Modelling the Dynamics of Plastic Waste in Local Coastal Areas of Low- and Middle-Income Countries: The Case of Kenya

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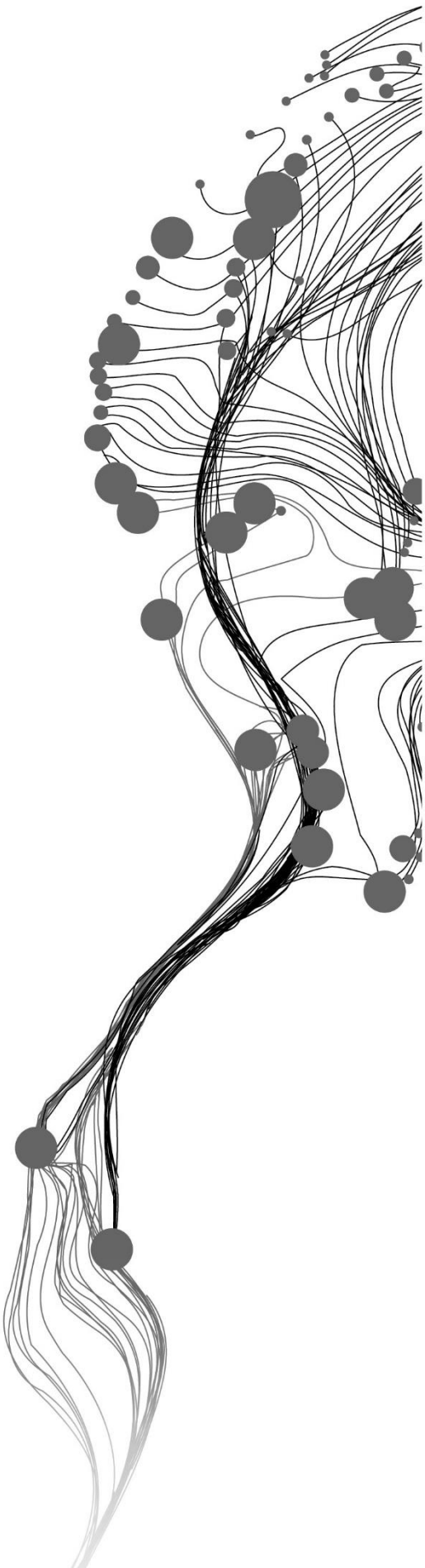

Modelling the Dynamics of Plastic Waste in Local Coastal Areas of Low- and Middle-Income Countries: The Case of Kenya

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ABSTRACT

Rapid population growth, urbanization, and weak policies of solid waste management are the main drivers of plastic pollution. In addition, waste produced by populations living up to 50 km from the sea is highly susceptible to entering the marine environment. Together, these indicators place coastal countries of low- and middle-income as critical contributors to marine plastic pollution. Although global models have been recently developed to project the plastic inputs from coastal areas into the ocean, such studies typically use national level data, overlooking the particular dynamics of local coastal areas. While most strategies of plastic waste management are implemented locally, decision-makers still have few tools to support the identification of priorities and access the impact of policies at local scale. This study attempted to address this gap by proposing the structure of a model that captures the local dynamics of the plastic waste system in a coastal region of Kenya, a lower-middle income country. In contrast to most system dynamics (SD) models presented in the scientific literature, this study made no prior assumptions about the system, and stakeholders played a pivotal role in the model conceptualization. Semi-structured interviews were conducted with 32 key informants from seven professional backgrounds, in three out of the six counties that constitute Coastal Kenya. The narrative that emerged from the interviews was further explored through non-participant observation. Moreover, the spatial identification of urban and rural areas enabled an overall depiction of the study area. A thematic analysis of the interviews generated a codebook that presented the properties and roles of stakeholders, stocks, flows, actions of prevention currently in place, and challenges faced by the system. The codes were converted into an SD model presented in three parts: (i) the structure of a quantifiable model of stocks and flows; (ii) a conceptual system model of actions of prevention performed by stakeholders, resulting in processes able to modify the magnitude of the flows; and (iii) a conceptual system model that presented the challenges faced by the system and indicated how these challenges influence the flows. A closer examination of the model's first part, along with the thematic analysis and literature review, revealed information about the extent of the gap on quantitative data about plastic waste production and management in the study area, providing insights for further research and taking a step towards the model's future simulation. The results suggested that the model might significantly support decision-making processes that aim to reduce marine plastic pollution in local coastal areas. The model's usability encompasses the identification of flows that should be primarily modified to undermine the increasing marine plastic pollution, challenges to be addressed and actions of prevention to be reinforced or created. Because all model's elements are codes that can be retrieved from the interviews, the particularities of the study area were successfully captured and detailed. Therefore, the main contribution of this study to the academic discourse was presenting the structure of a system dynamics model for local coastal areas of low- and middle-income integrally constructed through an inductive and qualitative approach.

Keywords: marine plastic pollution; low- and middle-income countries; local coastal areas; plastic waste management; system dynamics model; thematic analysis; inductive approach.

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ABBREVIATIONS

BMU	Beach Management Unit
CBO	Community-based organization
CN	Curve number (indicates potential runoff)
EPR	Extended-Producer Responsibility
KI	Key informant
KNBS	Kenya National Bureau of Statistics
MPW	Mismanaged plastic waste
NEMA	National Environmental Management Authority
NGO	Non-governmental organization
PPP	Public-private partnership
PW	Plastic waste
RQ	Research question
SD	System dynamics
TA	Thematic analysis

1. INTRODUCTION

Few decades of massive and fast-growing plastic production have caused the accumulation of the material not only on land, but also on open seas, shorelines, deep seas and even remote islands (Barnes et al., 2009; Barnes, 2005). While plastic is accounted for around 10% of the discarded waste worldwide, it comprises around 85% of all waste in the marine environment (UNEP, 2021). Studies that consider business-as-usual scenarios predict that the weight of plastic in seaways will be larger than the weight of all fishes by 2050 (Dabrowska et al., 2021).

Coastal watersheds are direct contributors to marine plastic pollution (Lebreton and Andrady, 2019), and waste produced by populations living within 50 km of the coast has high potential of reaching the ocean (Jambeck et al., 2015; Ritchie and Roser, 2018). Likewise, rapid population growth, industrialization, and weak policies of management typical from developing countries are the main drivers of marine plastic pollution (Akindele and Alimba, 2021; Ghaffari et al., 2019; Naji et al., 2017). Therefore, understanding the dynamics of plastic waste in coastal areas of low and middle-income countries is particularly relevant to address the global challenge of marine plastic pollution.

1.1. Background and justification

Debates about municipal solid waste management (MSWM) play a central role in urban planning, social and environmental sciences. The topic relates to 12 of the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development (UN, 2015) (Rodić and Wilson, 2017). Once waste is generated, it can be classified into two categories: managed, or mismanaged.

The managed fraction is the result of policies of reuse, recycling, adequate collection, safe disposal systems and technological innovation (Lau et al., 2020). The mismanaged part is the material that is either inadequately disposed or littered, and its volume is strongly related to socio-economic and urban infrastructure indicators. While several high-income countries have fully adopted principles of circular economy in the waste management, the adoption of sustainable practices in low- and middle-income countries is hindered by inexperience, lack of knowledge and socio-economic disadvantages (Ezeudu and Ezeudu, 2019).

Developing countries have heterogeneous practices of waste management, low recycling rates and high volumes of illegal disposal (Akindele and Alimba, 2021; Alpizar et al., 2020; Chenillat et al., 2021). Among the 20 countries with the largest mass of mismanaged solid waste in 2010, only the United States had its Gross National Income (GNI) classified by the World Bank as high; 7 were upper-middle; the other 12 were lower-middle or low income (Jambeck et al., 2015).

Within the mass of mismanaged solid waste, plastic is the type that arouses the greatest concern, due to its increasing presence in the consumer marketplace, abundance in the environment and negative impacts in sensitive ecosystems. Furthermore, packaging is accounted for 46,7% of the plastic waste worldwide, indicating an alarming volume of single-use products (Geyer et al., 2017).

Coastal developing countries are critical contributors to marine plastic pollution due the confluence of increasing plastic consumption, weak policies of management and proximity to the sea (Jambeck et al., 2015; Ritchie and Roser, 2018). Therefore, although it is necessary to strengthen policies for sustainable waste management in all locations that have human activity, it is generally agreed that coastal areas of

low- and middle-income countries should be of primary concern. To address the challenge of marine plastic pollution, it is crucial to understand the cycle of plastic waste at local scale, from the source to the point it reaches the ocean and becomes marine debris. However, the lack of data in many countries, especially in the ones with fast growing economies, makes this understanding rather challenging (Rimaityte et al., 2012). The data gap is particularly significant in African countries, which have the largest population growth and where recycling policies started long after plastic became widely used (Jambeck et al., 2018).

1.2. Definition of plastic waste

Plastics are polymers formed by smaller molecules called monomers, made from organic materials mostly originated from petroleum. Debris are called macro-plastics when their size is larger than 25 mm; meso-plastic when the size is between 5 and 25 mm; and microplastic when they are smaller than 5 mm (Albores et al., 2016). This research is focused in understanding the cycle of meso and macro-plastic.

