



Analyzing Waste Management Strategies for “Cinque Terre” Area

Daniela Ambrosino¹ and Stefania Mangano²

¹ Department of Economics, University of Genoa, Genoa, Italy
daniela.ambrosino@unige.it

² Department of Political and International Sciences, University of Genoa, Genoa, Italy
stefania.mangano@unige.it

Abstract. This study presents a comprehensive analysis of urban solid waste management in Riomaggiore, located in the Cinque Terre National Park, a prominent Italian tourist destination. The municipality faces significant challenges due to overtourism, leading to increased waste production that threatens its socio-environmental integrity. This paper explores fluctuations in waste volume related to tourism growth, particularly in the post-pandemic context, while examining the local administration’s efforts to rationalize waste collection. Through interviews with key stakeholders and secondary data collection, the study evaluates the relationship between tourist influx and municipal solid waste generation, identifying critical periods of heightened waste production. The study employs a quantitative modeling approach, implemented by the spreadsheet Excel, to assess current waste management practices, framing the issue as a transportation problem within a multi-level network. While this analysis serves as a partial examination, it establishes a vital foundation for future optimization strategies aimed at enhancing sustainability in waste management. Ultimately, Riomaggiore can act as a pilot case for broader applications within the Cinque Terre, emphasizing the importance of effective waste management in preserving both the environment and the local community’s heritage.

Keywords: Urban Solid Waste Management · Overtourism Impact · Sustainability Strategies · Quantitative Modeling

1 Introduction and Methodology

This study provides a comprehensive analysis of the current urban solid waste management in the municipality of Riomaggiore, located in the Cinque Terre National Park. This area is a significant Italian tourist destination along the northwestern Mediterranean coast in the Liguria region. In recent years, it has faced substantial challenges due to overtourism, resulting in a dramatic increase in waste production that strains the integrity of its unique socio-environmental characteristics. These features have contributed to its designation as a UNESCO World Heritage site since 1997.

© The Author(s) 2026

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 24–41, 2026.

https://doi.org/10.1007/978-3-032-21842-1_3

In addition to illustrating how the volume of urban solid waste has fluctuated due to the uncontrolled expansion of tourism [1], particularly in the post-pandemic period, this study examines how the local administration has begun to rationalize waste collection. It also explores potential areas for further improvement through the implementation of strategies aimed at optimizing existing waste management systems. These efforts seek to enhance the sustainability of a uniquely valuable yet highly fragile territorial context.

Primary data were collected through interviews with the Head of the Technical Office of Riomaggiore, providing insights into the existing waste management protocols. This allowed for an assessment of potential strategies to mitigate environmental impacts [2] and improve process efficiency while optimizing costs. Those data have been collected also through a series of interviews conducted with a group of local stakeholders employed in the tourism sector, as direct beneficiaries of the policies implemented by the Municipality.

Additionally, complementary secondary data were obtained from literature reviews, governmental and non-governmental reports, and statistical materials. This enabled an evaluation of the strong correlation between the increase in municipal solid waste and tourist influx, as well as the identification of the periods of the year when the issue is most severe. It is important to note that comparisons between different variables were not always possible with older data.

This study presents a quantitative approach to evaluate the current waste management practices in Riomaggiore, thereby establishing a basis for enhancing efficiency and sustainability in future waste management efforts.

Riomaggiore can thus serve as a pilot case for the other two municipalities within the Cinque Terre territory. In an area as complex as this, despite the presence of a National Park, the municipalities are the primary decision-makers in matters of municipal solid waste management. However, they do not always possess the material and immaterial resources necessary to implement management policies with uncertain outcomes, which could potentially lead to conflicts within the local population. The innovation of this work lies in proposing a data-driven approach to improve waste collection management through context-specific data collection combined with targeted optimization and monitoring tools tailored to the unique morphology of a Cinque Terre municipality. The proposed approach enables the evaluation of waste-management strategies to increase collection efficiency, reduce transport costs and environmental impact, and offers a transferable model for other complex contexts.

1.1 Waste Management

Waste management refers to the activities and processes involved in managing waste produced by communities and organizations. Key aspects include the collection and transportation of solid waste, separation and recycling of materials, treatment to reduce harmfulness, and proper disposal methods such as landfilling or incineration. Additionally, waste management aims to recover resources from waste and promote sustainable practices through community education and awareness. Effective waste management is essential for protecting the environment, public health, and promoting sustainability by reducing the environmental impact of human activities.

In heavily touristic areas, effective waste management is especially critical, as the influx of visitors significantly increases waste generation. A well-managed waste system not only protects the environment and public health but also enhances the experience for tourists, helping to maintain the local community's appeal and reputation.

Within the evolving framework of smart cities, waste management is a crucial area presenting both challenges and opportunities for sustainable urban development. Indeed, smart cities leverage technology and data to enhance urban living, prioritizing efficiency, sustainability, and citizen well-being. Key characteristics encompass connected infrastructure, data analytics, optimized public services (including smart waste management utilizing advanced technologies and artificial intelligence), environmental sustainability, citizen engagement, intelligent mobility, energy efficiency, security, resilience, and an innovative economy. Smart waste management, by leveraging new technologies and AI to enhance quality of life for residents and tourists while improving environmental quality, is therefore inherently aligned with and integrated into the smart city framework. Fundamentally, it represents employing technology to address urban challenges and elevate the quality of life for all [3].

In highly visited tourist areas, facing waste management challenges mirroring those in densely populated urban centers, traditional waste management systems increasingly struggle with inefficiencies, environmental impact, and social inequalities. Consequently, smart destinations are modernizing waste management through the integration of advanced digital technologies and computational intelligence tools [4]. Quantitative approaches, mathematical models applied to support solid waste management, have been revised in [5]. Mathematical programming has been widely applied to solid waste management issues, with many researchers focusing on multiple objectives. [6] highlights the inclusion of social aspects in solid waste management studies and the challenges of quantifying these aspects for optimization. Sustainable solid waste management frameworks must consider the interests of various stakeholders, including local authorities, residents, tourists, and all economic operators within the industry, thereby fostering a collaborative approach that supports environmental sustainability and community well-being. To address social factors, researchers employ methods such as interviews and surveys to gather insights from stakeholders. However, [6] stresses that only 10% of the reviewed studies involved stakeholders in defining social indicators for decision-making. A methodology for quantifying social metrics in solid waste management systems, addressing the challenges of integrating these indicators into optimization frameworks and highlighting the impact of employee turnover and exposure risks on operational efficiency and safety is developed in [7].

