



## Developing a Plastic Waste Management Program: From River Basins to Urban Beaches (Case Study)

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### Highlights:

- Preventive planning enhances plastic waste management.
- All water environments must be considered.
- Coastal areas must share experiences.

**Abstract.** Solid waste accumulation in coastal environments has been a growing concern. In the coastal megacity of Recife, Pernambuco state, Brazil, plastic waste issues currently exist both at the ocean scale and river basin scale. The city is known as the ‘Brazilian Venice’ thanks to the Capibaribe River, which crosses many neighborhoods, running in a west-east direction into the Atlantic Ocean. This paper provides the initial basis to develop a Plastic Waste Management Program proposal for implementation in the city of Recife, given the lack of resolutions that have looked at plastic waste management through integrated water environment scales (from river basin to ocean). The methodology used included articulation and documental collection from four main public agencies from the state/city and stakeholders. The results showed its relevance for better plastic waste management in Recife, considering an integrated water environment on a river basin-to-ocean scale by using the recognized major connected water environments (Capibaribe river and Boa Viagem beach). Similar integrated program proposals could be made for other coastal areas, enabling not only the identification of fragilities but also the exchange of information regarding the theme.

**Keywords:** *Boa Viagem beach; Capibaribe river; coastal environments; environmental policy; plastic waste; Recife city; SDGs; solid waste management.*

## 1 Introduction

Researchers around the globe are constantly exploring sustainable alternatives and solutions to the current worldwide situation of environmental degradation caused by solid waste. In the context of plastic waste, industrial development has contributed significantly to the diffusion of sources of pollution, and the properties of plastic itself, such as longevity, toxicity, and propensity to disintegrate into microplastics adding more complexity to the management processes [1]. In aquatic environments, concerns regarding plastics management are being even more debated, especially at the ocean scale, where marine species are dying every day. However, there are still few studies that analyze the problem using an integrated approach, considering all the water environment scales (from river basin to ocean scale). Microplastics exported by rivers are the result of poorly managed plastic waste and fragmentation [2]. According to [3], although the exchange of plastic waste between rivers and ocean is, on average, considered low, it can fluctuate greatly depending on local factors, reinforcing the importance of considering peculiarities correlated to cultural and climate factors. In this sense, context-appropriate evaluations are needed to provide proper planning and solutions under different realities.

In Brazil, this issue has led to several concerns, having in view the country's large coastal area and the diversity of its water environments. The relationships maintained by stakeholders with water related policies in Brazil have become an important task since 1997 when the National Water Resources Policy was established through Law No. 9433 [4]. Regarding solid waste management, regulations are grounded in sanitation federal law 11445 of 2007, which provides the guidelines for sanitation services: water supply, sewage collection and treatment, rainwater drainage systems, urban cleaning, and solid waste management. Water resources management is under the responsibility of the states, whilst sanitation policy is a responsibility of both state and municipality. In the sanitation sphere, although there are policies for an established municipal consortium for waste management, in practice these are limited to urban areas. This generates management conflicts concerning solid waste pollution, problems which do not obey geopolitical boundaries, going beyond rural and urban scales, including the dynamic flow of the river basins.

In Pernambuco State (Northeast Brazil), water resources management is based on State Law No. 12984 of 2005 [5], which created a State Water Resources Policy and the Integrated Water Resources Management System [6]. Even with major advances in water policies and regulations, however, none of the above laws or regulations included orientation or articulation of solid waste management together with water management.

The global campaign *Clean Seas*, promoted by the United Nations Environment – UN Environment, was instituted in Brazil in September 2017 intending to reduce plastic disposal in the ocean through public and private policy implementation to reverse the current situation of pollution in water bodies [7,8]. With specific regard to freshwater, the worldwide scenario is dramatic. On a global scale, it is estimated that rivers carry between 1.15 and 2.41 million tons of plastic waste to the sea [9,10]. It was in this context that in 2018, the *Clean Rivers for Clean Seas* initiative, also promoted by the UN Environment in Brazil, was launched, having among its objectives the engagement of civil society, public authorities and private initiative to reduce the volume of plastic litter transported by the Amazon river. The largest river in the world measured by water discharge promotes an inflow of about 38,900 tons of plastic a year into the ocean, making it one of the 20 major polluting rivers in the world [9].