In the last decades, a number of materials such as glass, wood and ceramic were substituted by plastics (Kedzierski et al., 2020). In 2009, 4% of the oil and gas extracted in the world was used in plastics production (Hopewell et al., 2009). The projection is that this number reaches 20% by 2050 (Lebreton and Andrady, 2019).

The chemical classification of meso and macro-plastics is not critical in this study, and the material will be denominated 'plastics' overall. However, it is important to understand what types of plastic products are enclosed by the term. For this reason, the classification used by The Plastics Industry Trade Association (PLASTICS, 2016) is demonstrated in Table 1, with further information compiled by the author from various sources (Bashir, 2013; Ellen MacArthur Foundation, 2016; PLASTICS, 2016; Rouch, 2021; Seaman, 2020). The last column shows the percentage of the ratio between the weight of plastic waste generated and primarily produced in 2015, globally (Geyer et al., 2017).

Table 1. Types of plastic and percentage of production turned into waste in 2015.

Type	Acronym	Name	Examples	$\frac{weight\ waste}{weight\ prim.\ prod.} x100$	Additional information
1	PET or PETE	Polyethylene	Water and soda bottles; ready meal trays; condiment bottles; blister packaging.	97%	Can be recycled; should not be reused, products are intended for single use.
2	HDPE	High-density polyethylene	Most of food products; milk cartons; shampoo and detergent bottles; grocery bags.	77%	One of the safest types of plastic, difficult to break down even when heated. Recycling is relatively simple and cost-effective.

3	PVC	Polyvinyl chloride	Pipes; credit cards; medical equipment; bubble foil.	39%	Contains numerous toxins that can leach throughout its entire life cycle. Less than 1% is recycled. Should not be reused.
4	LDPE	Low-density polyethylene	Most of thicker plastic bags (such as the ones given in shopping malls); cling wrap; beverage cups; frozen food bags.	89%	Safe for reuse, but seldomly recycled. However, recycling centres are accepting the material more and more in the last few years.
5	PP	Polypropylene	Microwave and refrigerated containers; disposable diapers; buckets; plastic furniture; toys.	81%	Safe for reuse, but rarely recycled. Recycling centers around the world are starting to accept it more.
6	PS	Polystyrene (Styrofoam)	Single-use cutlery; takeout food containers; protective packaging; CD/DVD cases.	68%	Easily breaks-up and is quicky dispersed in the environment. The market for recycling is still very small globally.
7	Other	Layered or mixed	Multi-material packaging; Tupperware; baby bottles.	68%	Reuse and recycling protocols are not standardized. Might release BPA (Bisphenol A), an endocrine disruptor, especially when heated.

A stratified random sampling carried out in Watamu Ward (Kilifi County, Kenya), whose population is approximately 50% urban and 50% rural (KNBS, 2019b) indicated that 55% of all discarded plastic waste was LDPE, followed by PET (40.7%), HDPE (2.9%) and PP (1%) (Gwada et al., 2019). These findings are supported by Okuku et al. (2021), who demonstrated that the majority of plastic litter found at a beach in Mombasa (Kenya) in 2020 was the type used in food products (usually LDPE or PET), with 78.4%. The second and third types were personal care products, with 11.6%, and household products, with 9.5% (both usually made of HDPE). Among the packaging products, PET represented 48.2% of the total collection.

Even though plastic has high potential for recovery, primary production is considered to be economically more viable than recycling (Kedzierski et al., 2020). According to Geyer et al. (2017), less than 2% of the total plastic production was recycled in the last 70 years, while 98% was either incinerated or disposed on landfills and environment.

1.3. Drivers of plastic pollution in coastal areas

Urbanization is one of the main drivers of plastics waste generation, as urban residents typically consume more goods and services than rural residents (Wiedenhofer et al., 2013). This relationship is demonstrated by the fact that the global urban population increased by 3.5 billion inhabitants in less than 70 years - 1950 to 2018 - (United Nations, 2018), whereas the cumulative production of plastic went from 0 to 7 billion tonnes in the same period (Ritchie and Roser, 2018). Urbanization also has a positive correlation with the emergence of supermarkets, origin of the majority of plastic products consumed by the middle class (Deloitte, 2014), as shown in Figure 1.

Figure 1. Section with several types of plastic in two supermarkets in Kenya (Kwale and Mombasa)

Although there is no quantitative data on plastic waste production in rural and urban areas of developing countries, a study developed in Beijing, China, demonstrated that the fraction of plastic in solid waste streams is around 13% in urban areas to 6% in rural areas (Yang et al., 2012).

In addition to rapid rates of global urbanization, it must be considered that 40% of the world's population live in coastal areas (UNESCO, 2011). Due to being an interface between land and sea, coastal areas are not only subject to local sources of plastic waste (services of leisure, recreation, habitat and livelihood such as fishing), but also receive plastic from inland, through wind, rivers and watersheds runoff (Ogunola et al., 2018). Moreover, tides and ocean currents are responsible for bringing plastic debris from other countries. A study by Santos et al. (2005) found that beaches in the northeast of Brazil receive garbage from North America, Europe, Africa, Asia and other countries of South America.

The combination of urban population growth, increase of coastal population and increase of consumption patterns is particularly critical in sub-Saharan African countries. According to Barrios et al. (2006), the urban population of the mentioned area faced an increase of more than 140% in 30 years (1960s to 1990s) and is expected to face a growth 2.5 larger than the growth of other developing countries. The increasing urban population in sub-Saharan countries, however, does not seem to be accompanied by improvement on infrastructure, in which policies of waste management are included. Instead, sub-Saharan countries face high levels of indiscriminate waste disposal, one of the most important causes of marine plastic pollution.

Akindele and Alimba (2021) indicate that the lack of adequate management practices and low awareness about the consequences of plastic pollution are critical in Africa. Illegal dumping occurs in open spaces, roads, riverbanks and canals, and landfills are unsanitary. The problem is aggravated by the lack of potable water in Africa, raising the use of PET bottles (Akindele and Alimba, 2021).

Furthermore, bad quality fishing gears are increasingly being adopted by poorer communities, with high potential of being lost, broken and abandoned in the sea (Adeyemi et al., 2019).

1.4. Flows of plastic waste from land into the ocean

All plastic ever produced can be classified into three categories: currently in use, post-consumer managed and mismanaged plastic waste (MPW) (Geyer et al., 2017). Mismanaged plastic waste is the "material which is at high risk of entering the ocean via wind or tidal transport or carried to coastlines from inland waterways. […] the sum of material which is either littered or inadequately disposed" (Ritchie and Roser, 2018, para. 8). Therefore, it is the category with the highest potential of becoming marine plastic debris.

In terms of systems thinking, all plastic waste ever produced is either part of a stock, which is the accumulated fraction, or is a flow, which is the material able to increase or reduce stocks. As explained by Voinov (2008), "stocks are always measured in terms of certain quantities of material, while flows are always rates of material transferred per unit of time" (pp. 61-62). Therefore, marine plastic pollution occurs when flows of plastic waste accumulated in land increase the plastic waste stock in the sea. Several authors point to the fact that in coastal areas, the flows of mismanaged plastic into the ocean are larger than in landlock areas due to the proximity to water.

A seminal study that quantifies the inputs of land-based plastic waste into the ocean was published by Jambeck et al. (2015). According to it, an estimate 4.8 to 12.7 million metric tons of plastic waste produced by populations living within 50 km from coastlines have entered the sea in 2010. These data place coastal areas of developing countries as major contributors to marine plastic pollution. Kenya, for instance, has generated an estimate 22.658 tonnes of mismanaged plastic waste in 2010, and is expected to generate 87.109 tonnes in 2025 (Jambeck et al., 2015).

Another key study is Lebreton and Andrady (2019), who established a model that projects the global MPW generation and, by analysing watershed boundaries, concluded that rivers are the main conductors of plastic waste into the sea.

Both Jambeck et al. (2015) and Lebreton and Andrady (2019) consider the degree of solid waste mismanagement as a pivotal element of the models. However, data about solid waste management is rarely available, especially in developing countries. For this reason, both studies used estimates to create different scenarios of mismanagement at country-level. A major drawback of this approach is that it overlooks local characteristics of management, considering that all areas of a country present the same dynamics on their plastic waste management systems.

1.5. Impacts of marine plastic pollution

Since 1970, biologists have been reporting the dreadful impacts of plastic debris in marine wildlife due to ingestion and entanglement (Auta et al., 2017; Avery-Gomm et al., 2018; Clark et al., 2016; Peng et al., 2020; Thompson et al., 2009). Marine turtles are particularly vulnerable due to their dietary behaviour. Consumption of plastic by turtles is well documented and can occur by accident, when plastic is mixed with food, or by visual mistake, when the animal is unable to differentiate plastic from food (Nelms et al., 2015). Entanglement is also considered a major cause of marine turtle mortality. A literature review conducted by Duncan et al. (2017) indicates that all ocean basins have reports of turtle

entanglement in anthropogenic debris. Seals, sea lions, dolphins, whales, sea birds and fishes are also vulnerable to plastic entanglement, especially caused by lost or discarded fishing gears (Jones, 1995).

