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Article

Biofences: A successful system for cleaning waterways in Montevideo, Uruguay

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Abstract: In Montevideo, waterways are used by citizens and by small and medium-sized commercial waste generators (both regulated and unregulated) as sites for the final disposal of solid waste. Additionally, they act as recipients of surface runoff from the basin during rainfall. The improper disposal of waste is considered one of the most underestimated forms of environmental degradation while also having a significant visual impact. To contribute to the development of comprehensive environmental management guidelines for water bodies, the Department of Environmental Engineering at the Institute of Fluid Mechanics and Environmental Engineering (DIA-IMFIA) developed a project in collaboration with the Montevideo City Government (IM). The main objective was to evaluate and propose recommendations to minimize the presence and persistence of solid waste in water bodies. For this purpose, a point in the Chacarita stream in Montevideo was chosen as the study area. A biofence was installed as a retention device to quantify waste, based on the analysis of retention devices successfully implemented in other Latin American countries. Non-returnable plastic beverage containers were reused for the construction of the biofence. The working methodology involved defining the study area together with the IM. Subsequently, in this area, a diagnosis was conducted to assess the current functioning of waste management systems. The installed biofence proved to be an effective system for retaining floating solid waste, capturing approximately 290 kg of waste during the 16 days it was in operation. Based on the results obtained, the DIA-IMFIA team has collaborated with the IM to train its staff in the construction, installation, and operation of bio-barriers. Throughout 2024, the IM has consolidated the implementation of bio-barriers in other water bodies in Montevideo as an institutional line of work.

Keywords: biofences; urban waterways; urban solid waste management; solid waste retention devices; Montevideo

1. Introduction

Historically, human societies have developed in the surroundings of waterways. The relationship between water and urban space has been analyzed from different perspectives by various authors and there has been an increasing use of specific terms to describe their relationship in historical, geographical and environmental aspects. In many cases, there has been uncontrolled developments of cities that have exerted anthropogenic pressure on the environment. This anthropogenic pollution includes the pollution experienced in waterways, both from discharges and from urban solid waste that ends up in waterways [1].

The growing trend towards sustainability and greater environmental awareness have transformed the perception of issues that were not previously considered crucial.

Today, international governments are striving to incorporate sustainability criteria in the formulation of policies, plans and programs. Among the most significant challenges at national and international levels is solid waste management, exacerbated by the increase in single-use products that have proliferated in recent years and have become integrated into many daily activities.

The United Nations (UN) estimates that currently more than 13 million tons of waste end up in our oceans each year, while in 2013 the figure was 6.4 million tons of waste. Plastic accounts for 85% of the waste that reaches the oceans. It is expected that by 2040, the volume of waste reaching the sea will almost triple, with an annual amount of between 23 and 37 million tons. This means around 50 kg of plastic per meter of coastline worldwide [2]. Specifically, in Latin America and the Caribbean, according to the Waste Management Outlook report, launched by UN Environment in 2018 [3], every day in the region, 17,000 tons of plastic waste end up in landfills without any degree of control. After a certain time, the plastic disintegrates into tiny particles that are often ingested by fish and that could eventually reach our food chain.

According to studies carried out between 2015 and 2017 to quantify the amount of global plastic, it was found that almost 90% of the mass of plastic in the comes from the ten most polluting rivers in the world. Based on this, it is argued that approximately 70% to 75% of global water pollution is the result of deficiencies in the management of human activities that take place on the Earth’s surface [4].

Comprehensive and holistic approach frameworks, low-impact techniques and eco-technologies have been available in the last fifty years. They are presented as the most appropriate solution, but they have not been established; there is still a long way to go before they are widely accepted [5]. According to Brown and Farrelly [6], the greatest impediments to moving towards better practices are not technological but social and institutional. The interaction between water resources and formal and informal solid waste management is common in many urban areas, resulting in the presence of waste in bodies of water and causing serious impacts on water ecosystems. This is still true, to the point that the less presence there is in the territory of formal waste management and the less strength there is in the management of water systems, the greater the risk of contamination of bodies of water by the presence of solid waste [7].

Some studies that attempt to model the generation of waste in a population aim to find the parameters that are most sensitive to this variable. Among these studies, [8] confirms a hypothesis about the relationship between the waste generated and socioeconomic aspects of the population and infrastructure available for waste treatment; also, in the study of Fan et al. [9] states that there are several parameters that are effectively linked to the generation of municipal waste. They are the month, precipitation, average temperature, maximum temperature, gross domestic product, population, education of men and women, building size and economic income.