The abovementioned initiative is part of the National Plan for Combating Garbage at Sea (*PNCLM*), which also foresees another 29 short, medium and long-term actions. The Plan is part of the National Agenda for Urban Environmental Quality and it is the most recent national strategy to combat plastic pollution. Almost 300 Brazilian coastal municipalities are currently associated with the *PNCLM*, but only 153 (55.8%) have fulfilled their obligations for preparing their municipal plan for integrated solid waste management [11]. This reflects the fragilities on implementing Public Policies in the country, having in view that the National Policy on Solid Waste (*PNRS*), established by Law No. 12305 of 2010, foresees the design of such plans [12].

Concerning Pernambuco, the State has a total coastal zone extension of 187 km, with 4,410 km<sup>2</sup> of superficial area divided into three sectors: north, metropolitan and south. In this extensive area, the beaches are a strongly vulnerable environment due to the accumulation of waste arriving from innumerable sources. Garbage does not obey city boundaries, spreading indiscriminately and reaching even unlikely locations [13]. To combat this, in the state capital, Recife, the Boa Viagem urban beach, an important tourist center, has been the target of intense campaigns related to litter pollution management in the last decade. Although Recife has a Metropolitan Solid Waste Plan (*PMRS*), the city does not have any specific action for dealing with garbage at sea, as suggested in the *PNCLM*, to reduce the problems at the level of rivers and estuary areas. Pernambuco's capital is interlaced by rivers and channels, forming fluvial islands. Recife is also known as the Brazilian Venice, especially thanks to the Capibaribe river, which crosses many neighborhoods in the city, running in west-east direction to the Atlantic Ocean [14]. Despite its importance as a connecting element throughout the city, the river faces serious degradation problems and it is one of the most polluted in the country. On the other hand, Boa Viagem Beach,

which became famous because of shark attacks, has been named as one of Brazil's cleanest urban beaches.

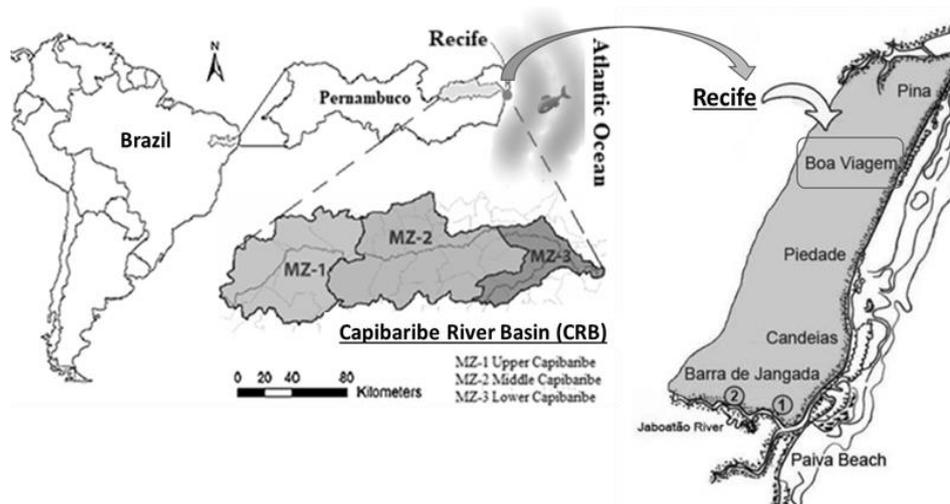
Given these facts, our study used Recife as a case study to develop a proposal for a plastic waste management program to be implemented in the city, as there is a lack of a specific and integrated policy that considers plastic waste management in water. For this purpose, the Capibaribe river and Boa Viagem beach were used as elements for analysis, articulated with representative public agencies from the state/city and stakeholders. The case study choices were based on the relevance and recognition of both the Capibaribe River and the Boa Viagem beach as major symbols of Recife's aquatic environments, especially considering their roles in both the cityscape and global tourism.