Solid waste management faces a critical global challenge, but the integration of artificial intelligence (AI) and information and communication technology (ICT) offers innovative solutions to enhance waste management practices supporting real-time data collection and monitoring. Smart bins equipped with sensors, for instance, can track fill levels and communicate with collection systems to dynamically schedule waste pickup, optimizing routes and minimizing fuel use and emissions [4, 8]. This not only results in operational cost savings but also contributes to the reduction of the city's environmental footprint.

AI-driven predictive models improve waste forecasting and recycling initiatives, while these technologies optimize collection routes and enable accurate waste sorting, significantly increasing recycling rates. A systematic review identifying challenges in implementing AI and ICT in solid waste management is presented in [9], while contributing to the conversation on sustainable waste management practices and future trends.

Recent literature presents integrated smart waste management (ISWM) as an innovative and technologically advanced method for waste management and collection. ISWM permits to improve both the efficiency and effectiveness of waste management, while also looking for sustainability and cost reduction. This comprehensive approach addresses the entire waste stream, from generation to final disposal. This approach is grounded in Internet of Things (IoT) technology, which involves a network of interconnected devices capable of communicating and exchanging data. The information gathered from IoT devices enables municipalities to enhance the efficiency of their waste management operations [10]. The authors of [10] propose a multi objective optimization approach for a multi-level network.

Digitalization and new technologies, essential components of smart destinations, play a crucial role in solid waste management. However, their application and integration must be tailored to the specific operational and social context of the community.

Transportation and logistics operations represent a substantial portion of the total costs within the waste management system [11]. As a result, the vehicle routing problem (VRP) has garnered significant attention as a means to reduce costs associated with this phase of the waste management process [12]. A two-stage model designed to optimize waste management by assisting a regional authority in locating sorting facilities and determining their capacities, while optimizing vehicle route lengths for waste collection and minimizing Greenhouse Gas emissions is presented in [13].

In this work, we present a preliminary attempt to utilize a spreadsheet-based modeling approach to evaluate the waste management strategy implemented by the Municipality of Riomaggiore for handling waste generated by accommodation facilities and second homes. We frame this issue as a transportation problem within a multi-level network. This modeling decision stems from the region’s unique landscape and morphology, which often necessitate door-to-door collection conducted on foot, as vehicle access is impractical. Furthermore, the limited roadways require the use of small electric vehicles that are incapable of performing conventional waste collection routes. The proposed quantitative approach is designed to provide an initial framework for organizing waste management effectively, ultimately leading to the optimization of the entire process. Although it is a partial study, it marks a crucial first step toward more comprehensive solutions.

The rest of the paper is organized as follows: Sect. 2 provides an overview of the territory of Riomaggiore and its characteristics. Section 3 analyzes the impact of increased tourism on waste production in the area, while Sect. 4 details the waste management practices in Riomaggiore. Section 5 presents the quantitative approach employed in this study, and Sect. 6 outlines the conclusions and suggestions for future research.

2 Riomaggiore's Territorial Characteristics

The focus of this study is Riomaggiore, along with its settlements of Manarola, Volastra, and Groppo (Fig. 1). The municipality is situated in the province of La Spezia, within the Cinque Terre area, approximately 90 km east of the city of Genoa. An inset map shows the location of the area within Italy, marked with a red pin.

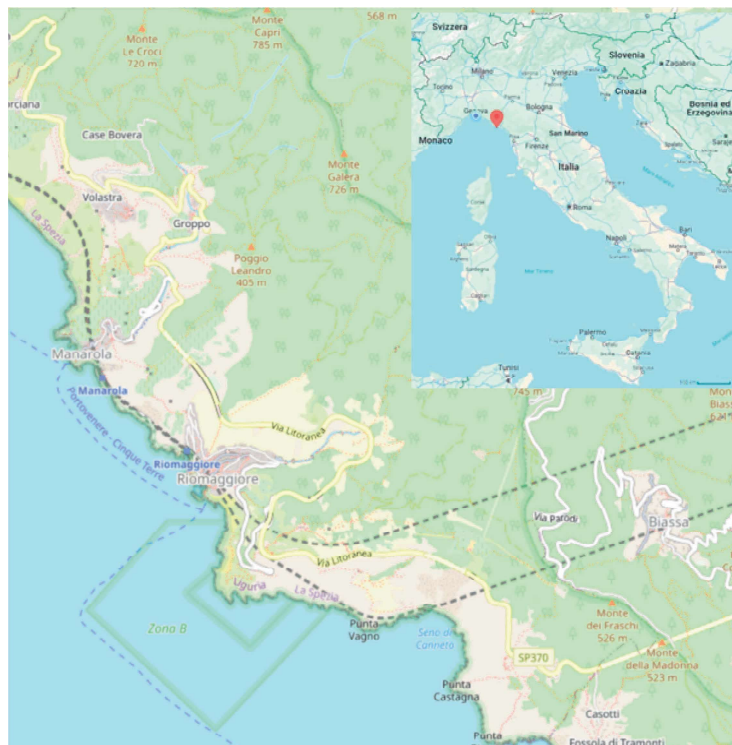


Fig. 1. Riomaggiore and its settlements: Manarola, Groppo and Volastra. Our elaboration from <https://www.parconazionale5terre.it/map.php>, <https://www.google.it/maps>.

As mentioned, this area was designated a UNESCO World Cultural and Natural Heritage Site in 1997, alongside Portovenere and the islands of Palmaria, Tino, and Tinetto. Two years later, on October 6, 1999, it was established as a National Park by a decree from the President of the Republic. Covering 3,868 hectares, it is the smallest park in Italy, yet it has the highest population density, with approximately 4,000 inhabitants. The park includes the municipalities of Monterosso al Mare, Vernazza and its hamlet of Corniglia, as well as Riomaggiore and its hamlet of Manarola. Riomaggiore, encompassing an area of 10.30 km², is the southeasternmost municipality of the Cinque Terre. It is situated between the Ligurian Sea and the mountain range that branches off from the Apennines near Monte Zatta, extending southeastward and acting as the watershed between the Val di Vara and the coastal region.