Solid waste management is defined as the comprehensive process that encompasses the control of the generation, storage, collection, transportation, processing and disposal of solid waste, seeking to comply with principles of public health, economy, engineering, conservation and aesthetics, and to respond to public expectations. Since the associated problems, such as waste diversity, dispersed urban development and funding limitations, are complex, it is essential to identify and adjust the key relationships and aspects for effective and orderly management. In solid waste management, a hierarchical strategy must be followed with the following priorities: avoid, minimize, treat and dispose. This implies that, from an environmental perspective, the best option is to prevent waste generation in the first place and the last option should be the final disposal of the waste. A Comprehensive Solid Waste Management Plan is an approach that covers all stages of solid waste management. This plan includes technical, environmental, economic, institutional and legal aspects, with the aim of addressing and solving environmental problems related to urban solid waste. It is developed to mitigate the negative impact of waste on bodies of water and sanitation systems, seeking more effective and sustainable management of waste [10].

In the study carried out by Jambeck et al. [11], improperly managed waste is defined as material that is not disposed of properly, including illegal or open-air landfills. This waste could reach the oceans from the continental water network, wastewater, tidal surges or wind. In this work, it is suggested that most of the countries with the highest generation of solid waste that is not managed properly have a medium socioeconomic level, where economic growth is taking place, but an infrastructure with the capacity to treat plastic waste has not been developed. If infrastructure for the management of this waste is not developed, it is estimated that the amount of plastics that would reach marine ecosystems would grow by an order of magnitude by 2025. It is also suggested that to achieve a 75% reduction in the mass of improperly managed solid waste. Waste management in the 35 countries with the highest generation should be reduced by 85%. A comprehensive approach is then required for its solution, which is not currently present in Montevideo [7].

In relation to the implementation of waste retention methodologies in water bodies, one of the main challenges is that waste accumulation does not occur at a single point [12]. In this context, a survey of methods currently used across Latin America was conducted to identify systems capable of retaining waste through static mechanisms that do not require energy consumption or continuous monitoring and are feasible for installation in Montevideo. This research led to the identification of biofences.

Biofences are an alternative floating barrier (trap) designed to stop larger discarded items carried from the upper watersheds of watercourses to the middle and lower sections. The structure of biofences is not complex; in fact, they are artisan systems that are easy to construct. They consist of rows of bottles arranged in a circular manner, with alternating bottles filled with water or sand and securely sealed in the center to stabilize the barrier (acting as anchors). These rows of bottles are placed in the center of a mesh, which is then secured with a rope. The rows are organized by positioning bottles nozzle-to-nozzle in one row and bottom-to-bottom in the next. The length of the barrier is determined by the width of the river to ensure it can be anchored on both banks. The materials required for construction include PET plastic bottles with caps (e.g., soda bottles, ensuring uniform size), polyethylene mesh 30/45–40 mm/m, nylon rope (5/8 ”, ¾”, and 1”), iron anchors (depending on the watercourse characteristics, particularly the expected flow), and ground anchors (e.g., cables or slings) [13].

Biofences are not high-tech tools, but they are an innovative system introduced in 2016 in Guatemala with the purpose of capturing floating waste in rivers and lagoons. They are now being used in Honduras, Panama, Argentina, the Dominican Republic, and other countries. In 2018, the World Economic Forum recognized biofences as one of the five best environmental innovations in the world. This environmental commitment of Guatemala with its bioswales is part of the Clean Seas campaign (“Clean Seas”) of the United Nations Environment Program (UNEP) that was launched in 2017 at “The Economist World Ocean Summit” in Indonesia. Currently, more than 50 countries have joined this project; 16 of them belong to Latin America and the Caribbean: Argentina, Barbados, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Grenada, Guatemala, Guyana, Honduras, Panama, Peru, Saint Lucia and Uruguay [14].

To contribute to developing comprehensive environmental management guidelines in waterways, the Department of Environmental Engineering of the Institute of Fluid Mechanics and Environmental Engineering (DIA-IMFIA) developed a project with the Municipality of Montevideo (IM), aimed at defining, evaluating and proposing recommendations for minimizing the arrival and permanence of solid waste in bodies of water [7]. The objectives of this research project were as follows:

General Objective:

Contribute to developing comprehensive environmental management guidelines in waterways, based on local data and aligned with the circular economy paradigm.

Specific Objectives:

1) Analyze the applicability of biofences as solid waste retention devices in waterways of Montevideo.

2) Propose daily rates of floating solid waste retained by the biofence during the evaluation period.

3) Define future lines of work to further analyze the results obtained from the implementation of bio-fences.

2. Materials and methods

Within the framework of the project “Solid Waste Management in the Montevideo Water Network, Aimed at its Reduction,” developed by the DIA-IMFIA of the Faculty of Engineering, and funded by the Program “Eng. Oscar J. Maggiolo,” two six-month work stages were proposed.

In the first work stage, the background information related to the topic was identified, considering the basic concepts related to Urban Solid Waste Management, and the current national and departmental regulations. Subsequently, the area of interest for the study was characterized and a first approximation was made to the design and construction elements of waste retention devices in bodies of water currently used. Finally, a bibliographic review was carried out on predictive models of waste in the water network implemented at an international level. Specifically, at this stage, work was done on the characterization of some waterways in Montevideo. With the observations obtained in situ, it was possible to document results that allow a better understanding of the behavior of waste in the water network and to have inputs to develop models that describe the evolution of the variables involved. In the final stage of the project, a biofence was installed in the Chacarita stream.