## **2 Materials and Methods**

### **2.1 Study Area and Context of Region**

Created by complementary Law No. 14/1973, and composed of 14 municipalities, the Recife Metropolitan Region (RMR) has an area of 2774 km<sup>2</sup>, with the most populated cities being Recife, Jaboatão, Olinda and Paulista [15,16]. The coastal megacity of Recife (1.5 million inhabitants [15]) is famous for its beautiful landscapes and traditional festivities, such as Carnival, a huge tourist attraction. The Brazilian Venice has been facing great pressure to improve the resilience of the city to environmental problems. Climate change reports have alerted about the hazards in coastal areas and island nations with respect to the rise in sea levels in the coming decades [17]. The characteristics of being a sea-level city, the flat topography, with mangrove and floodplain landfills, poor macro and micro drainage networks, and poor maintenance and operation have aggravated these scenarios [18].

Scuba diving tourism is intense since Recife is considered the Brazilian shipwreck capital. On the continental shelf that crosses the beaches in the regional municipality of Recife, there are more than 70 sunken vessels, among them 9 purposely wrecked for underwater tourism and scientific research [19]. Many of these shipwrecks are located close to Boa Viagem beach, the major urban beach of the State. Boa Viagem has an important environmental educational program coordinated by city hall, called '*Praia Limpa*' which means 'Clean Beach'. Despite this, the beach is also famous for severe environmental problems, such as shark attacks and contamination by plastic fragments and pellets [20-23]. Also known for its impact in Recife's landscapes, the Capibaribe River is now one of the most polluted in the country, with some stretches taken over by plastic trash. Figure 1 shows the study area.



**Figure 1** Case study location (adapted from [6,20]).

The Capibaribe river basin can be divided into three macro zones: MZ-1, MZ-2, and MZ-3, identified as upper, middle and lower Capibaribe respectively. The upper and middle regions suffer from water deficit. At the lower area, at Recife, there is a positive water balance, only needing proper water resources management regarding the aquifer's area recharges, pollution control and demand orientation [24,25]. The basin extends for about 280 km from the source to the river's mouth in Recife.

## 2.2 Plastic Waste Management Program Proposal Methodology

This research was developed through the integration and data collection from four main public agencies from the state/city and stakeholders: Infrastructure Secretariat (*SEINFRA*); Pernambuco State Water and Climate Agency (*APAC*); Water Resources Secretariat (*SRH*) and the Maintenance and Urban Cleaning Company (*EMLURB*). Five documents were used for analysis and articulation: a) State Water Resources Plan; b) State Solid Waste Plan; c) Capibaribe River Basin Hydro-environmental Master Plan; d) Metropolitan Solid Waste Program of Recife and e) Urban Drainage Master Plan of Recife.

To provide a basis for a management program proposal, the main fragilities, gaps, and potentials for integration of regulatory devices were identified in order to construct a compiled model that includes adequate plastic waste management, from macro to micro drainage. The documental analysis, together with the information collected from stakeholders, made it possible to identify target points that need to be considered in a final plastic waste management program. These target points represent key themes for action by the public authorities so that

arising issues can be properly explored and worked out in detail in a final plastic waste management program document.

The target points were categorized into three thematic axes/dimensions. For each thematic axis, its respective target points were defined and the main management leader (agency) responsible for coordination, evaluation and validation of the program proposal draft was identified. Although this only represents the first stage of the proposed program, this categorization provides an important initial basis to support action plan strategies that must be incorporated into a final management program. An accurate identification of target points leads to lower chances of leaving something out when concerning essential issues that must be addressed to achieve the program purposes.