The original core of its historic centre dates back to the 13th century and is situated in the valley of the Rio Maggiore stream. The settlement consists of parallel, tower-like houses built according to the Genoese tradition, following the steep course of the stream. The more recent *Stazione* district, developed in the second half of the 19th century, is situated in the adjacent valley of the Rio Finale. The two valleys, where the settlement extends, are separated by the steep *Campione* ridge, at the base of which lies the town's castle.

According to ISTAT data, in 2023 Riomaggiore had a population of 1,313 residents, with approximately two-thirds residing in the main settlement of Riomaggiore and the remaining third in Manarola.

The geomorphological and settlement characteristics of Riomaggiore are crucial for understanding the challenges related to urban solid waste collection, especially when waste volumes surpass the territory's actual absorption capacity as a result of overtourism. In order to better understand this situation, it is essential to analyze both the weather patterns and the impact of increased tourism on waste production, threatening the environmental, social and economic sustainability of the municipality and, more generally, of the entire Cinque Terre area.

3 Overtourism and Waste Production in Riomaggiore

The history of the massification of tourism in the Cinque Terre began with the construction of the coastal road in the 1950s and 1960s, which made accessible an area hitherto known for wine production [14]. Over time, accessibility and the region's unique charm have transformed it from an agricultural area into one of the main overtourism areas in Italy. However, it is important to note that while the area is accessible by car, train, and sea, navigating within the villages themselves is far from easy. This presents challenges not only for tourism supply but also for the management and disposal of urban solid waste.

According to a study conducted for the Cinque Terre National Park by [15, 16], which relied on a preliminary estimate of tourist flows into the park by correlating various data sources, historical records, and assumptions about park access, it was found that in 2023, nearly 3.5 million tourists were concentrated within an area of just 1 km², representing only 3% of the park's total area. The highest influx occurred during the spring and summer months, particularly from April to September, when over 85% of visitors were recorded (Fig. 2), reflecting an overall increase of approximately one million compared to 2022.

This situation indicates a high concentration of visitors in the municipality of Riomaggiore. Official tourism data, which track arrivals and overnight stays in hotels and other accommodation facilities (excluding second homes), although significantly lower than the estimates provided by [15] for the entire region, offer insight into the levels of tourist concentration and seasonality (Fig. 3).

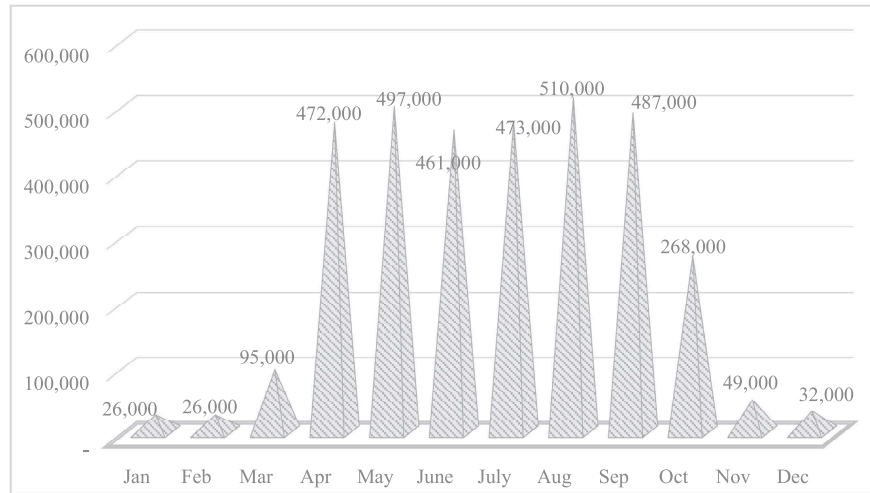


Fig. 2. Estimated visitors to the Cinque Terre in 2023. Source [16].

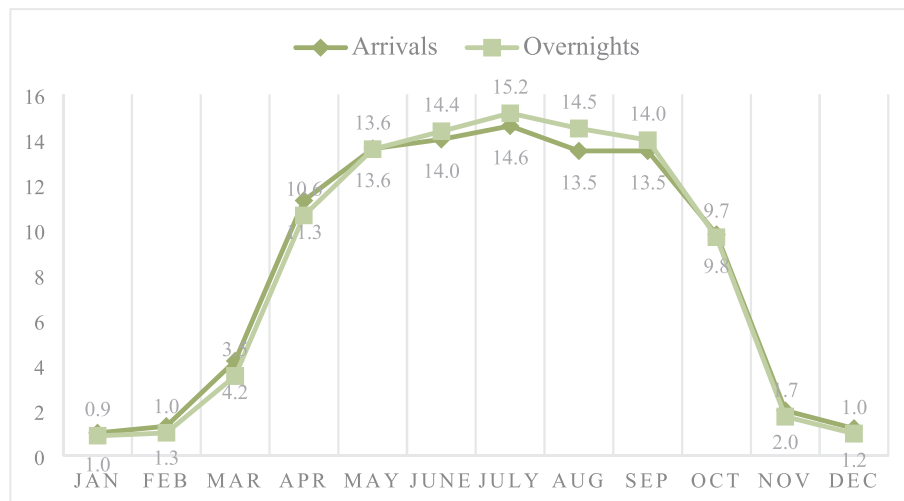


Fig. 3. Percentage trend of arrivals and presences in Riomaggiore in 2023. Source: ISTAT, 2025.

In 2023, tourist arrivals in Riomaggiore reached 107,739, while overnight stays totaled 259,076. Compared to 2019, these figures represent an increase, with overnight stays experiencing a higher percentage growth of approximately 12%, while arrivals saw a more modest rise of 1.3%. When compared to 2014, both metrics demonstrate significant growth, increasing by 87.9% for arrivals and 97.1% for overnight stays, equivalent to absolute increases of 57,325 and 131,452, respectively.