As a starting point, the study area was selected, delimited together with the municipal counterpart. In this area, a diagnosis of the current situation regarding the functioning of waste management systems was carried out. Aspects related to cultural, historical and socioeconomic patterns were identified, among others. Opportunities for improvement in current systems were identified, as well as the strengths that have allowed the population to have a clearer environmental conception. An evaluation was carried out of different pre-existing predictive models applied to the reality of Montevideo, as well as an evaluation of the efficiency of current solid retention devices in water courses, both in dry weather and in floods, to obtain quantitative data that allows sizing the problem of the presence of waste in water courses. As a result, it was decided, in conjunction with the IM, to construct and operate a 10 m long biofence as a retention device in the Chacarita stream in the city of Montevideo, based on the analysis of barrier alternatives that have already been successfully implemented in other Latin American countries (**Figure 1**). It was the first prototype to be put into operation in Uruguay. For the construction of the biofence, non-returnable plastic bottles were incorporated into a more circular management.

Figure 1. Biofence built and installed in the Chacarita stream.

The micro-watershed to work on the installation and monitoring of waste retention devices is located within the Carrasco Creek watershed, and has as its main channel the Chacarita stream, a tributary of the Manga Creek (**Figure 2**). This stream was chosen due to the large amount of waste deposits; there are areas where not even the watercourse is visible, but rather a path of waste, as can be seen in **Figure 3**, an image taken in May 2022.

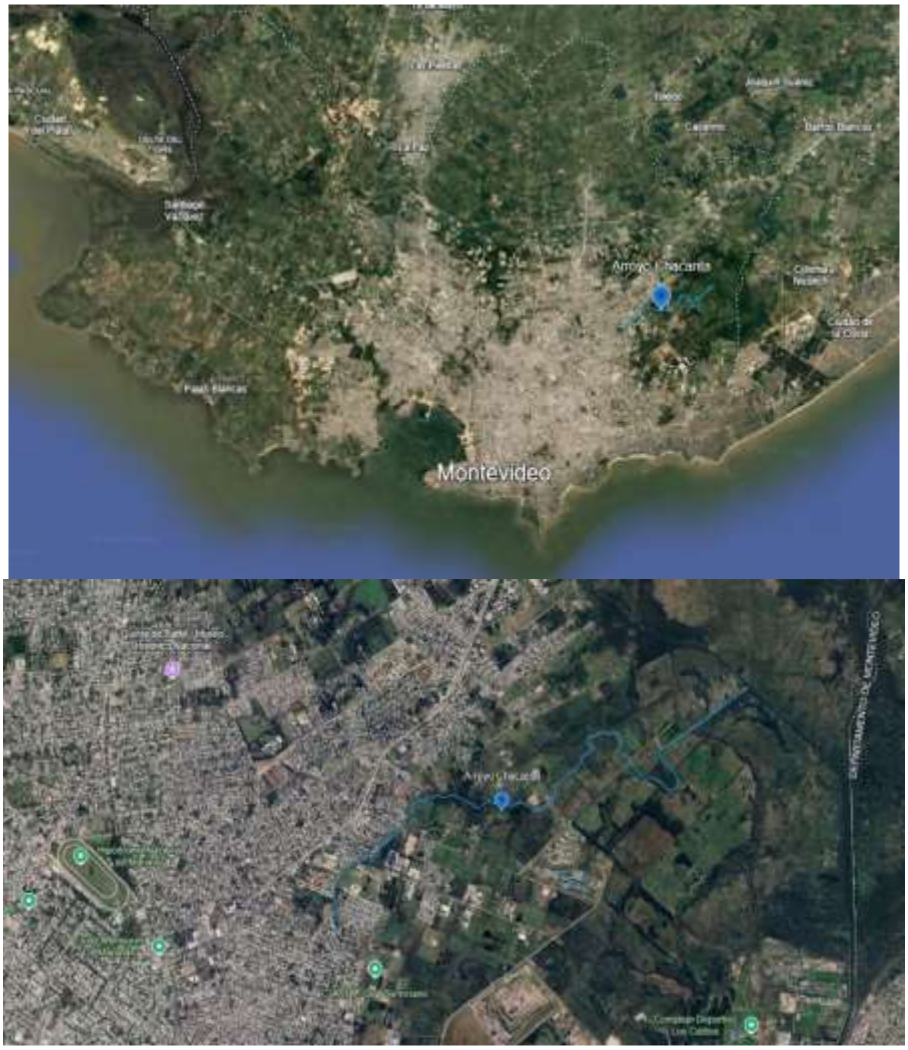

Figure 2. Location of the Chacarita stream in Montevideo.

Figure 3. Chacarita stream, May 2022.