### **3 Results and Discussion**

#### **3.1 Critical Analysis of the Data**

The first step consisted of identifying the fragilities, gaps, and potentials of integration of the regulatory devices. A brief explanation regarding the regulations analyzed is given below:

1. State Water Resources Plan: published in 1998, it has made a remarkable contribution to the State's technical assets in water planning. Despite the legal provision that indicates the need for biennial revisions, the document has not been updated since its publication. The state plan did not have the participation of civil society, but its detailed diagnosis enabled its consolidation as a reference for professionals working in the area [26,27].
2. State Solid Waste Plan (*PERS*): guides solid waste management at the state level and encompasses the various waste classes in response to the National Solid Waste Policy. It contains strategies for meeting established goals that correspond to the guidelines, which are composed of programs, projects, and actions and have specific monitoring and evaluation methods [28].
3. Capibaribe River Basin Hydro-environmental Master Plan: published in 2010, this plan was based on the Capibaribe River Basin Water Resources Master Plan (*PDRH*), completed in 2002, regarding the State Water Resources Utilization Plan, prepared in 2005, as well as other state and federal plans related to the theme. The elaboration process included critical participation of a river basin committee technical board, which contributed suggestions and content evaluations at several formulation stages [6,25].
4. Metropolitan Solid Waste Program of Recife: this program concerns the solid waste management on the RMR scale, based on a situational diagnosis. It follows the same composition as the federal and state plans, defining guidelines and strategies for meeting *PNRS* goals and assumptions [29].

5. Urban Drainage Master Plan of Recife: concluded in 2016 by Recife's city hall, it brings unprecedented guidelines to improve flood-prone area conditions among other management instruments. The plan also includes the drainage of eight relevant river basins that cross the city: Beberibe, Camaragibe, Capibaribe, Jaboatão, Jiquiá, Jordão, Moxotó and Tejipió [30]. Table 1 shows a synthesis of the documental evaluations. Together with the regulation analysis, also investigated were existing civil society programs/projects in the RMR responsible for promoting action designated to improve water environment conditions by clean-up campaigns. Table 2 shows some of the initiatives explored by this research.

**Table 1** Regulatory devices' gaps and fragilities related to integrated plastic waste management.

<b>State Water Resources Plan (Pernambuco, 1998)</b>	
<b>Gaps</b>	<b>Fragilities</b>
The theme is not addressed in the State Plan. An important fact is that the document was published in 1998 without having been updated, so that this theme has not been explored yet.	Absence of revisions/updates (plastic waste issues are 'recent' compared to the plan's time of publication).
<b>Capibaribe River Basin Hydro-environmental Master Plan (Pernambuco, 2010)</b>	
<b>Gaps</b>	<b>Fragilities</b>
In Document 1 (Diagnosis) there is no diagnosis regarding plastic or microplastic waste pollution in the river. Absence of a plastic waste roadmap.	In Document 3 (Investment Plans) no actions are planned regarding preventive action or plastic waste monitoring along the river, especially related to water infrastructure.
<b>Solid Waste State Plan (Pernambuco, 2012)</b>	
<b>Gaps</b>	<b>Fragilities</b>
Diagnosis does not include the situation of coastal and river scale waste. In item 1.3.3. lack of microplastic residues description from industrial processes, such as pellets. In Guidelines and Strategies, item 4.1 of Solid Urban Waste, absence of proposal to combat pollution by plastic waste in water bodies in order to prioritize areas near rivers and seas, such as river banks, mangroves and beaches. Absence of guidelines for reduction and supervision of solid waste generation in line with tourism and entertainment activities in Pernambuco.	No goals incorporation neither indicators that encompass the plastic pollution theme in water bodies, as well as prioritization of the river scale. Regarding reverse logistics, the issues with plastic packaging are not mentioned. The strategy adopted that deals with the incentives for solid waste management projects, within the scope of funding promoted by the State Environmental Fund ( <i>FEMA</i> ), does not mention those related to social mobilization for cleaning coastal areas or rivers and mangroves, including specific environmental education actions aimed at combating waste pollution at these sites. In the guideline of society's access to public cleaning services, Strategy II does not prioritize riverbank, mangrove and beach areas.