The provisional data for 2024 indicate a slight decline compared to the previous year, with arrivals decreasing by 2.1% and overnight stays falling by 2.7%. This trend may

reflect the impact of policies aimed at redistributing tourist flows. Efforts are underway not only to regulate tourism but also to redirect it, encouraging tourism organizations to adopt alternative management strategies and to promote a deeper appreciation of the area’s natural and cultural heritage [17]. However, achieving this is not straightforward. While redirecting visitors to less frequented areas could be a potential solution, first-time visitors to the Cinque Terre are often reluctant to forgo the scenic paths overlooking the sea or the iconic “Via dell’Amore”. This highlights the necessity of managing the region as sustainably as possible, including effective waste management.

The trend in tourist flows significantly influences the generation of urban solid waste. Figure 4 illustrates the monthly trend of urban solid waste production in Riomaggiore for 2019 and 2023 (in tonnes), revealing an overall increase of nearly 30% between the two years. Furthermore, the monthly distribution closely aligns with the pattern of tourist flows (see Fig. 3).

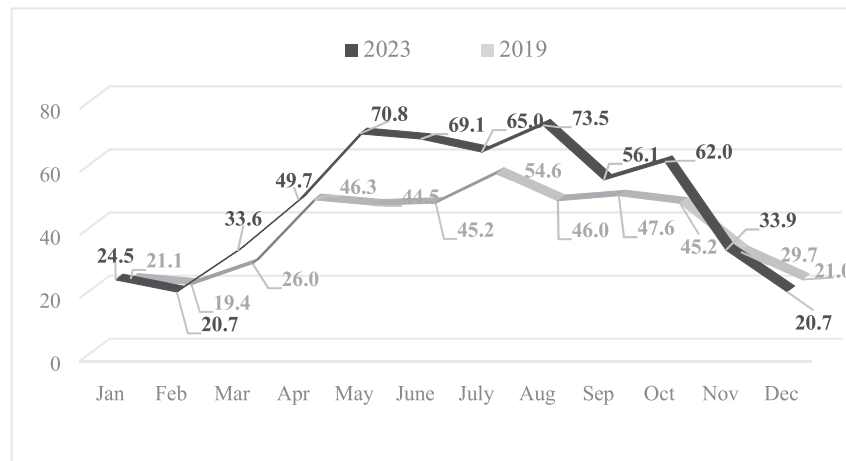


Fig. 4. Monthly trend of urban solid waste production in Riomaggiore in 2019 and 2023 in tonnes. Source: Regione Liguria, https://servizi.regione.liguria.it/page/welcome/RIFIUTI_URBANI

Figure 5 displays urban solid waste production per capita for the top 10 municipalities along with Riomaggiore for the years 2023, 2019, and 2007 (in kg). It highlights that per capita waste generation in Riomaggiore increased by approximately 21% between 2019 and 2023, and by about 45% when comparing 2023 to 2007.

The trend of these two variables indicates that the costs borne by the local population for waste management are significantly high—not necessarily from an economic standpoint, as the municipality provides support, but in terms of social and environmental well-being. The increasing number of tourists directly contributes to heightened waste production, necessitating efficient management strategies. In this context, the municipality has already implemented various policies and supported targeted actions.

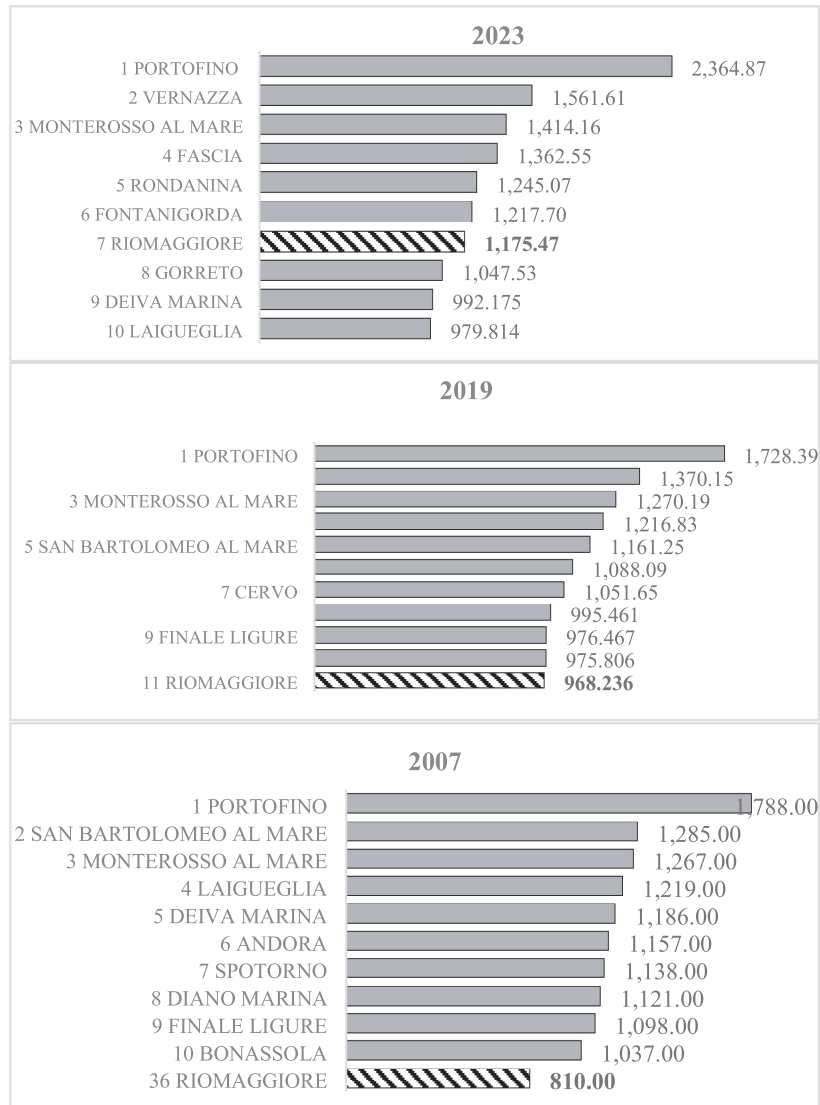


Fig. 5. Urban solid waste production per capita first 10 municipalities and Riomaggiore years 2023, 2019, 2007 in kg. Source: Regione Liguria, https://servizi.regione.liguria.it/page/welcome/RIFIUTI_URBANI

4 Waste Management in Riomaggiore

The in-deph interview with the Head of the Technical Office of the Municipality of Riomaggiore confirmed that best practices implemented in other tourist destinations are not effective here due to the area's unique morphological characteristics, which complicate waste flow management.