Studies also suggest that plastic pollution decreases the economic and social value of oceans, especially for tourism and fishing (Ballance et al., 2000; Fadeeva and Van Berkel, 2021). In 2011, an island in the coast of South Korea (Goeja Island) reported a 63% decrease in the number of visitors after rainfalls caused the accumulation of plastic debris in the coastline. The lower number of tourists represented a revenue loss of 29 to 37 million dollars (Jang et al., 2014).

Moreover, plastic carried by ocean currents can float across rather long distances, transporting non-native animal species to new locations during the process and settling in areas in which it may remain for centuries (Barnes, 2002; Goldberg, 1994). The small Henderson Island, located in the eastern of South Pacific and rarely visited by humans, was estimated to have a deposit of 37.7 million plastic debris in 2016, with approximately 27 items per meter arriving every day (Lavers and Bond, 2017).

Low rates of biodegradation also make plastic persistent in the trophic chain (Diaz-Mendoza et al., 2020). Recently, the effects of microplastic in human health have been emerging as an important area of research. The presence of microplastic has been observed in 11 of the 25 most consumed species of fishes worldwide, as well as in shellfish such as crustaceans (Barboza et al., 2018).

1.6. Prevention and management

Numerous studies have attempted to investigate and suggest strategies to prevent marine plastic pollution. Table 2 provides examples and references of some of these publications, classified according to four categories, as suggested by Ogunola et al. (2018).

Table 2. Examples of strategies to prevent marine plastic pollution.

Strategy type (Ogunola et al., 2018)	Examples and references (compiled by the author)
Preventive and regulatory	• Ecolabelling (Pettipas et al., 2016) • Recycling (Dahlbo et al., 2018; Hopewell et al., 2009) • Bans (Xanthos and Walker, 2017) • Fees (Martinho et al., 2017) • EPR (Extended Producer Responsibility) (Nahman, 2010) • Reduction of unnecessary packaging (Schnurr et al., 2018)
Action plans and regulatory agreements	• Clean-ups (Lozoya et al., 2016) • International conventions *Note*: Kenya is part of several multilateral agreements, such as the United Nation Convention on the Law of the Sea (UNCLOS 1989); International Convention for the Preservation of Pollution from Ships (MARPOL 1994); Nairobi Convention for Protection, Management and Development of the Marine and Coastal Environment of the Western Indian Ocean (1985); Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (2000); Bamako Convention (UNEP 1998); FAO Code of Conduct for Responsible Fisheries; and Honolulu Strategy (NEMA, 2022).

Behavioural changes	• Education and awareness creation (Koushal et al., 2014) • Targeting children and youth (Hartley et al., 2015)
Technological	• Biotechnology (Kalogerakis et al., 2015) • Substitution by biodegradable materials (Schnurr et al., 2018) • Energy recovery (Albores et al., 2016)

The literature also shows that the viable strategies for developed countries and developing countries are widely different, and so are the challenges faced by these two groups of nations. The large number of informal settlements in the Global South, for instance, is correlated to poor practices of waste management, with severe consequences to human health and environment (Gutberlet et al., 2017). Furthermore, residents of informal settlements are highly dependent on community-based and individual (informal) initiatives to manage their waste.

In an analysis of suitable policies for developing countries, Alpizar et al. (2020) proposed a framework to select and design strategies to reduce marine plastic pollution. The study presented a problem-based selection tool, which is a matrix of three targets and four instruments, generally oriented to behavioural changes, as shown in Table 3.

Table 3. Problem-based Selection Tool for developing countries (Alpizar et al., 2020).

	Price-based instruments	Rights-based instruments	Regulation instruments	Behavioral instruments
Targeting the plastic industry	- A tax based on environmental performance of the plastic products. - Subsidies for research and innovation.	- Extended producer responsibility (EPR).	- Standards for pellets spills from the industry.	- Information provision. - Nudging such as setting defaults to "no plastics". - Use of social comparisons.
Targeting consumption of plastic by households and firms	- Increasing the price on plastic products. - Deposit-refund schemes for plastic bottles. - Waste charge.	- Waste-based billing.	- Bans (single-used plastic, light-plastic bags). - Mandatory recycling.	- Information provision. - Nudging such as setting defaults to "no plastics". - Use of social comparisons. - Explicit use of social norms.
Targeting disposal of plastics	- Weight-based pricing of waste. - Subsidizing appropriate behavior.	- Extended producer responsibility. - "Pay-as-you-throw" (PAYT) systems. - Provision of waste collection that promotes separation of waste for recycling.	- Landfill bans. - Mandatory recycling laws.	- Education, information campaigns. - Information appealing to social and personal norms, pro-social behavior. - Door-to-door information provision. - Face-to-face information facilitating the adoption of recycling.

Note: Reprinted from "A framework for selecting and designing policies to reduce marine plastic pollution in developing countries", by Alpizar et. Al, 2020, *Environmental Science & Policy 2020, Vol. 109,* p. 28.

Similarly, Prata et al. (2019) discussed current practices to improve plastic waste management, with effects in production, consumption and disposal. The study highlighted that implementing an Integrated Waste Management System is a slow and expensive process, which is an additional challenge for developing countries.

Together, these studies indicate that education and awareness are central elements for reducing marine plastic pollution. However, the change in behaviour must be followed by institutional improvements,

mainly towards reducing consumption and increasing the options for adequate discarding, hence decreasing littering and illegal dumping.

Moreover, some innovative projects have been developed in the last few years. One that stands out is The Ocean Cleanup, a Dutch non-profit organization that aims to collect 90% of the floating plastics in the ocean by using a U-shaped barrier that conducts the debris into a retention zone. The initiative also proposes the cleaning of the thousand most polluted rivers in the world (The Ocean Cleanup, 2022). Additionally, a review published by Helinski et al. (2021) presented 40 devices that can be used to clean freshwater systems.

1.7. System dynamics in waste management studies

To date, several studies have investigated different aspects of solid waste management using system dynamics (SD) modelling. A systematic literature review on waste management retrieved 379 studies that selected SD modelling as the main method. Among them, 31 were considered to have potentially relevant information for this research (non-global models that consider different sources of waste, management and/or policies). However, only 13 are focused in developing countries. Among those, 12 have modelled the total municipal solid waste production, thus not considering particular sources of plastic waste generation. The exception is Dhanshyam and Srivastava (2021), who conducted a study on policies to mitigate plastic waste pollution in India. The study, however, is not related to a coastal area.

Dianati et al. (2021) combined four sectors (waste collection, biogas, landfills, and scattered waste) in an SD model to calculate the environmental and health impacts of waste-to-biogas scenarios in Kisumu County, Kenya. One of the main findings of this study was that the ban of burning on landfills would cause the volume of waste to increase 2.3 times in 15 years in those landfills, but the aggregate greenhouse gas emissions within the county would be 35% lower.

Sudhir et al. (1997) proposed an SD model to simulate the consequences and alternatives of solid waste management in a metropolitan city of India. Although being able to capture the relationships between public health, environment, costs and social aspects, the study considers all solid waste produced in the area, thus a great share is accounted for organic waste. Similarly, Sufian and Bala (2007) developed a model to project generation, capacity of collection and capacity of energy production from the whole solid waste produced in Dhaka city (India). However, it is also not possible to separate the findings related to plastics streams.

Some system analysts have focused their studies on the model conceptualization rather than the model simulation. One study created a conceptual model to evaluate the impacts of Extended Producer Responsibility (EPR) in the plastic waste management in Indonesia (Destyanto et al., 2019). The model conceptualization is aimed to serve as reference for future simulation models that evaluate waste management. Another study is the one by Gutberlet et al. (2017), which combines systems thinking and action net theory with qualitative data (semi-structured interviews and observations, among others) to identify the actions that should be reinforced, disconnected or reformulated in the solid management of informal settlements, also in Kisumu County (Kenya). The main finding was that weak links in waste management chains should be bridged by reinforcing existing initiatives from stakeholders. Two thirds of the waste considered by this last study, however, was organic.

Together, these studies show the applicability of system dynamics to analyse weaknesses and potentialities of waste management systems. Nonetheless, none of the reviewed publications was found to present a model that describe the flows of plastic waste in local coastal areas of developing countries. This study aims to contribute to this knowledge gap by structuring a model that demonstrates the pathways of plastic at risk of becoming marine pollution in a local coastal of a lower-middle income country in Africa.

1.8. Research problem

The most impactful and cost-effective strategies to address marine plastic pollution are conducted at local level, especially in areas that border the sea (Winterstetter et al., 2021). Implementing such strategies is only possible when decision-makers have enough tools to apprehend the magnitude of the problem and understand the mechanisms that conduct the material into the ocean.

Recent studies have established models to quantify and project the global inputs of plastic waste into the sea. However, they typically employ country-level data and overlook particularities of local areas. As an example, the average population of a country with extensive rural area might not represent the reality of this country's urban centres, likely to have high population density and more voluminous waste generation. On the other hand, models that forecast solid waste generation and policies' impacts at local level usually do not consider plastic as the main element. Instead, they focus on general solid waste, mostly composed of organic matter (Curda et al., 2013; Placek et al., 2015; Rafew and Rafizul, 2021). In the marine environment, however, plastic is the most common anthropogenic material and can be accounted for more than 90% of the litter found alongshore (Okuku et al., 2020).