**Table 1 Continued.** Regulatory devices' gaps and fragilities related to integrated plastic waste management.

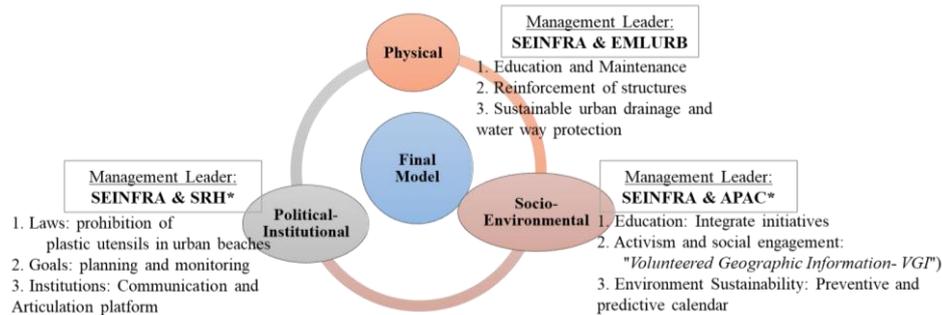
<b>Metropolitan Solid Waste Program of Recife (Recife, 2018)</b>	
<b>Gaps</b>	<b>Fragilities</b>
In the Situational Diagnosis and Prognosis, there is no information about plastic pollution in river and coastal areas. The strategic guidelines do not address solid waste management within the scope of plastic pollution in areas such as riverbanks, mangroves and beaches. Absence of guidelines aimed at eliminating commercialization and offering free use of disposables in commercial establishments.	Prioritize selective collection in areas of greater social and environmental vulnerability to plastic pollution, such as riverbanks, mangroves and beaches. The Sustainable Consumption Promotion Project does not mention mechanisms to reduce disposable waste generation (straws, glasses, cutlery). The Environmental Education Program does not prioritize regions of social and environmental vulnerability to plastic pollution, such as riverbanks, mangroves and streams.
<b>Urban Drainage Master Plan of Recife (Recife, 2016)</b>	
<b>Gaps</b>	<b>Fragilities</b>
In Chapter 5 (Maintenance and Recovery of System Units) of the Drainage Manual no structural measures are mentioned, such as the placement of structures at the gutter entrance or installed inside drainage channels to separate and contain coarse pollutants. The Drainage Manual only mentions corrective and preventive maintenance, no predictive maintenance.	Item 5.1 of the Drainage Manual defines three types of maintenance (corrective, preventive and predictive), but the ideal would be to separate by type of maintenance technique used, if this did not occur.

**Table 2** Civil society initiatives related to combating plastic pollution in RMR.

<b>Initiatives (Programs/Projects)</b>	<b>Main Activities</b>
Recife Without Trash/Green Girl Group	Initiatives aimed at raising awareness on plastic uses and which through social networks disseminate data about the problem of plastic pollution in Recife and worldwide. They run clean-up efforts and awareness campaigns, as well as offer sustainable solutions to replace the use of plastic in everyday life.
Plastic Away and Pernambuco Without Trash movement/Recife Youth Environmental Collective	Clean-up campaigns and joint efforts on beaches and mangroves, allied with awareness-raising strategies that include an ecological trail through areas threatened by plastic pollution, as well as the preparation and dissemination of protest posters.
Ocean Education Project	Extension Project of the Oceanography Course – Federal Rural University of Pernambuco (UFRPE), which aims to promote environmental education focused on plastic pollution in the ocean. It conducts cleaning actions and workshops aimed at preserving the ocean and coastal ecosystems, plus didactic and itinerant exhibitions aiming to promote the appreciation of these areas.
Sustainable Chat and My Greener World	Provide information and social-environmental tips, including awareness about the disposal of solid waste. Promoting engagement in favor of environmental protection and solid waste collection actions in coastal and mangrove areas.