In order to identify the context of the makeshift dwellers in the Chacarita area, a characterization process was carried out based on Hernández [15], which consists of describing the environmental, social and economic features of the micro-watershed; the environmental aspects consider the surface hydrological features, land use coverage and types of climate in the area; the social characterization considers the description of the main population variables such as population growth and unsatisfied basic needs; the economic characterization that involves the identification of the main economic activities in the area.

The micro-watershed is located to the northeast of Montevideo. It is surrounded by the neighborhoods of Chacarita de los Padres, Bella Italia, Bañados de Carrasco, and Punta Rieles. Within this region, several unregulated settlements are located, at the headwaters of the stream and in the Chacarita Stream.

The "Chacarita Watershed" (Montevideo) is a characteristic example of the historical processes of urban peripheral structuring, which now incorporates areas of policy coordination in its current management and raises questions about its future development. The northeast sector of Montevideo is one of the areas with the highest poverty indexes in the city, with the Chacarita Stream being a clear example of an ongoing issue concerning the relationship between cities and waterways. Along its course, different types of "linkage" to the watercourses, both regulated and unregulated, can be identified. The headwaters remained vacant land for decades, but in recent years have been pressured by unregulated housing occupations. The middle course, which crosses through traditional developments from the late 19th and early 20th centuries, was channeled as a stormwater collector. Large undeveloped plots adjacent to the channeled collector gave rise to two types of urban occupation in the second half of the 20th century: social housing complex (Juana de América Cooperative) and settlements located directly on the collector itself (Santa Teresa Settlement, north of the Juana de América cooperative). In its lower course, at the urban-rural interface, the stream remains open with unregulated occupation of its floodplains, resulting in significant impacts from flooding events (Chacarita de los Padres Settlement) [16].

The IM, through Resolutions Nº 4023/14 and 1421/15, established the "Chacharita Stream Watershed Council" as an inter-institutional coordination and control mechanism to articulate feasible actions and projects in the medium and long term, aimed at building an inclusive city that gradually reverses territorial segregation and exclusion, while recognizing the right to the city. In this planning context and in accordance with Article 20 of Law Nº 18.308, the process for developing the Partial Plan for the Chacarita Basin (Resolution Nº 537/18) was initiated, and its Manifestation was approved by the Mayor of Montevideo through Resolution Nº 3581/20. The objective of the "Chacarita Partial Plan" is to create territorial conditions for the comprehensive transformation of the area, help reverse the processes of deterioration in degraded or depressed sectors, promote social cohesion, improve the quality of life of its residents, and enhance the different neighborhood identities as well as the natural and cultural resources. The interventions should foster sustainable development, orienting the processes towards the consolidation of an integrated territory both internally within the area and with other parts of the city through the coordination of various activities developed in the basin, both urban and rural, considering the social, cultural, economic, and environmental factors present in this territory.

In the context of this plan, and looking for recent precedents, it is noted that in July 2020, waste collection and cleaning activities were carried out both inside and outside the stream. Excavators and trucks were used for this purpose. The cleaning tasks were coordinated by the Departmental Coexistence Service and executed by officials from various municipal departments. After cleaning the watercourse, where tons of waste were removed, approximately 400 m of a section of the local sewer network were repaired. During the cleaning of the stream, it was observed that some of the waste originated from nearby industries that were discharging waste. Additionally, vandalized and abandoned vehicles were removed from the stream's banks.

The biofence was located on a private place close to Punta Rieles Avenue (**Figure 4**). The width of the cross section of the streambed from one bank to the other was estimated at 6.0 m. The base of a tree outside the streambed was taken as an altimetric reference; this point was 2.0 m above the water level and the horizontal distance between this point and the point from which the width of the streambed was 3.5 m.

Figure 4. Study point selected for the installation of the Biofence.

The following materials were used to build the biofence: 12 m of nylon netting, approximately 30 m of rope, more than 160 bottles with a volume between 1.5 and 2.5 liters, approximately 75 rivets, two sandbags of 35 kg each one, and at least five 2-meter iron rods. In **Table 1**, an estimate of the costs per meter of biofence and the approximate total cost in dollars of a 10-meter biofence are presented, based on the materials used in this project.

Table 1. Cost estimate per meter of biofence.

Material	Cost per m (US$)	Cost per unit (US$)	Comments
Nylon fishing net	4 per m^2	145	Net of 40 m^2
Sandbag (35 kg)	--	2	--
Iron rod 6 mm	1	3	6 m rods
Nautical rope	1	27	Roll of 30 m
Fishing line	--	6	Roll of 900 m
Rivets	--	1	5 units per m

According to **Table 1**, the cost per meter of biofence is approximately US $6, so the total cost of a 10-meter biofence will be around US $60. It is important to mention that for each meter of the biofence built in this project, less than 1 m^2 of netting is used, so the actual cost may be even lower. According to [17], who compared 40 different waste retention devices implemented in recent years, biofences are classified within the group of 'floating barriers' and are in the 'low cost' category (< US $10,000), being one of the most economical waste retention devices among those currently implemented. Thus, biofences have shown to be not only environmentally effective but also cost-efficient systems for retaining floating solid waste in urban waterways in Montevideo city.