To develop appropriate and feasible policies to reduce the amount of plastic in the environment, decision-makers need to understand local dynamics. This is the reason why waste management systems should be modelled at local levels: they need to translate the reality and comprise the particularities that contribute to plastic pollution in small scales.

1.9. Research questions

This main objective of this research is to structure a model to describe the dynamics of plastic waste in a local coastal area of a lower-middle income country. The research questions and sub-questions that guide this study are presented below:

1. What are the flows of plastic waste in the study area?
    a) What are the main characteristics of the flows?
    b) Which stakeholders are part of each flow?
    c) What are the roles and functions performed by the stakeholders?
    d) What are the properties of the stakeholders?

2. What are the actions put in place to prevent marine plastic pollution?
    e) Which stakeholders are involved in the actions?
    f) Which flows are affected by these actions?

3. What are the processes that contribute to plastic waste entering the sea?
    g) What are the challenges and issues that affect the flows?
    h) What are the challenges and issues that affect the stakeholders?

i) What are the challenges and issues that affect actions of prevention?

4. How can the system be described?
   j) Which subsystems are part of the plastic waste system in the study area?
   k) What are the stocks, flows and variables of the system?

5. What is the extent of the data gap considering the determined model structure?
   l) What is the current availability of secondary quantitative data about plastic waste in the study area?
   m) What is the data gap yet to be addressed by further research?

6. How can the flows of plastic waste between local areas be demonstrated?

2. METHODOLOGY

This section will present and justify the selection of methods, approaches and tools used to achieve the research objective and answer the research questions. The methodology was designed in an exploratory approach to (i) define the flows of the system; (ii) determine what is currently done to prevent marine plastic pollution; (iii) determine the stocks, flows, and variables of the system; (iv) examine the extent of the data gap; and (vi) explore methods to describe how flows occur between local areas.

2.1. Study area

The main reasons for the selection of Kenya as the study area were:

1. It is a coastal country of lower-middle income (World Bank, 2021).
2. It is located in Africa, the continent with the highest rate of population growth, and part of the Sub-Saharan Africa, whose population is expected to double by 2050 (United Nations, 2019). Consequently, the plastic waste pollution is expected to also increase dramatically in the years to come.
3. Like other African countries, Kenya faces rapid urbanization and middle-class expansion, which are further indicators of plastic consumption increase (Akindele and Alimba, 2021; Fenech and Perkins, 2014; WorldBank, 2016).
4. Although African countries are considered hotspots of plastic pollution currently and in the future, they have weak policies of waste management, largely due to data gap (Jambeck et al., 2018). Furthermore, African countries are the ones with the smallest number of studies about plastic pollution in aquatic environments (Hamid et al. 2018).
5. Despite being in Africa, English is widely spoken in Kenya, which facilitated communication and eliminated the need for an interpreter.

Kenya is located in Eastern Africa and is home for approximately 50 million people (KNBS, 2019a). It shares borders with five countries: Uganda (West), South Sudan (Northwest), Ethiopia (Northeast), Somalia (East) and Tanzania (Southwest). Six counties constitute Coastal Kenya: Lamu, Tana-River, Kilifi, Mombasa, Kwale and Tana River (ordered from North to South). Due to time constraints, data collection in all six counties was not feasible. Therefore, the criterium of highest population density was used, resulting in the selection of Kwale, Kilifi and Mombasa counties for data collection (Figure 2).

Mombasa is the capital and only city in Mombasa County. Despite being the smallest county in area (229.7 km^2), it has the second largest population in the Coast and is highly urbanized (Jumuiya, 2021). It is also the location of the biggest port in East-Africa: Kilindini Harbour, known as the “Port of Mombasa”. Kwale has a relatively long coast, with significant ecosystems that must be protected. It is the location of Diani Beach, a major touristic destination in East Africa. Finally, Kilifi is the county with the longest coastline, the largest population (1.45 million people, according to the Kenya Bureau of Statistics - KNBS), and the second largest area of mangroves in Kenya (20.643 acres) (Koech, 2021).

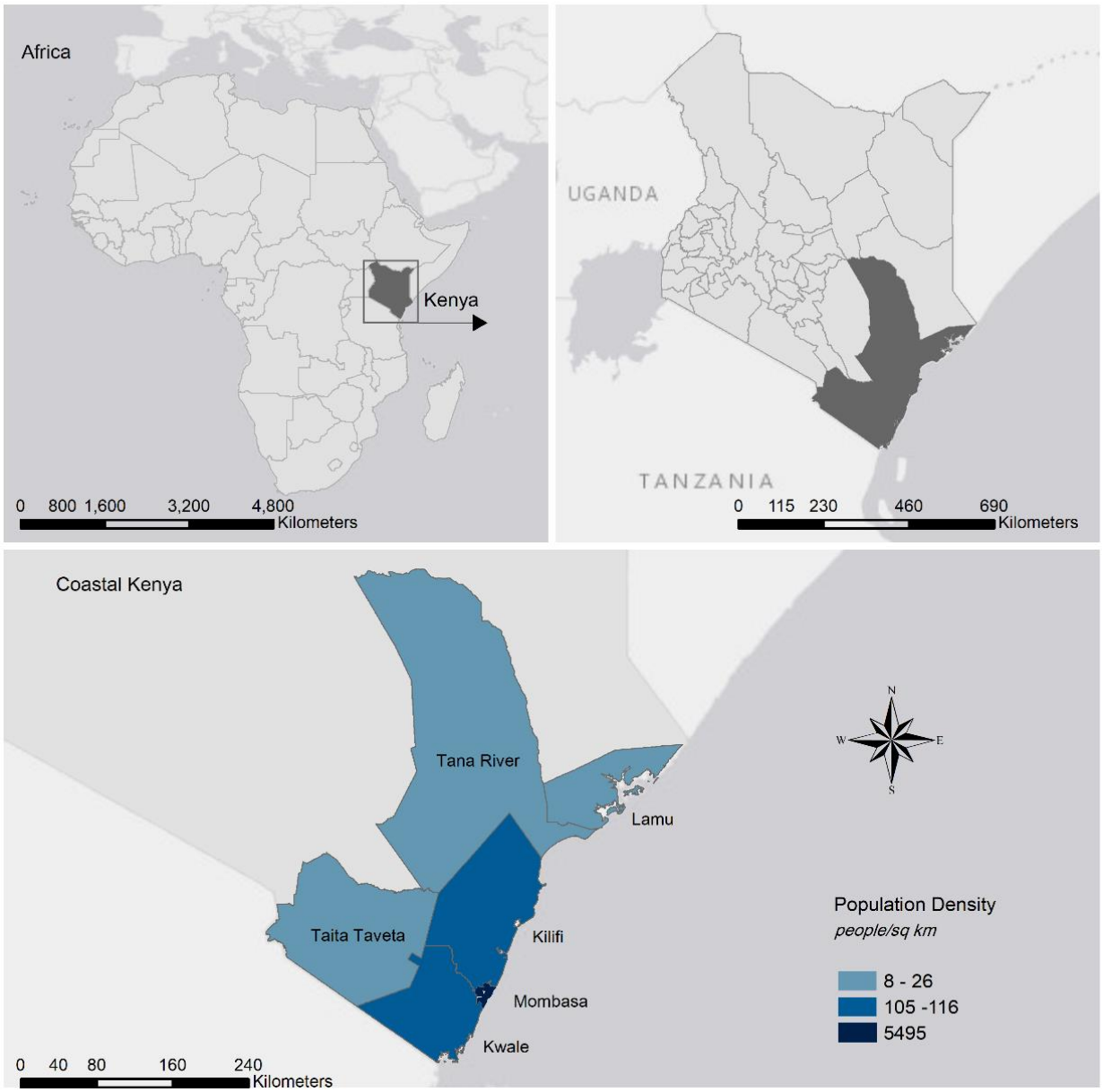


Figure 2. Location of Kenya; location of Coastal Kenya; population density of Coastal Counties.

In 2010, the Constitution of Kenya established a decentralized system of government, wherein legislative and executive powers were devolved to counties. While the Ministry of Environment and Forestry formulates the national policies regarding environment (protection, conservation and pollution prevention and control), the 47 Kenyan counties are responsible for laws and regulation of a number of functions, including solid waste removal. In coastal counties, waste management laws are still in draft stage (NEMA, 2022).

The main instrument of environment policies implementation is the National Environment Management Authority (NEMA), which works in collaboration with the counties. NEMA is responsible for the coordination and supervision of all matters related to environment and has offices and directors at county level. Besides NEMA, several other government agencies share the responsibilities of reducing marine

plastic pollution in Kenya, namely: Kenya Maritime Authority (KMA), Kenya Ports Authority (KPA), Kenya Coast Guard Service (KCGS), Kenya Fisheries Service (KeFS), Kenya Wildlife Service (KWS), Kenya Forest Service (KFS) and Water Resources Authority (WRA). Furthermore, since 2016, the Kenya Marine and Fisheries Research Institute (KMFRI) promotes research on marine litter.