## 1.1 Target Point Identification and Categorization

Figure 2 shows the main result of the documental analysis, which together with information from the stakeholders allowed us to identify three target points for each thematic dimension considered. In the section about the political-institutional and socio-environmental dimensions, the need for articulation with state/city agencies is highlighted.



**Figure 2** Identified target points.

Nine target points were identified and categorized into three dimensions with attention to unique characteristics and issues of coastal areas, as the multipurpose nature of coastal activities requires specific consideration. Early coastal area planning and management programs were generally in response to urgent problems. However, the approaches have evolved into more collaborative coastal management, which attempts to address present-day problems whilst preventing new ones [31]. From this perspective, the target points are grounded in this collaborative approach, which aims to deal with the current reality and focuses on prevention mechanisms. In developing countries, prevention policies are probably the only viable option to reduce river export of microplastics to coastal areas [2]. Hence, the following considerations to put the target points into practice were made:

1. Physical dimension – The maintenance schedule of the current macro and micro drainage infrastructures must be carried out along with educational incentives to stimulate people's awareness regarding irregular litter disposal. Proper educational measures for riparian families on the Capibaribe river and among vendors on Boa Viagem beach that teach them how to manage their solid waste based on sanitary values. Structure reinforcement is mandatory, which includes not only drainage infrastructure but also the insertion of new eco stations to collect recycle waste. Preventing solid waste retention from micro drainage will result in decreased frequency of inspections and cleaning of drainage devices (for gutters there is a fixed 180-day period to check for obstructions). Water way protection comprises awareness signposts/artistic

monuments along river and beach stretches and landscape projects, such as the project ‘Windows for the River’ and river gardens, encouraging ecosystem preservation.

2. Socio-environmental dimension – It is essential to raise awareness regarding environmental resources. Civil society initiatives, mostly by young people, perform waste cleaning actions on beaches and riverfront areas in Recife, using social media networks as a tool not only to disseminate the work developed but also to provide quantitative registration and typology information of collected waste. Still, there is a disarticulation among these initiatives and the public agencies. Solving this fragility requires proactivity from the agencies to properly register all existing initiatives and integrate them into planning processes.
3. Political-institutional dimension – Planning that does not consider preventive measures can lead to negative effects and destroy natural and quasi-natural structures, especially in the urban development field [32]. The relevant legislation and regulatory devices of RMR are not enough to ensure environmental protection of water bodies against plastic pollution. There are public management projects such as ‘*Praia Limpa, Praia Viva*’ (Clean Beach, Living Beach), based on environmental education on the Recife beaches, and the *Ecobarco* (Eco Boat), which aims to collect floating waste in Capibaribe river stretches. Both projects have been developed by *EMLURB*, which also provides paper bags for garbage collection on the Boa Viagem beach. However, discussions about new laws on disposable bans are still in the early stages and an interinstitutional articulation platform to improve planning is also an urgent need, as the region faces challenges in monitoring and implementing the goals foreseen in the regulatory devices [33].

#### 4 Conclusion

Lack of global standardization related to plastic and microplastic waste problematizes the consolidation of a specific regulatory framework for managing plastic waste in aquatic environments in Brazil. At the state and city levels, this dimension must not only consider local peculiarities but also be aware of national and international standardization advances as well as developments in regulations. The present paper provides the basis for a plastic waste management proposal to be implemented in the city of Recife. This consists of the first proposal stages of: (1) identifying the fragilities, gaps, and potentials of integration of the existing regulatory devices, and (2) identifying and categorizing the target points.

The target point identification allows the design of a final layout scheme of a plastic waste management program proposal that consists of three detailed steps

that will lead to the final program document: 1) planning meetings and task division; 2) workgroups: developing goal plans for each dimension and respective associated target points; 3) presenting content, validating, publicizing and implementing the program. The existence and devising of planning documents, such as a program proposal, represent an encouraging element that may attract investors to consolidate strategic action for environmental cleanup in Recife.