To address the situation described in the previous paragraph, Riomaggiore and its hamlets have adopted experimental and alternative waste collection methods to ensure higher cleanliness levels, particularly in areas frequently visited by tourists and hikers at various times of the day. As emphasized by the Head of the Technical Office, 2024 marks a transitional year for waste management strategies.

Micro waste collection islands have been established in the three villages specifically for accommodation facilities, as their waste disposal needs do not always align with the scheduled collection times due to guest check-out schedules. Bars and restaurants also benefit from a customized collection system, with waste pickups occurring in the evening and at dawn during the summer season for all types of waste. Additionally, most waste collection containers have been replaced, and a complete system renewal is planned for 2025.

Since spring 2024, waste collection services have been expanded to include evening pickups, even in areas near the Marina that are inaccessible to vehicles. Glass waste, in particular, is managed by a local craftsman who collects it overnight, transports it to a designated area, and coordinates its removal. These additional services were introduced because the area around the tourist harbor is often frequented by an increasing number of visitors who consume food and drinks by the sea after the last official collection. In residential areas, waste is collected through a door-to-door system that follows a specific schedule designating different collection days for various types of waste.

Additionally, to reduce plastic consumption—particularly from bottled water—three water stations will be installed. These stations will provide monitored drinking water in the three main villages of the municipality and will be managed by an external operator. Water will be available for a fee, with different rates for residents and tourists, sourced directly from the local water supply before undergoing purification.

Street cleaning has also been enhanced: during the summer months, streets and lifts are swept multiple times a day, thanks to the collaboration of local cooperatives working alongside the company responsible for routine waste management.

In conclusion, the comprehensive waste management strategies implemented in Riomaggiore—ranging from innovative collection methods and the establishment of micro waste collection islands to the installation of water stations and enhanced street cleaning—reflect a proactive approach to maintaining cleanliness and sustainability in this unique coastal municipality, especially in light of its increasing tourist activity.

A few months after the implementation of the initial measures described above, in August 2024, ten local stakeholders working in the tourism sector – particularly in tourist accommodation (e.g., short-term rental managers and B&B owners) and food service – were interviewed, as they represent the primary beneficiaries of the policies introduced. In general, the interviewees demonstrated good awareness of the initiatives undertaken by the municipality, such as the installation of dedicated ecological islands and the twice-daily collection of commercial waste. However, other measures – such as the collection of glass waste in the beach area or the planned installation of water dispensers aimed at reducing plastic use – were less well-known, highlighting a potential need for improved institutional communication.

The perception of tourist behaviour regarding waste management was largely negative: most respondents believed that visitors tend not to follow the rules and handle waste

carelessly. Some also pointed out infrastructural shortcomings, including an insufficient number and size of public waste bins, as well as the excessive use of single-use packaging. Nonetheless, evaluations of municipal policies were not entirely critical. There was openness to the adoption of technological solutions, although half of the interviewees expressed scepticism. More prominently, there was a clear demand for increased citizen involvement, proposals for incentive-based systems to encourage virtuous behaviour, and a widely shared recognition of the need to redistribute tourist flows more evenly throughout the year in order to ease pressure during peak seasons.

From an operational standpoint, the priorities identified included enhancing street and beach cleaning services, increasing collection frequency, improving the availability and quality of public waste bins, and carrying out more frequent maintenance in peripheral or less well-maintained areas. The newly introduced waste bins were generally well received, both in terms of functionality and aesthetics.

Finally, some interviewees emphasized the need to simplify the waste disposal system and to design alternative solutions for elderly residents, who often face challenges in this regard. Given the geomorphological characteristics of the area, waste disposal is not always straightforward. In such cases, the adoption of smarter systems would undoubtedly be beneficial.

In the following section, we propose an Excel spreadsheet to conduct an initial assessment of the presence of ecological micro-islands for waste collection.

5 An Optimization Approach for Evaluating the Waste Management System Based on Micro Eco-Islands

Based on the spatial distribution of accommodation facilities and second homes within the territory of Riomaggiore, known the location of the ecological micro-islands and by analysing the available connections among them, we were able to create a graph to better analyse the waste collection problem. The graph permits to visualise the waste collection network and to implement a transportation model in such a way to optimize the collection costs by suggesting a waste delivery strategy to the central depot.

As already mentioned the door-to-door collection system evolved to a model where waste from the various operators is delivered to the eco-islands, which are subsequently serviced by small collection trucks that can easily navigate the streets of Riomaggiore, Manarola, Volastra and Groppo.

Due to the area's morphological characteristics and the fact that the distances and travel times—whether on foot or using a small electric vehicle—are generally very short, we have chosen to cluster accommodation facilities and second homes; each cluster serves as a production node in our network and is characterized by a specific production rate. Conversely, the micro eco-islands represent collection points with defined capacities. Additionally, the network includes two peripheral depots designated for the temporary storage of waste until it is transferred to a central depot, far away closed to the city of La Spezia (see Fig. 6).