Despite the great number of institutions involved in the legislative framework, the responsibilities between different government agencies are considered unclear (NEMA, 2022). Marine plastic pollution is not a specific policy of the national level of government (Ministry of Environment and Forestry), although policies on waste management and protection of marine environment encompass the issue (NEMA, 2022). Recently, KMFRI and NEMA published the National Marine Litter Management Action Plan 2021-2030, which presents strategies to counteract the growing issue of marine plastic pollution. These strategies are distributed in four thematic areas: (i) prevention and reduction of litter from land-based sources (e.g. waste water treatment and incentive to circular economy); (ii) prevention and reduction of litter from sea-based sources (e.g. from maritime industry, ferries, tourism and fishing boats); (iii) prevention and reduction of transboundary waste (by reinforcing the International Convention for the Preservation of Pollution from Ships – MARPOL, signed in 1994); (iv) activities to support the implementation of the action plan (e.g. support to clean-ups, promotion of awareness and education on marine litter management) (NEMA, 2022).

2.2. Overall methodology

This study was developed in three dimensions: qualitative, quantitative, and spatial. In the qualitative dimension, interviews and non-participant observation were selected as methods of data collection, in an exploratory and descriptive design. The quantitative dimension aimed to determine which stocks and flows of the system can be quantified, thus determining the extent of the data gap. Finally, the spatial dimension sought to (i) create a map of urban and rural areas and (iii) analyse the potential surface runoff in the study area, to identify the locations in which plastic waste is at higher risk of being transported during rainy season.

Three softwares were used: ATLAS.ti (version 9), for the qualitative analysis; Vensim (version PLE x64), to create the system dynamic model; and ArcMap (version 10.8.1), to create the maps. Figure 3 depicts the overall methodology of the research. It will be detailed throughout the remainder of this chapter.

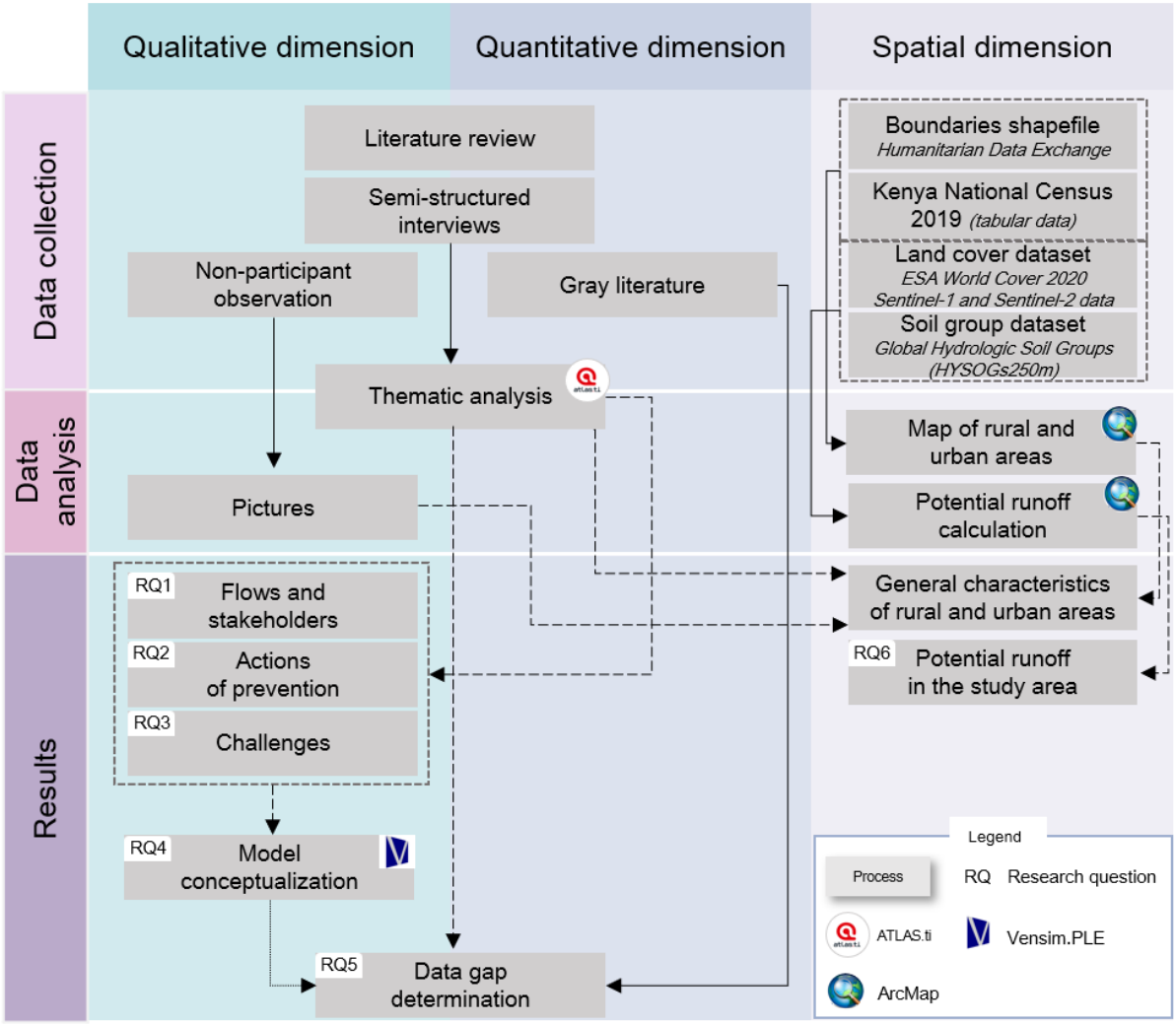


Figure 3. Flowchart of the overall methodology.

2.3. Qualitative data collection

The next two sections detail the qualitative data collection, for which two methods were applied: semi-structured interviews and non-participant observation. The fieldwork was carried out from the beginning of February to the beginning of May of 2022, in Kwale, Kilifi and Mombasa.

2.3.1. Interviews

To find out how different stakeholders understand the flows of production, discarding and management of plastic waste, 32 key informants were interviewed in a semi-structured approach. The method allows questions to be planned beforehand whereas opening space for the participants to guide the direction of the interview and explain points of view (Ahlin, 2019).

These characteristics of the semi-structured approach were fundamental because, although all key informants share a common background (living in the study area and being involved with the plastic

waste system), the interviews were designed according to the stakeholder's professional functions. The semi-structured questions allowed, for instance, the director of a national agency and the manager of a non-governmental organization (NGO) to give significantly different answers for the same question (e.g., 'How do your professional functions relate to the management of plastic waste in your location?'). An example of the script used in the interviews can be found in Annex 1. It is important to bear in mind, however, that the questions were intended to be a guideline for the interview, assuring that no important topic would be neglected. The interviews held no commitment to the order of questions or wording used in the script.

The sampling strategy was snowballing, a method that leads one key informant to indicate further key informants, causing the number of interviewees to increase over time (Allen, 2017). The first participant was a key informant from the Technical University of Mombasa.

The participants were not oriented to suggest a key informant of a particular stakeholder. Instead, they were asked to think about one or more persons that had any relationship with the plastic waste system. This strategy was used to assure that the respondent would indicate a key informant relevant for the system, not necessarily a colleague or someone from the same stakeholder category. The participants, indications, dates, and types of interaction are presented in Annex 2. Figure 4 demonstrates the share of each stakeholder category of participants. Government representatives were the largest number of interviewees due to their relationships with other categories, such as regulation of private sector, support to non-governmental organizations (NGOs) and community-based organizations (CBOs), and responsibility for the legal framework.

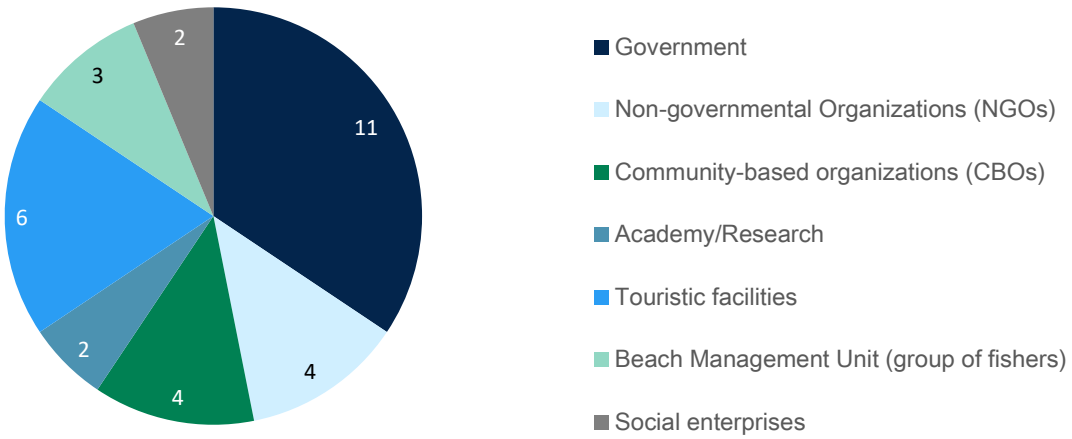


Figure 4. Key informants distributed by stakeholder category.