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### References

- [1] Dauvergne, P., *Why is the Global Governance of Plastic Failing the Oceans?* Global Environmental Change, **51**, pp. 22-31, 2018. DOI: 10.1016/j.gloenvcha.2018.05.002.
- [2] Van Wijnen, J., Ragas, A.M.J., & Kroeze, C., *Modelling Global River Export of Microplastics to the Marine Environment: Sources and Future Trends*, Science of the Total Environment, **673**, pp. 392-401, 2019. DOI: 10.1016/j.scitotenv.2019.04.078.
- [3] Schwarz, A.E., Ligthart, T.N., Boukris, E., & van Harmelen, T., *Sources, Transport, and Accumulation of Different Types of Plastic Litter in Aquatic Environments: A Review Study*, Marine Pollution Bulletin, **143**(March), pp. 92-100, 2019, DOI: 10.1016/j.marpolbul.2019.04.029.
- [4] Brazil, *Law No. 9.433/1997: Established the National Water Resources Policy*, Brasília, DF, Jan. 1997.
- [5] Pernambuco, *Law No. 12.984/2005: Establishes the State Water Resources Policy and the Integrated Water Resources Management System and Makes Other Arrangements*, Recife, Dec. 2005.
- [6] Moura, M.R.F., Montenegro, S.M.G.L., Ribeiro Neto, A., & Silva, S.R., *Challenges of Watershed Hydro-environmental Master Plans (Case Study)*, in *Water perspectives in Emerging Countries- Linking Water Security to Sustainable Development Goals*, 1ed.Göttingen: Cuvillier Verlag, **1**, pp. 40-53, 2018.
- [7] United Nations Environment Programme-UNEP, *Brazilian Government Signs Up to UN Clean Seas Campaign*, 2017, accessed from <https://www.cleaneas.org/impact/brazilian-government-signs-un-clean-seas-campaign>. (1 March 2019)
- [8] INPE - National Institute for Space Research, *ONU Clean Rivers for Clean Seas*, 2018, <http://www.ccst.inpe.br/onu-meio-ambiente-lanca-iniciativas-rios-limpos-para-mares-limpos/>, ( 1 March 2019).

- [9] Lebreton, L.C., Van der Zwet, J., Damsteeg, J.W., Slat, B., Andrady, A., & Reisser, J., *River Plastic Emissions to the World's Oceans*, Nature Communications, **8** (15611), pp. 1-10, 2017.
- [10] Lechner, A., Keckeis, H., Lumesberger-Loisl, F., Zens, B., Krusch, R., Tritthart, M., ... & Schludermann, E., *The Danube So Colourful: A Potpourri of Plastic Litter Outnumbers Fish Larvae in Europe's Second-largest River*, Environmental Pollution, 188, pp. 177-181, 2014. DOI: 10.1016/j.envpol.2014.02.006
- [11] Brasil, *Plan for Combating Waste at Sea*, Ministry of the Environment, National Agenda for Urban Environmental Quality, 41 p, 2019.
- [12] Brasil, *Law No. 12305/2010*, Institutes the National Solid Waste Policy, Brasília, DF, Aug. 2010.
- [13] Araújo, M.C.B., *Solid Waste in Beaches of the Southern Coast of Pernambuco: Origins and Consequences*, Dissertation (Masters), Technology and Geoscience C., Federal University of Pernambuco, Brazil, 2003.
- [14] Ribeiro Neto, A., Scott, C.A., Lima, E.A., Montenegro, S.M.G.L., & Cirilo, J.A., *Infrastructure sufficiency in meeting water demand under climate-induced socio hydrological transition in the urbanizing Capibaribe River basin- Brazil*, Hydrology and Earth System Sciences, **18**, pp. 3449-3459, 2014.
- [15] IBGE: Brazilian Institute of Geography and Statistics, *Brazil Demographic Census*, Rio de Janeiro, 2010.
- [16] IPEA: Institute of Applied Economic Research, *Atlas of Social Vulnerability in Brazilian Metropolitan Regions*, Brasília, DF, 2015.
- [17] WORLD BANK, *World Development Report: Development and Climate Change*, Washington, World Bank, 2010.
- [18] Alcântara, E., Cavalcanti, E., & Cabral, J., *Resilience and Adaptive Capacity for Sustainability in Cities Like Recife*, e-metropolis: Revista eletrônica de Estudos Urbanos e Regionais, **18**, pp. 36-47, 2014.
- [19] Galamba, J., *Standards Procedures for Managing Sustainable Diving Based on Environmental Education*, Dissertation (Masters), Master in Environmental Management and Policy, Federal University of Pernambuco, Brazil, 2009.
- [20] Hazin, F.H.V., Burgess, G.H. & Carvalho, F.C., *A Shark Attack Outbreak of Recife, Pernambuco, Brazil: 1992-2006*, Bulletin of Marine Science, **82**, pp. 199-212, 2008.
- [21] Costa, M.F., Ivar do Sul, J.A., Silva-Cavalcanti, J.S., Araújo, M.C.B., Spengler, A. & Tourinho, P.S., *On the Importance of Size of Plastic Fragments and Pellets on the Strandline: A Snapshot of a Brazilian Beach*, Environ. Monit. Assess., **168**, pp. 299-304, 2010.