3. Results

The waste problem increases as population density, consumption and urban development do [18]. The factors that catalyze this problem are informal waste management systems, unauthorized classifiers, and the existence of informal waste collection and valorization enterprises on the margins of waterways. In Montevideo this problem is notorious, with the dumping of waste into bodies of water being frequent, both by the population and by economic activities (mainly informal) (**Figure 5**, reproduced from [19]). In addition, there is a lack of awareness that the disposal of household waste is a significant environmental issue. The formal disposal site (for domestic waste) of the Municipality of Montevideo, which is responsible for the collection and proper final disposal of domestic waste generated in the city, is 'Felipe Cardoso' landfill, while the informal disposal system is carried out on private and public properties distributed throughout Montevideo, many of them located on the banks of waterways, or directly on the waterway. The disposal of waste into waterways for the year 2017 was estimated at approximately 38,000 tons [19], of which 90% comes from the contribution of the informal system of collection, classification, and final disposal.

Figure 5. (a) Casavalle stream at Av. Gral. San Martín; **(b)** informal classifier living close to the pantanoso creek.

In Montevideo, improper waste disposal primarily occurs because small and medium-sized commercial generators dump waste at specific locations, often followed by individual waste disposals. Environmental factors affecting these dumps are relevant for analyzing the main waste-generating activities, which always have identifiable parties responsible. It is essential to consider the characteristics of the responsible party, the reason, the location, and the type of waste. Irregular dumping and informal waste classification present complexities that require an interdisciplinary approach, including social and economic aspects. This involves examining processes such as street waste sorting, informal settlements near watercourses, and the interaction between formal and informal waste markets, taking into account the economic, territorial, and political interests involved [19].

The population is often unaware of the impact of waste on ecosystems and particularly on the water network. The only way for waste not to end up in a waterway is for the generators to dump it in formal systems; if it was dumped in dumpsters with lids (single or separate containers), the disposal of waste will be safe. In addition, for waste to be disposed of safely, it must not be removed by informal classifiers, but it often happens. Informal classifiers are incorporated as a parallel system to the formal collection system. They collect, classify and sell materials with economic value, but they also irregularly dispose of the mixed waste without value in the market. These materials end up in the urban hydrological network through stormwater runoff and the informal collection and disposal system. Although the amount of waste that reaches watercourses is small compared to the total waste generated in Montevideo, it is crucial to address this percentage. This waste ends up in sensitive areas of the hydrological network, affecting the functioning of the drainage system and the urban landscape, resulting in significant environmental impacts.

According to OPP [20], "40% of the waste generated is collected by the informal sector." This activity consists of removing waste from storage points before formal collection vehicles pass through the designated points. The informal sector classifies the collected waste into reusable and recyclable waste, generating waste, which is added to unused waste. This waste accounts for approximately 70% of the waste collected informally. Approximately 30% of it, corresponding to 90 t/day, is burned or dumped into waterways. The remaining 70% returns to formal systems. In Montevideo, households generate 1200 tons of garbage per day [21]. Thus, 101 tons per day are dumped into water bodies or incinerated, according to the percentage mentioned above. This result is consistent since it was expected that the tons of waste would increase from 2005 to 2017.

According to Bentos-Pereira [19] in Montevideo there were a total of 6412 informal classifiers in 2018 assuming a linear distribution, the 101 tons generated among the estimated number of classifiers, a total of 15.75 kg of waste was obtained for each classifier that, in the short or medium term, ended up in a waterway or was incinerated.

On the other hand, we have the survey carried out by the work team of the Statistics and Strategic Management Unit of the IM whose main objective was to characterize the population of the classified households, considering some sociodemographic characteristics. The study sample to which a survey was conducted was 1475 households located in unregulated settlements in the city, resulting in 409 of them there is at least one classifier, almost 50% of the household population is in the age range of 15 to 49 years, the average number of people living in an unregulated settlement is 4.5 people and the majority reached an educational level between 1 and 6 years that could be said to correspond to a primary level. It follows from the above that 18% of people living in unregulated settlements are classified as individuals. If this result is extrapolated to the population of the settlements that exist in the vicinity of the ravine, the estimate reached is that 800 people are classifiers

Although at a national level work is being done on a process of formalizing the work of informal sorters (Law 19.829, Integrated Waste Management), the bad practice of dumping waste into bodies of water continues, so it is irrelevant to refer to informal and/or formal sorters. According to OPP [20], "A strong correlation has been found between settlements with a majority population of sorters and the presence of waste in water courses close to these settlements." To delve deeper into the classifiers, who are the main agents that discharge into the water body, it is relevant to take into account their sociodemographic characteristics.