The analysis began with the clusterization of the accommodation facilities and an assessment of the waste quantities delivered by each cluster to the eco-islands; six clusters have been defined for Manarola, six for Riomaggiore, one for Volastra and one for

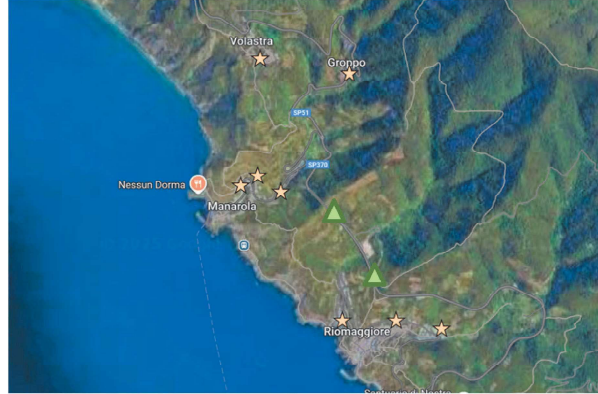


Fig. 6. The region under investigation with 8 micro eco-islands ★ and peripheral depots ▲

Groppo. Each cluster, composed by a number of facilities ranging from 6 to 16, is connected to the micro eco-islands present in their respective locality. The resulting network is depicted in Fig. 7. Each micro eco-island is connected to both the depots and the last layer represents the connection of the depots to the central one in La Spezia.

The optimization problem consists in determining the flow of waste from production nodes, i.e., the clusters of accommodation facilities and second homes to the micro eco-islands, and at the second level of the network, from the micro eco-islands to the available depots, while the last transfer is from the depots to the central one. Please note that the capacities of eco-islands and peripheral depots (d1 and d2) must be respected; we assume the central depot of La Spezia has not a capacity limit.

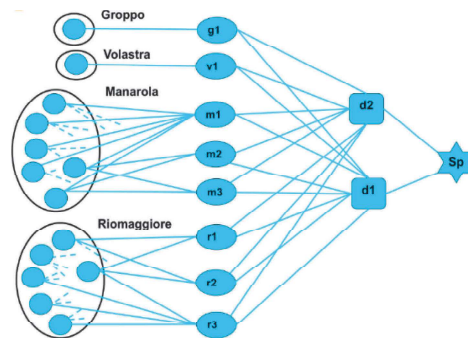


Fig. 7. The graph depicting the logistics of the waste collection system

The capacity of each micro eco-islands is limited and lower than the capacity of the peripheral depots; for this reason the waste flows are diversified day by day. This means that there may be a daily transfer of waste from the micro islands to the peripheral depots, while the peripheral depots will likely have biweekly transfers to the central depot in La Spezia, depending on the waste rate production and thus on the season and the flow

of tourists. Therefore, the analysis consider a specific time frame, such as a week. An example of waste flows in the network during some days of a week is depicted in Fig. 8. For each reported day, the waste flows are represented thanks to brown arcs.

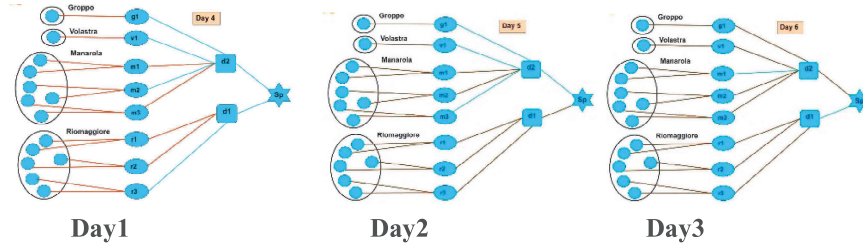


Fig. 8. A feasible solution for the Riomaggiore waste collection system – 3 days planning

From a managerial perspective, this basic approach allows for the evaluation of both the network's and the vehicles' capacity to manage the waste produced, the identification of the most effective collection policies in terms of days/trips from micro eco-islands to the central depot, and finally, the assessment of the feasibility of managing other waste categories within this collection network (e.g., glass).

Regarding the optimization model, we have addressed a multiperiod, single product transportation problem using spreadsheets Excel. In this initial study, optimization is solely focused on defining the flows between the layers of the network to ensure compliance with the capacities of the eco-island and depots, while minimizing both total collection costs and, indirectly, the environmental impact of the collection activities. The use of electric vehicles for transporting waste from micro-islands to depots allows us to disregard emission costs within this layer of the network. However, this consideration is not applicable to waste transfer from depots to the central facility. Therefore, we adopted a weighted cost function that penalizes transportation costs in the last layer of the network.

The problem has been implemented and solved using Excel's Solver. The spreadsheet is organized into different sections, each corresponding to a layer of the network and a specific day within the planning horizon. For each layer, the data are presented in light blue cells. The section related to the first layer is shown in Fig. 9. For this layer, the sheet reports the distances between each pair of facilities, as well as the quantities to be delivered to the nodes of the second layer (note that these data vary for each day of the planning horizon). The capacities of the facilities within each layer are also displayed; specifically, the capacity of the micro eco-island is reported in Row 36.

The green cells represent the decision variables; upon completion of the optimization process, these cells display the optimal flow among nodes/facilities within the layer under consideration (e.g., from production nodes to micro eco-islands in Fig. 9) for the specific day analyzed (Day 1 in Fig. 9). The gray cells contain formulas that compute the outflows and inflows—referring again to the layer shown in Fig. 9, they represent the total quantity transferred from each production node (outflow) and the total quantity entering each micro eco-island (inflow).