- [22] Bornatowski, H., Braga, R.R., & Vitule, J.R.S., *Threats to Sharks in a Developing Country: The Need for Effective and Simple Conservation Measures*, *Natureza e Conservação*, **12**, pp. 11-18, 2014. DOI: 10.4322/natcon.2014.003.
- [23] Castro, R.O., Silva, M. L., & Araújo, F.V., *Review on Microplastic Studies in Brazilian Aquatic Ecosystems*, *Ocean and Coastal Management*, **165**, pp. 385- 400, 2018. DOI: 10.1016/j.ocecoaman.2018.09.013.
- [24] Braga, R.A.P., Farias, C.R.O., Silva, S.R., & Cavalcanti, E.R., in: *Management and Socio-Environmental Education in the Capibaribe Basin*, 1, Recife, editora Clã, 144 pages, 2015. (Text in Portuguese)
- [25] Pernambuco, *Capibaribe River Basin Hydro Environmental Master Plan: Executive Summary*, Water Resources Secretariat, Recife, 2010.
- [26] Pernambuco, *Pernambuco State Water Resources Master Plan*, Secretariat of Science, Technology and Environment, Recife, 1998.
- [27] Silva, S.R., Freire, P.K.C, Barbosa, D.L, & Wanderley, S.F.S., *Water Resources Management in the State of Pernambuco*, 2003, <https://pt.slideshare.net/FernandoHenrique52/a-gestao-derecursoshidrico-sempernambuco-maio2003>, (14 March 2019).
- [28] Pernambuco, *Pernambuco State Solid Waste Plan*, Secretariat of Environment and Sustainability, Recife, 2012.
- [29] Recife, *Solid Waste Master Plan: Pernambuco Metropolitan Development Region - RDM/PE*, Pernambuco State Secretariat of Cities, 2018.
- [30] Recife, *Recife Rainwater Drainage and Management Manual*, City Hall of Recife/ Infrastructure and Urban Services Secretariat - SISUR/ Maintenance and Urban Cleaning Company- EMLURB, 2016.
- [31] Kay, R. & Alder, J. *Coastal Planning and Management*, Taylor & Francis, London and New York, 2005.
- [32] Nejad, J.M., Asadpour, F., *A Strategy for Sustainable Development: Using Nanotechnology for Solar Energy in Buildings (Case Study Parand Town)*, *Journal of Engineering and Technological Sciences*, **51**(1), pp. 103-120, 2019.
- [33] Gobbi, C.N., Sanches, V.M.L., Pacheco, E.B.A.V., Guimarães, M.J.e O. C., & Freitas, M.A.V., *Management of Plastic Wastes at Brazilian Ports and Diagnosis of Their Generation*, *Marine Pollution Bulletin*, **124**(1), pp. 67-73, 2017. <https://doi.org/10.1016/j.marpolbul.2017.07.004>.