In relation to the implementation of the biofence, it was installed in the waterway on Monday 8 May 2023. Subsequently, visits were made to the site and the device's operation was inspected, by means of photographic records during the fourteen days that the device was installed. **Figure 6** shows the photographic record of some of the biofence's operation moments.

Figure 6. Operation and cleaning the biofence installed in the Chacarita stream, May 2023.

On 11th, 16th, 18th and 23rd May 2023, the device was cleaned, collecting the waste retained by the biofence. The waste was removed and deposited into 85 cm × 105 cm bags to be weighed and subsequently characterized. The results are presented in **Table 2**. It can be stated that the experience of implementing a biofence for the retention of urban solid waste at the study point was successful and the operation of the device was correct. An important issue to mention is that the cleaning, weighing and characterizing of the waste extracted from the body of water were carried out entirely by the staff of researchers from DIA-MFIA. The work team consisted of five people, two of whom were not working on the project. The collaboration of the five researchers was necessary due to the physical effort required to extract all the waste retained by the biofence. The physical effort required and the need for more personnel assigned to this task, turned out to be a determining factor in not prolonging the evaluation period of the biofence's operation and the days of weighing and characterizing waste.

Table 2. Results of quantification of waste retained by the biofence installed in the Chacarita stream, May 2023.

Date	Waste collected (kg) (wet weight)
11 May 2023	43.3
16 May 2023	74.8
18 May 2023	57.5
23 May 2023	116.6
Total	292.2

Approximate values of daily rates of waste retention in the biofence were obtained, but they show a great dispersion. It is necessary to carry out more in-depth and extended campaigns over time to have a larger database to achieve a better estimate of the daily waste retention rates and to be able to develop a calibrated and validated model at the local level.

The installation day of the biofence was Monday, 8th May. Three days passed before the first day of removal and weighing of the waste retained by the fence, which was 43.3 kg, on Thursday, 11 May. The next day of weighing was 5 days later, on 16 May, where 74.8 kg were collected. Then, 2 days later, 57.5 kg were collected. This third sampling, corresponding to 18th May, was very important, because it had shown that the retention behaviour of the biofence does not appear to be linear. This is consistent with what Benítez et al. [22] state about the behaviour of the generation of domestic solid waste depends on many variables whose relationship between them is not so direct. When the daily waste accumulation rate was calculated, great variability was obtained.

Furthermore, it is not only the daily generation at the household level that varies: the waste from informal classifiers confers a rhythm of waste arrival that is not homogeneous: the number of hours spent working and the amount of discarded material depends on multiple variables each day, starting with the amount of money that is required that day to cover the needs of his/her family; hence also the needs may be different depending on, for example, the time of the month. This, without considering the incidence of rain or other meteorological phenomena, which also plays a role in the arrival of waste to urban waterways.

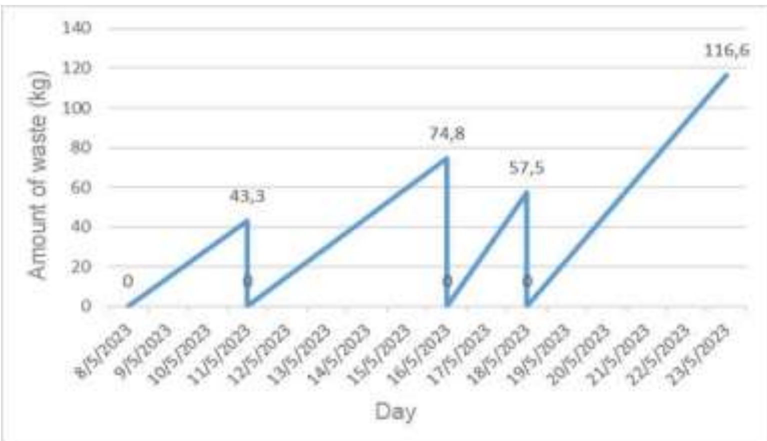

Figure 7. Time evolving of accumulated waste in each sampling period.

The last weighing of waste was done on 23 May, 5 days after the previous weighing. This data also shows that almost three times more waste was collected on that day than the first day, having carried out the two campaigns 5 days after leaving the biofence in initial conditions. The evolution can be seen graphically in **Figure 7**.

Another important aspect to consider is the day of the week on which the four days of cleaning, weighing and classifying of waste retained in the device were carried out. As it can be seen in **Table 3**, the first day was carried out on Thursday 11th of May, obtaining that day the lowest of the weighing data of waste. This data is even lower than that obtained on Thursday of the following week, even though the weighing data of Thursday 11th of May corresponds to four days of waste accumulation, while that of Thursday 18th of May corresponds to three days. Another interesting comparison that can be presented is that of the two data obtained after the weekends. The weighing data obtained on Tuesday 16th of May is lower than that obtained on Tuesday of the following week. A possible explanation for this is that the weighing data for Tuesday 23rd of May corresponded to a holiday weekend.