	A	B	C	D	E	F	G	H	I	J	K	L
	cost first level (distance in m)	r1	r2	r3	m1	m2	m3	v1	v2		tot cost first level	
1	c1_r	200	400	900	1000000	1000000	1000000	1000000	1000000	day1	1741500	
2	c2_r	400	200	300	1000000	1000000	1000000	1000000	1000000	day2	1739550	
3	c3_r	900	500	200	1000000	1000000	1000000	1000000	1000000	day3	1744900	
4	c4_r	550	300	400	1000000	1000000	1000000	1000000	1000000	day4	1775800	
5	c5_r	700	350	700	1000000	1000000	1000000	1000000	1000000	day5	1682900	
6	c6_r	750	400	800	1000000	1000000	1000000	1000000	1000000	day6	1008950	
7	c1_m	1000000	1000000	1000000	500	400	1000	1000000	1000000			
8	c2_m	1000000	1000000	1000000	200	100	700	1000000	1000000			
9	c3_m	1000000	1000000	1000000	250	150	800	1000000	1000000			
10	c4_m	1000000	1000000	1000000	100	100	500	1000000	1000000			
11	c5_m	1000000	1000000	1000000	150	200	600	1000000	1000000			
12	c6_m	1000000	1000000	1000000	300	200	800	1000000	1000000			
13	c1_v	1000000	1000000	1000000	1000000	1000000	1000000	100	1400			
14	c2_v	1000000	1000000	1000000	1000000	1000000	1000000	1400	100			
15												
16												
17	DAY 1											
18	q transferred first level	r1	r2	r3	m1	m2	m3	v1	v2	total q transferred	q to deliv	
19	c1_r	0	450	0	0	0	0	0	0	450	450	
20	c2_r	0	0	450	0	0	0	0	0	450	450	
21	c3_r	0	0	380	0	0	0	0	0	380	380	
22	c4_r	0	0	390	0	0	0	0	0	390	390	
23	c5_r	0	0	430	0	0	0	0	0	430	430	
24	c6_r	0	0	420	0	0	0	0	0	420	420	
25	c1_m	0	0	0	0	380	0	0	0	380	380	
26	c2_m	0	0	0	0	420	0	0	0	420	420	
27	c3_m	0	0	0	0	430	0	0	0	430	430	
28	c4_m	0	0	0	450	0	0	0	0	450	450	
29	c5_m	0	0	0	460	0	0	0	0	460	460	
30	c6_m	0	0	0	270	170	0	0	0	440	440	
31	c1_v	0	0	0	0	0	0	350	0	350	350	
32	c2_v	0	0	0	0	0	0	0	350	350	350	
33												
34	total q per micro eco- island (inflow micro eco-is)	0	450	2070	1180	1400	0	350	350			
35												
36	micro eco- island capacity (Kg)	1400	1400	2100	1400	1400	2100	1400	1400			

Fig. 9. The first level network in the spreadsheet Excel: data, decisions and formulas

Furthermore, the total cost associated with waste transportation in the first network layer is reported in the gray cells located in the top-right section of Fig. 9 (Column K). The same structure is applied to the second and third network layers (see Fig. 10). The second layer involves the micro eco-islands and peripheral depots (d1 and d2). At the end of each day, a waste stock may be present in each peripheral depot, calculated as the initial stock (for Day 1) or the stock at the end of the previous day (for subsequent days), plus the inflow from the micro eco-islands, minus the outflow sent to the central depot.

Moreover, Fig. 10 reports the total daily costs, calculated as the sum of the costs across all layers. The total cost is displayed in the yellow cell and serves as the criterion for evaluating the effectiveness of a collection solution within the given network. The total cost to be minimized is the weighted sum of the transportation costs across the three levels of the network over the considered time horizon. In more detail, we optimize the collection costs, identifying the optimal flows on the network while collecting all the

produced waste. We assume that each operator prefers to ship its waste to the closest micro island, for this reason we minimize the total distance travelled for reaching the eco-islands; moreover, we minimize the total distance traveled for empty the eco-islands and transfer the waste to the depots. Finally, the last term to minimize is the cost for transferring waste to the central depot. This last component is weighted more than the others representing the most important element for the environmental aspects.

M	N	O	P	Q	R	S	T	U	Y	W	X	Y	Z
cost second level (km)	d1	d2		tot cost second level		cost thirt level	CD		tot cost third level			total cost	
r1	5,7	4,4		13162		d1	46	day1	0		day1	14904	
r2	4,6	3,2	day1	13154,5		d2	54	day2	0		day2	14694	
r3	4,2	2,8	day3	13196,8				day3	700000		day3	1064942	
m1	1,7	3,1	day4	19321,4				day4	0		day4	21097	
m2	1,7	3,1	day5	14226,3				day5	378000		day5	562911	
m3	2,1	3,4	day6	13769,2				day6	322000		day6	498578	
v1	2,8	4,2											
v2	1,6	3											
											tot	2197325,6	
DAY 1													
q_transferred second level	d1	d2	total q transferred	inflow micro eco-island							initial stock	d1	d2
r1	0	0	0	0									
r2	0	450	450	450									
r3	0	2070	2070	2070		DAY 1					at the end of day1		
m1	1190	0	1180	1180		q transferred third level	CD	inflow depot			storage q	d1	d2
m2	1400	0	1400	1400		d1	0	3280				3280	2520
m3	0	0	0	0		d2	0	2520					
v1	350	0	350	350									
v2	350	0	350	350									

Fig. 10. The second and third levels in the spreadsheet Excel: data, decisions, formulas, and main objective.

Gray cells in Figs. 9 and 10 contain formulas used to enforce constraints related to capacity and flow conservation within the network in the optimization model. For example, at each micro eco-island, the total inflow must be equal to the total outflow; the total outflow from each production node must correspond to the quantity to be delivered; and the capacity of each micro eco-island must be respected (i.e., the total inflow to each micro eco-island on each day must not exceed its capacity). Regarding each peripheral depot, the total quantity stored at the end of each day must not exceed its storage capacity.

We have represented the transportation problem in such a way to find the best solution for transferring the waste during the considered planning horizon. Additionally, thanks to this spreadsheet we are able to identify the maximum amount of waste that the network is able to transfer from the production points to the La Spezia depot.

Paying attention to the collection network, with a focus on the relationships between the eco-islands and the downstream processes, which include peripheral depots and the central depot for waste disposal, we can observe that the actual network presents 2 depots (d1 and d2) both directly connected with La Spezia depot. Analysis of flows at the last level of the network revealed the potential to optimize waste transfers by implementing a single collection route that visits both peripheral depots before proceeding to the central depot in La Spezia. Given current flow volumes, this configuration also allows the peripheral depots to serve as interim storage for other waste types (e.g., glass), further optimizing their transfer to La Spezia.

Moreover, it is possible to use the spreadsheet to evaluate different networks, for example, a network with only one depot serving all eco-islands, or on the opposite, a network with more peripheral depots, defining the best number of depots, their capacities and their location.

