles, reflecting local domestic and commercial consumption patterns. Added to this dominant fraction is a specific component linked to artisanal fishing activities, evidenced by the significant presence of plastics nets and ropes in port and coastal areas, which constitutes a marked feature of the Toliara context.

Spatial analysis reveals strong heterogeneity in the distribution of plastic waste, with clearly identified hotspots around markets, commercial areas, and the port, where high population density, intense economic activity, and irregular municipal collection combine. In contrast, peripheral neighborhoods exhibit more diffuse pollution but remain exposed to waste transfers driven by wind, runoff, and tides, favoring the spread of pollution toward sensitive coastal zones (Velis & Cook, 2021; UNEP, 2021) [13, 15].

This persistent accumulation has direct environmental and public health consequences, including obstruction of drainage systems, increased flood risk, degradation of urban soils, and the progressive fragmentation of plastics into microplastics likely to contaminate terrestrial and marine ecosystems. In this context, the quantitative and spatial data produced by this study constitute an operational scientific basis for guiding local strategies for sustainable plastic waste management, based on targeted reinforcement of collection, valorization of recyclable fractions, and the gradual integration of circular economy principles, while also highlighting the need for further research incorporating seasonal variability and more detailed plastic characterization.

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How to Cite This Article

Karena HE, Mahery NB, Tartin A, Laurent R, Jipaty TH, Ruphin FP. Quantitative assessment and spatial distribution of plastic waste pollution in Madagascar (case study: Toliara). Int J Multidiscip Res Growth Eval. 2026;7(1):343–348.