Table 3. Quantitative and qualitative analysis of the evolution of the amount of waste accumulated in the monitoring weeks.

Date	Day of the week	Waste (kg)	Accumulation rate (kg/day)
8 May 2023	Monday	Installation of bioefence	
11 May 2023	Thursday	43.3	14.4
11 May 2023	Thursday	Waterway cleaning	
16 May 2023	Tuesday	74.8	15.0
16 May 2023	Tuesday	Waterway cleaning	
18 May 2023	Thursday	57.5	28.8
18 May 2023	Thursday	Waterway cleaning	
23 May 2023	Tuesday	116.6	23.3
23 May 2023	Tuesday	Waterway cleaning	

4. Discussion

The installation of the first prototype of biofence in Uruguay led to the analysis of the operation of this device. Based on this, the most relevant aspects are presented, identified from the qualitative analysis of the monitoring of the biofence during the two weeks of operation, and, above all, from the weighing data of the waste retained by this new device.

The experience of implementing a biofence for the retention of urban solid waste at the study site was successful and the device functioned correctly. Also, approximate values of daily rates of waste retention in the biofence were obtained, values that show a great dispersion. Regarding this, during the monitoring and weighing campaigns at the study site, within the framework of this project, data were generated without previous precedents in Uruguay, and it was possible to verify that this type of device, such as the Biofence, is applicable to water courses with characteristics similar to those of the Chacarita ravine, obtaining good results. In addition, it can be said that the quantity and composition of the waste found in the water network is particular to each basin, given that it strongly depends on the particularities of the territory and hydrometeorological conditions. In addition to the above, previous experiences of monitoring waste in water courses present measurements in different units (volume, drained, wet, dry weight) which makes it difficult to compare the results and, often, do not provide all the necessary data on the context to be able to characterize and identify the influence of the context on the quantity of waste found, and the establishment of monitoring methodologies is also relatively recent. It is therefore difficult to extrapolate previous monitoring experiences to the Montevideo basins, each with its own territorial characteristics. At the same time, theoretical estimates of the presence of solid waste must be calibrated for each site. With this, it can be stated that more in-depth and extended campaigns must be carried out overtime to have a larger database and to be able to develop a calibrated and validated model at a local level.

On the other hand, monitoring and maintenance of the Biofence is essential, cleaning the water course and removing waste is essential for its optimal operation. As mentioned above, regular inspection activities were carried out during the execution of the project, ranging from periodic visual inspections of the Biofence, verifying damage, wear or deterioration, verification of the integrity of the anchors, the condition and connection of the bottles and that there is no obstruction by objects or aquatic vegetation and excessive growth of aquatic plants in and around the Biobarda must also be monitored and controlled. Failure to control this can affect the flow and efficiency of the Biofence. It was evident that at least two operators are required for their optimal maintenance. In addition, operators must have complete personal protection equipment. It is also important that operators are trained in relation to the operation of the Biobarda, as well as in appropriate safety practices. Since the watercourse had low water levels, maintenance of the Biobarda meant that the workers had to go into the ravine to extract the waste retained by the Biobarda, mainly using a small boiler (total length 173 cm, pipe thickness 2 cm and diameter 50 cm). Despite having personal protection elements and tools, contact with water is greater and risks associated with direct contact with the waste present in the watercourse may arise [7].

Once the pilot project was completed and based on the results obtained in the project "SOLID WASTE MANAGEMENT IN THE MONTEVIDEO WATER SYSTEM, AIMED AT ITS REDUCTION", the Municipality of Montevideo decided to implement bio-fences at an institutional level as solid waste retention devices in the Montevideo water system. To this end, the construction, installation, monitoring and maintenance of bio-fences was incorporated into the Liberated Areas Program. On the other hand, work is being done on the design and implementation of other types of devices such as Bubble Barriers, which will allow for comparisons of the performances between the different devices, and to have more data such as those generated in the Chacarita stream, which are of great importance since they have no precedents in Uruguay and are inputs for the development of new models and comparison with other models applied internationally.

The Municipality of Montevideo understands that to ensure the optimal functioning of the bio-fence project, it is essential to address several dimensions. Among them, the need to remove the waste accumulated in the bio-fences well in advance of the arrival of rains, to avoid the loss of the materials retained by the barrier, stands out. In addition, it is important to carry out a detailed analysis of the characteristics of the water courses, especially in terms of depth and variability, to effectively adapt the bio-barriers to local conditions. In relation to the bio-barriers currently installed, within the framework of the Liberated Areas Program, the IM work team has reported that the reduction of the points with installed bio-barriers is strongly related to vandalism (6 bio-barriers), the theft of the rope that holds the bio-fence and the mesh that forms it has been common. The second cause of loss is extreme flooding events (2 bio-fences), in the rain that occurred in the first half of this year some equipment was lost.