6 Results and Conclusions

Preliminary results of the quantitative approach employed in this study indicate that the current waste management network, dedicated to a specific waste product, can effectively handle waste during peak summer periods. Using the Excel spreadsheet, we are able to identify the optimal collection strategies that minimize both overall costs and environmental impact. Furthermore, we are able to propose more promising strategies by modifying the collection process in the last layer of the network, which has the most significant environmental impact, and by integrating the collection of other waste streams, such as glass, which increase the total waste management costs within the municipality.

These results are important but remain a theoretical outcome, as tourism operators managing accommodation facilities are responsible for depositing their waste at the eco-islands, thus it does not guarantee proper management. The municipal incentives are crucial to ensure that operators efficiently deliver waste to the eco-islands. The municipality’s goal is undeniably to measure the quantity of waste delivered by various operators, enabling the development of appropriate pricing policies. This is an essential foundation for achieving an efficient waste collection system in the area.

Although numerous data regarding waste in Riomaggiore are available, a more detailed data collection system would facilitate the implementation of a more efficient management system. Therefore, from a data perspective, it is essential to design datasets to monitor and optimize waste management.

Effective monitoring of the waste management system relies on two pillars: quantitative and qualitative monitoring. By offering clear, evidence-based results, it enhances community awareness of the tangible benefits and fosters greater support for sustainable practices. Additionally, transparent and credible data serve as a compelling demonstration for other municipalities and stakeholders, encouraging them to adopt similar successful strategies and facilitating the dissemination of effective waste management models on a broader scale.

However, it is important to acknowledge that many smaller municipalities face significant challenges in organizing an accurate and systematic data collection process, which can impede effective monitoring and decision-making. In the case of the Cinque Terre, a unified shared system should be designed to address these difficulties, with Riomaggiore taking a leading role in guiding this digitalization process—an essential step toward establishing a smart waste management system appropriate for a smart city context.

Before concluding, we must remind that this preliminary study provides insights on optimizing a collection process that is a subsystem of the whole waste management system of Riomaggiore. Even if, in the previous section we mentioned the possibility of using the transportation system involving the micro eco-islands to other waste, i.e., glasses that has a specific collection process, a more comprehensive study addressing the overall waste management system is necessary for obtaining a sustainable waste management system. The possibility is to extend the optimization model to a multi-product, multi-period transport problem in such a way to define the most effective collection strategy for various types of waste managed within the micro eco-islands.

Finally, a general consideration regarding the potential to improve the collection cost and sustainability thanks to the usage of new technologies, for example by equipping the entire system with sensors would enable a more rational and efficient collection process.

References

1. Bergantino, A.S., Buongiorno, Intini, M.: Turismo e mobilità sostenibile nelle aree naturali protette pugliesi. *Riv. Econ. Polit. Trasp.* (2021)
2. Koliotasi, A.S., Abeliotis, K., Tsartas, P.G.: Understanding the impact of waste management on a destination's image: a stakeholders' perspective. *Tour. Hospit.* **4**(1), 38–50 (2023)
3. Kumar, A.: A novel framework for waste management in smart city transformation with industry 4.0 technologies. *Res. Glob.* **9**, 100234 (2024)
4. Nesmachnow, S., Rossit, D., Moreno-Bernal, P.: A literature review of recent advances on innovative computational tools for waste management in smart cities. *Urban Sci.* **9**(1), 16 (2025). <https://doi.org/10.3390/urbansci9010016>
5. Singh, A.: Solid waste management through the applications of mathematical models. *Resour. Conserv. Recycl.* **151** (2019)
6. Gutierrez-Lopez, J., McGarvey, R.G., Costello, C., Hall, D.M.: Decision support frameworks in solid waste management: a systematic review of multi-criteria decision-making with sustainability and social indicators. *Sustainability* **15** (2023)
7. Gutierrez-Lopez, J., McGarvey, R.G., Noble, J.S., Hall, D.M., Costello, C.: Quantification of social metrics for use in optimization: an application to solid waste management. *J. Clean. Prod.* **480** (2024)
8. Zhang, Y., Wu, L., Xu, H., Wang, Z.: IoT-based smart waste management system: a review and case study. *J. Environ. Manage.* **301**, 113942 (2022). <https://doi.org/10.1016/j.jenvman.2021.113942>
9. Idrissi, A., Benabbou, R., Benhra, J., El Haji, M.: Solid waste management through the application of AI and ICT: a systematic literature review. *J. Environ. Eng. Sci.* (2024)
10. Hashemi-Amiri, O., Mohammadi, M., Rahmanifar, G., Hajiaghahi-Keshteli, M., Fusco, G., Colombaroni, C.: An allocation-routing optimization model for integrated solid waste management. *Expert Syst. Appl.* **227** (2023)
11. Peng, H., An, C., Ng, K.T.W., Hao, J., Tian, X.: Advancing cleaner municipal waste transport through carbon accounting in the cap-and-trade system. *Transp. Res. Part D: Transp. Environ.* **114** (2023)
12. Rahmanifar, G., Mohammadi, M., Sherfat, A., Hajiaghahi-Keshteli, M., Fusco, G., Colombaroni, C.: Heuristic approaches to address the vehicle routing problem in the IoT-based waste management system. *Expert Syst. Appl.* **220** (2023)
13. Caramia, M., Pinto, D.M., Pizzari, E., Stecca, G.: Clustering and routing in waste management: a two-stage optimization approach. *EURO J. Transp. Logist.* **12** (2023)

14. Tizzoni, E.: La stagione turistica nelle Cinque Terre tra anni Cinquanta e Sessanta: Aspetti ambientali, politici, economici e sociali. *Storia Regione* **32**(1), 219–238 (2023)
15. MIC-HUB, Parco Nazionale delle Cinque Terre, Liguria (2023)
16. Parolotto, F.: Parco nazionale delle cinque terre: studio sulla mobilità e ipotesi progettuali. In: *Overtourism? Riflessioni per la tutela del patrimonio nazionale ed un turismo sostenibile*, Rome (2024). <https://www.youtube.com/watch?v=6cTshfNQ-A0>
17. Vegnuti, R.: Cinque Terre, Italy: a case of place branding: from opportunity to problem for tourism. *Worldwide Hospit. Tour. Themes* **12**(4), 471–483 (2020)

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