Most interviews were scheduled directly with the key informant, by telephone (a cell phone number was usually provided by the participant who made the indication). In all cases, the key informants chose where the interview would take place. Most of the times, the interaction happened at the key informant's work environment. The mode of interview followed a preference hierarchy:

1) Face-to-face interviews: majority of cases (29 out of 32).
2) Online interview: one case, due to the participant's preference.

3) Telephone interview: employed when the key informant explicitly informed his/her preference by this mode, or if the researcher noticed, while scheduling, that the interview would last a short time. Each case happened once, both with hotel managers: one opted to call when available; the other one informed, during the scheduling call, that the facility did not use any type of plastic. In this case, further questions were asked by telephone and the face-to-face interaction was not necessary.
4) Questions sent by e-mail: reserved for cases in which all attempts of scheduling the previous modes were exhausted. It happened once, and the respondent did not return the questions, despite several requests. Thus, no interview was made through this mode.

In all cases, the following steps were taken prior to the questioning:

a. Presentation of the Research License granted by the National Commission for Science, Technology & Innovation (Nacosti) of the Republic of Kenya.
b. Brief explanation about the topic of the research, how the data obtained was going to be used and why the key informant was selected for the interview.
c. Permission request to voice-record the interaction. Every participant was informed that the reason for the recording was exclusively the transcription, and that the audio would not be published or used for any other purposes. The recording device (Olympus WS-853) was positioned within the field of vision of the respondent and paused whenever there was an interruption unrelated to the interview, such as a telephone call or a person entering the room. From the 32 participants, only one did not allow the recording.

Although notes were taken during the interviews, the audio recordings were essential to assure that all information provided was somehow captured (including online and telephone interviews). At the end of the process, 17 hours and 25 minutes of audio were compiled, supporting the assumption that a great share of information would be lost if notes were the only instrument used for registering the data. Nonetheless, the fact that recording devices have a role in the interview and influence data is indisputable (Rutakumwa et al., 2020). In the case of this research, given that the nature of questions was not personal or confidential, it was considered that recording the interactions had advantages over relying only on notes. This will be discussed in more detail in Chapter 4.

2.3.2. Non-participant Observation

The fieldwork period of nearly three months enabled the researcher to eyewitness places, activities, and behaviours. The approach was non-participant observation, in which the interaction with people and scenarios is minimal (Gray, 2017). Such observations generated a significant number of pictures, taken with a camera programmed to include a coordinate system of decimal degrees. Among the hundreds of photographs taken, 150 were selected by criteria of location (aiming a balanced distribution over the study area) and degree of information depicted. Then, the images were plotted into a Google map (Google, 2022), which can be accessed online at https://bit.ly/Plastic_Coastal_Kenya. The map (shown in Figure 5) allows the visualization of the exact location of the picture, thus providing an overall view of the plastic waste system. Additionally, the tool offers the possibility of being edited by other users, so that stakeholders, researchers, and other organizations can upload further pictures in the future. Furthermore, some images from the observations were distributed along Chapter 3 (Results).

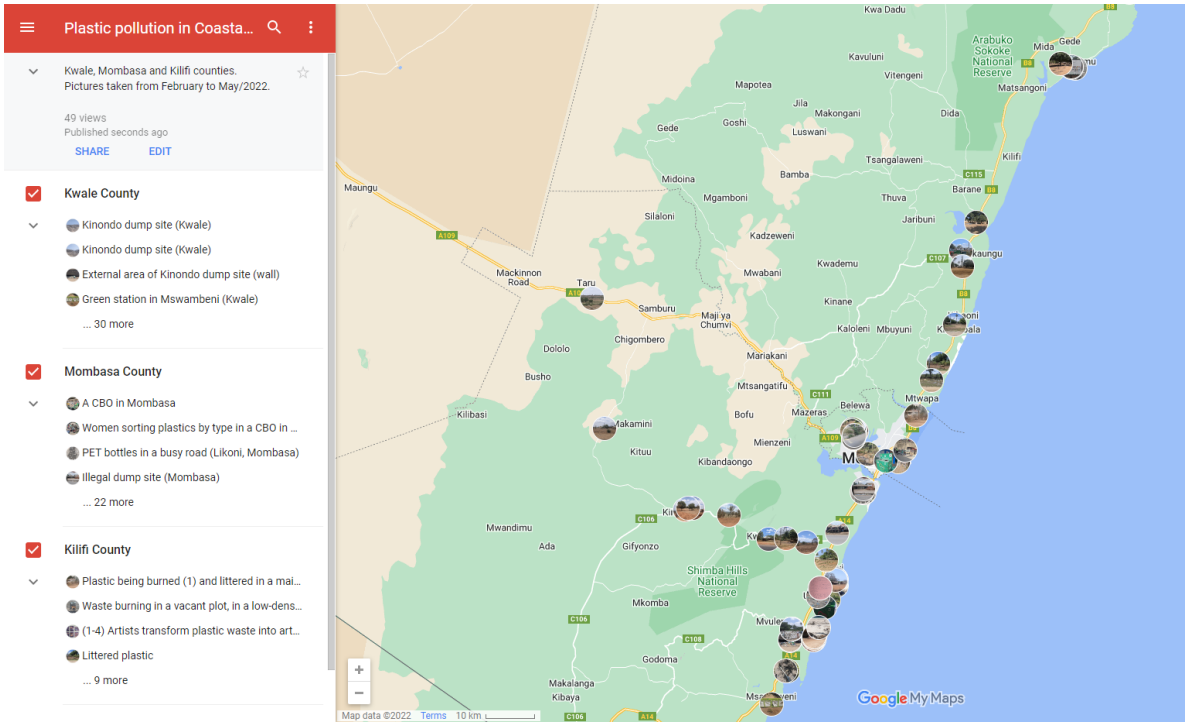


Figure 5. Print screen of the Google map with plotted pictures.
Available at https://bit.ly/Plastic_Coastal_Kenya

2.4. Qualitative data analysis

Although the interviews were registered in audio, the object of analysis was text (audio transcripts). Bernard and Ryan (1998) consider that text can be analysed as a proxy for experience, when the goal is to access the individuals' perceptions, feelings, and experiences; or as an object in and of itself, when linguistic elements have a central role. In this research, text was a proxy for experience. Because data collection had its origin in semi-structured interviews, the format of the text is denominated free-flowing (Bernard and Ryan, 1998). With that considered, two types of analysis are suggested by the authors: word analysis and thematic analysis (TA). The choice for the last will be justified and detailed in the sections that follow.

2.4.1. Approaches selected

A major drawback of applying the word analysis in this research was the significant heterogeneity of respondents and questions. Because questions were asked according to the professional roles of the participants, the word count would likely provide unreliable results. For instance, it is expected that a representative from the government mentions 'public collection' more times than an interviewee that works in an institution that is not involved with this activity. Therefore, for the word count to be reliable, the number of respondents from each stakeholder should be the same – which was not the case of this study, mainly due to the snowballing strategy.

Thematic analysis, in its turn, captures implicit and explicit ideas within the data, generating codes and themes. Nonetheless, the approaches used in thematic analysis largely depend on the area of research

and encompass a number of techniques, thus TA is considered an umbrella term for different types of analysis (Braun and Clarke, 2006). Therefore, two approaches were selected: the reflexive thematic analysis method (RTA), developed by Braun and Clarke (2006); and the applied thematic analysis (ATA), developed by Guest et al. (2011). Although both approaches were generally suitable for this research, each of them presented drawbacks for the specific case of this study. For this reason, features of both were merged in a method able to address the entirety of this research.

In the one hand, the procedures suggested in RTA are highly effective in conducting the organization of codes into themes and sub-themes. The method is composed of six phases that lead the analysis in a hierarchical fashion (codes, sub-themes and themes), and suggests procedures of refinement and iteration (Braun and Clarke, 2006). However, the approach rejects the creation of a codebook and the quantification of codes, which is considered by some authors the most efficient manner of showing that the analysis was rigorous and objective (Hannah and Lautsch, 2011).

On the other hand, the applied thematic analysis approach suggests the creation of themes in a less reflective way (e.g., by analysing repetitions or metaphors), but places the codebook as a central piece of the analysis. A codebook is defined by Guest et al. (2011) as “a discrete analysis step where the observed meaning in the text is systematically sorted into categories, types, and relationships of meaning” (p. 71). Because this research aimed to provide information about the system for decision-makers and stakeholders, the codes had to be displayed (i) individually, (ii) in relation to other codes and (iii) as part of a broader group (the themes). A manner to do that is through the codebook presented in the ATA method (Guest et al., 2011).

In addition to the studies mentioned, Saldaña (2021) was used as a reference for the practical coding process (e.g., type of coding selection, which in this case was descriptive).

2.4.2. Thematic analysis design

Figure 6 synthetizes the thematic analysis design created for this study. The process was carried out through numerous iterations, typical of the reflexive thematic analysis approach. Codes were merged, split, and received different titles throughout the analysis; groups of codes were reviewed several times and modified to create more relevant relationships between the codes. As a result, the themes also faced updates until being registered in the codebook. The codebook was considered stable when all themes, sub-themes and sub-sub-themes could be related to the research questions and sub-questions that guide this work.