Regarding the efficiency of the points that are currently equipped with biofences, there are two points where their efficiency is not considered adequate, the remaining six points have a good collection of waste. Since October 2023, approximately 10 tons of waste have been removed from these points. The efficiency of the bio-fences must be measured in relation to their retention capacity, but also as an element of work on environmental issues with the residents of Montevideo. Various instances of collective construction of bio-fences have been carried out with schools, environmental volunteers, companies and residents in general.

One of the main limitations in the operation of bio-fences is related to the removal of retained waste, since it involves the entry of operators into the waterway and collecting waste along it. This project seeks to evaluate different devices that facilitate the extraction of retained waste. It is proposed to analyze the design, construction and installation of new pre-existing technologies for the retention of urban solid waste in the waterways of Montevideo, considering the advantages, but also the difficulties associated with the implementation of the Bio-fence. This, to evaluate the applicability of these new technologies in the waterways of Montevideo and propose guidelines that allow, based on the characteristics of each waterway, to define which of the implemented and analysed technologies is the most pertinent.

5. Conclusions

Between 2022 and 2023, the work team from the DIA-IMFIA of the Faculty of Engineering, University of the Republic, carried out the project "SOLID WASTE MANAGEMENT IN THE MONTEVIDEO WATER NETWORK, AIMED AT ITS REDUCTION." This project, funded by the 2021 IM-Udelar "Eng. Oscar Maggiolo" Program, focused on the collection and characterization of waste in Montevideo's waterways. The development of this project was influenced by a prolonged drought that began in the last quarter of 2022, which impacted the selection of installation points and the duration of the deployment and monitoring campaigns for the devices.

As a first conclusion, it can be stated that the main problem of waste in the water network of Montevideo is not related to floods, but it is permanent. This can be affirmed because, in 2023, Uruguay found itself in a major water crisis, with many months without rainfall; these weighing campaigns were carried out in months of extreme drought.

The biofence is an environmental initiative that has been used in several countries in Central and South America. However, in Uruguay it was the first prototype put into operation. Given its efficiency and good results, it has been considered beneficial to implement more of these devices in other waterways in Montevideo, with characteristics similar to those of this study. In fact, the work team of the Office of Integrated Management of Bodies of Water of the IM led the process of institutionalizing the implementation of biofences in some bodies of water in Montevideo. As a first activity, the IM work team together with the researchers of DIA-IMFIA, led the training process for participants of the IM Solidarity Days Program, for the construction, installation and maintenance of 40 biofences in watersheds of Las Piedras, Pantanoso, Miguelete and Carrasco streams and del Oeste creek. In addition to the IM and DIA-IMFIA teams, young people from the neighbourhoods and the Scouts Movement of Uruguay also participated.

The experience of implementing a biofence for retaining urban solid waste at the study point was successful and the operation of the device exceeded the expectations of the work team. In addition, approximate values of daily rates of waste retention in the biofence were obtained. The values are very few, thus, they present a great dispersion. Being able to carry out similar campaigns, prolonged over time, performing tests with other similar devices would allow generating a greater quantity and quality of data to feed a model to be developed exclusively for Montevideo or for Uruguay, complying with the characteristics of the waterways of our country. A significant amount of data would also allow for calibration and validation, creating a tool to evaluate this type of problem.

On the other hand, the monitoring and maintenance of the biofence is essential; the cleaning of the water course and the removal of waste is the key for its proper operation. During the execution of the project, regular inspection activities were developed, ranging from periodic visual inspections of the biofence, verifying damage, wear and tear or deterioration, verification of the integrity of the anchors, the condition and connection of the bottles and that there is no obstruction by objects or aquatic vegetation. Excessive growth of aquatic plants in and around the biofence must also be monitored and controlled. Failure to control can affect the flow and efficiency of the biofence.

At least two persons are required for optimal maintenance. In addition, these operators must have complete personal protective equipment. It is also important that handlers are trained in the operation of the biofence, as well as in appropriate safety practices. Since the watercourse had low depths, biofence maintenance required handlers to enter the stream to extract the waste retained by the biofence, mainly using a small tank (total length 173 cm, pipe thickness 2 cm, diameter 50 cm). Despite having personal protection elements and tools, risks associated with direct contact with water and waste may occur.

It should be noted that the data collected in the weighing and characterization campaigns of waste retained in the Chacarita stream are unprecedented in Uruguay. This information gives rise to the continued development of initiatives such as this one in which monitoring of contraption of this nature is carried out. It was possible to demonstrate that this type of contraption can be developed and installed easily, obtaining very good results.

However, as previously mentioned, these solutions are not sufficient to reduce the generation of waste, where a high percentage ends up in this type of bodies of water. Having these trash collectors correctly does not guarantee the preservation of waterways in our country; much more in-depth work is required with the population, with emphasis on the development, improvement and analysis of urban solid waste management systems.

In summary, the installation of the biofence as a contraption for retaining urban solid waste in an urban waterway has shown good results. It is a cost-efficient solution, but it is not easy to maintain.

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