Moreover, as detailed by Braun and Clarke (2006), some decisions must be taken prior to the thematic analysis execution. For instance, the level of analysis can be latent (interpretative) or semantic (descriptive); it can describe the entire dataset or provide rich details about a particular theme or group of themes. The epistemology of the thematic analysis should also be determined: essentialist/realist, by which motivations, experiences and meanings are straightforward theorized, or constructionist, that attempts to theorize the sociocultural contexts and structural conditions of the individuals. In this case, the thematic analysis was essentialist, semantic and described the entire dataset.

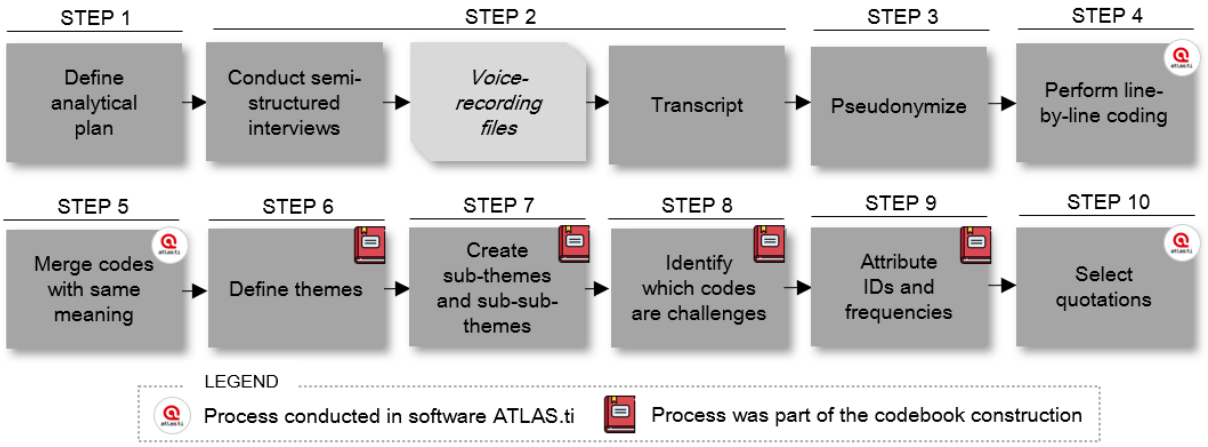


Figure 6. Flowchart of the Thematic Analysis.

The figure is detailed in the following paragraphs.

Step 1: Establishing analytical objectives

Guest et al. (2011) state that establishing objectives is the very first step of the analysis plan. The practical purpose of this analysis is describing the plastic waste system in the study area. The analytical purposes are related to five out of six research questions and aim to identify, explore and describe: (i) the flows of plastic waste and the stakeholders involved in the flows; (ii) the actions currently in place to prevent marine plastic pollution; (iii) the challenges faced by the system; and (iv) how the stakeholders see the current data gap. The analytical approach is inductive and content-driven, meaning that the content of the text drives the construction of the codes and the identification of themes and sub-themes.

Step 2: Data intimacy

Becoming familiar to the data was an organic process, constructed during the interviews, transcription, multiple reviews of audio and text, and notes made about the general characteristics of each interview (Braun and Clarke, 2006; Saldana, 2011). Due to time constraints and the large extent of audio recordings, the interviews were partially transcript, following the indication of Strauss and Corbin (1990) that the text selected for transcription must contribute to the analysis. Therefore, parts of the audio unrelated to the interview (e.g., conversations of personal nature, stories unrelated to the topic) were not considered.

Step 3: Pseudonymization

Before being uploaded to the software of analysis, the documents were pseudonymized according to the University of Twente's guidelines (University of Twente, 2022). The interviews received a code following the system *KI_number_stakeholder_(level)_county*. The 'level' was only used for participants of the category 'government'. For instance: KI_13_government_sub-county_Kwale means that key informant number 13 is a representative of a government department located in a sub-county of Kwale County. Because social enterprises are activists and have interest on having their work disseminated, their names were mentioned, under written authorization provided by the CEOs.

Step 4: Line by line coding

Next, the transcripts were uploaded to ATLAS.ti, a software of qualitative analysis licensed for the University of Twente. The first phase consisted of a line-by-line coding, by which individual sections of the text received a label that attributed meaning to the excerpt (Saldana, 2011). The labels are called codes; the excerpts are the quotations. As stated by Braun and Clarke (2006), it is valid to note that one quotation might have multiple codes, as exemplified below:

Hotels are not a problem for the plastic pollution. The biggest problem is the community and the businesspeople on the streets. This is a bit difficult to control – they drink water and throw the bottle on the street. We really need more awareness and also law enforcement. KI_31_government_sub-county_Kilifi	**Codes:** hotels' good practices / community is a critical issue / littering / lack of awareness / PET bottles / need for regulation and enforcement

The approach selected in this step was descriptive coding, in which the code represents the topic of the information, or the subject addressed by the quotation (Tesch, 1990).

Step 5: Merging codes

In step 4, the coding was only led by information. There was no concern for codes with the same meaning being written in different ways or repeated. Thus, step 5 was dedicated to merging codes with the same meaning, which considerably reduced the quantity, thus facilitating further analysis. An example of merging are the codes '*beach littering*' and '*plastic thrown at the beach*'. At the end of this step, 385 codes became 264.

Step 6: Defining themes

The 264 codes were organized in a hierarchy diagram designed to answer the research questions (RQ) and sub-questions. The first level of the hierarchy are the **themes,** defined by the research questions (RQs). The exception is RQ3, which is not a theme for reasons that will soon be explained. In summary, the first level of the hierarchy is composed of four themes:

- Theme 1 (RQ1) - Flows: information about the pathways of plastic once it becomes waste. Through this theme it is possible to identify the processes responsible for making plastic waste managed or mismanaged.
- Theme 2 (RQ2) - Prevention: the actions currently put in place to reduce marine plastic pollution.
- Theme 4 (RQ4): the group of quantitative information. These codes are numeric information, which can be later used in the equations of the system dynamics model.
- Theme 5 (RQ5) - Data gap: although this research question was initially expected to be answered after the construction of the model, the interviews already revealed information about it. Therefore, this group brings together the quotations in which respondents mentioned "lack of information" (about a certain topic).

Research question 3 (Theme 3) aimed to investigate the challenges to be addressed by decision-makers to improve the system. However, these hindering factors do not make sense in isolation. Their meaning can only be apprehended when considered in relation to the flow, stakeholder or action of prevention

impacted by them. For this reason, the codes related to RQ3 were presented throughout the whole diagram, identified by a **pink box**.

Step 7: Creating sub-themes

As previously explained, the first level of the hierarchy was determined by the research questions (RQs) and consisted of themes. Correspondly, the second level of the hierarchy diagram embodied the **sub-themes**.

Sub-themes are groups of codes clustered to answer the RQs. For instance, the first theme/RQ (What are the flows of plastic waste?) was answered by the sub-themes '*collection, littering, burning, burying, illegal dumping*, etc'.

Some sub-themes required one more level of disaggregation. For instance, the sub-theme '*collection*' was disaggregated into **sub-sub-themes** determined by the stakeholders that perform collection: '*by government, by social enterprises, by NGOs, by informal collectors*, etc'. In other words, each sub-theme (or sub-sub-theme, if existent) is the title of a group to which several codes are attached. Together, these groups of codes answer the research questions and sub-questions.

For reasons that will be explained in step 9, each sub-theme was identified with a capital letter, symbolizing the title of the sub-theme (e.g., Collection = C), while each sub-sub-theme was identified with a lowercase letter. For instance, '*by NGOs*' is the sixth sub-sub-theme of the sub-theme '*collection*' (which is C), hence its identification is Cf. Another example is the sub-theme '*natural transportation of plastic waste*', which does not contain any sub-sub-theme. Therefore, its identification is only N.

The theme that clusters quantitative information was not included in the codebook. Instead, the numbers formed a table that attempts to present an overview of the quantitative data gap (Annex 6).

Step 8: Identifying codes seen as challenges for the adequate management of plastic waste

The codes that key informants consider challenges faced by the system (RQ3) were identified with a pink box. These codes were mentioned by the respondents as issues that either directly contribute to marine plastic pollution or hamper the improvement of the system (e.g., problems faced by initiatives that attempt to prevent marine plastic pollution). The identification of the code as a challenge was lexical (e.g., the respondent said '*the problem is*') or by the context of the answer (e.g., the respondent mentioned a cause for the streets being dirty).

Step 9: Attributing IDs and frequencies

One of the outcomes of the applied thematic analysis is the codebook, which in the case of this research is a hierarchy diagram composed by (i) Themes; (ii) Sub-themes and (iii) Sub-sub-themes (if any).

As mentioned in Step 7, each code group was identified with a capital letter and a lowercase letter (if necessary). Likewise, codes were identified with a number. Therefore, each code possesses an alphanumeric unique ID (e.g., Ca15). Some codes appear in different groups. Therefore, they share the same numerical ID, but different letters. For instance, the code '*broken fishing nets are left on the beach*' is code number 79 regardless its group. However, it can be 79 Lc (L = littering, c = on beaches) or 79Fa (F = disposal of fishing material; a = fishing nets).

Moreover, the frequency of mention of every code was added to the codebook (Annex 3). This frequency is represented by a rectangle in the right upper side of the code box, informing the number of times the code was mentioned throughout the 32 interviews. The codes that appear only once have a white rectangle. The codes that appear in more than one group have a coloured rectangle.

The unique IDs were used to relate quotations to codes (Annex 4). Moreover, the IDs were intended to be part of the final model design, signalling the position of each element (stocks, flows, variables) in the codebook. Nevertheless, the tools offered by Vensim do not facilitate this, and the inclusion of additional text made the visualization more difficult. For this reason, the IDs were not displayed in the model.

Steps 6 to 9 are outlined in Figure 7, with the same layout they are presented in the codebook

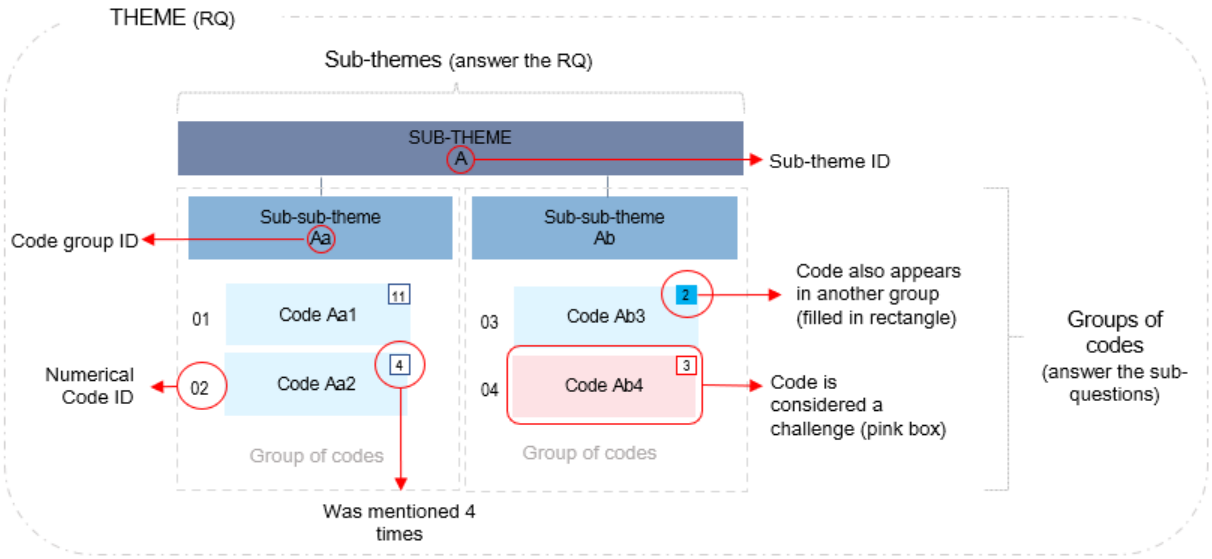


Figure 7. Schematic representation of the codebook hierarchy.

Step 10: Selecting quotations

To demonstrate how the findings have been generated by data, some quotations (excerpts of text that received the code) were included in the results (Patton, 2002). The coding process yielded 458 quotations, hence a selection was carried out. The selection followed the procedures detailed by Eldh et al. (2020), who consider that quotations are a way of highlighting certain features of the data. Therefore, the main criterium of selection was the extent to which a quotation was able to clarify and detail the data. Quotations that were substantially similar to the code itself (e.g., '*Plastic waste is transported by wind*') were not included. Moreover, the excerpts selected are verbatim the statement given by the respondent. Changes were made exclusively when more context was needed for comprehension, and were marked in parenthesis and italic (e.g., 'They *(residents of rural areas)* usually burn their waste').

Annex 4 shows the selected quotations, which are linked to the codes by ID. In total, 140 out of 458 quotations (30.6%) are presented in the referred Annex.

2.5. Model conceptualization

This study employed system dynamics modelling to conceptualize the structure of a model that describes the plastic waste system in a region of Coastal Kenya. The foundations of system dynamics (SD) were set in the mid-1950s, by Jay Forrester. According to Forrester (1968), systems are composed by functions that interact and have interrelationships with each other, thus creating a determined behaviour that changes over time (hence the term 'dynamics').

A dynamic system is formed by stocks that represent accumulations, and flows that are able to increase or decrease the level of the stocks. Therefore, in the model at issue, the stocks (portrayed by boxes) represent the accumulation of plastic waste. In case of plastic waste mismanagement, the final stock is the ocean (marine plastic pollution). The flows (portrayed by double arrows) are processes that move plastic waste from one stock to another. A flow have a certain magnitude and can be determined by the stakeholders, being consequences of their actions (i.e; modes of disposal of plastic waste); or by processes that do not have human interference (i.e; transportation by wind). Finally, there are variables that impact the flows, increasing or reducing their magnitude. A schematic representation of an SD model is exhibited in Figure 8.

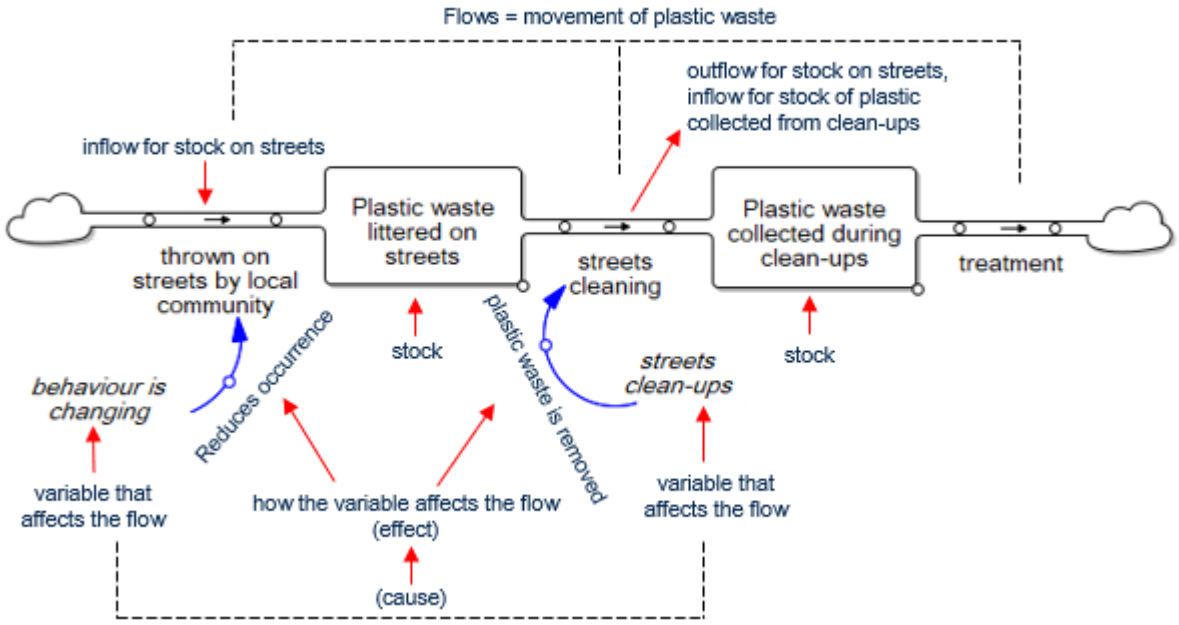


Figure 8. Schematic representation of a System Dynamics Model.

The model structure presented in this study was built entirely through the results yielded by the thematic analysis. Therefore, every element of it can be found in the codebook and is further detailed by quotations extracted from the interviews. Differently from the majority of system dynamics models presented in the literature, no assumptions were made about the system, thus the approach is exclusively inductive.

The software Vensim (version PLE x64) was chosen for the construction of the model for providing a free version for academic use. Moreover, Vensim enables the download of a model reader, allowing free access for decision-makers and stakeholders.

The model was presented in three parts. The first part is the structure of a quantifiable system dynamics model. Although quantification was not part of this research, every flow of the model can be translated by an equation that represents a rate for a determined period of time, such as a month. Similarly, stocks must have their initial levels determined. The quantification enables the simulation of the system's behaviour over time. In this first part, stocks and flows were classified into five categories, represented by colors randomly selected: (i) yellow: production; (ii) orange: plastic waste that can still be retrieved from stock; (iii) blue: plastic waste temporarily stored; (iv) pink: adequately managed plastic waste; and (v) mismanaged plastic waste that will likely not be recovered anymore. The codes that generated the first part of the model are grouped under Theme 1 in the codebook (Flows).

The second part is a conceptual system model that indicates which actions are currently carried out to prevent plastic pollution. These actions are stakeholders' properties that result in processes that affect the flows, either by reducing the magnitude of the ones that contribute to plastic pollution (such as littering), or strenghtening the flows related to adequate management (such as disposal of plastic waste in garbage bins). Actions of prevention are theme P in the codebook, and the codes are placed in green boxes.

The third part is a conceptual system model that demonstrates what are the challenges faced by the system and which flows are influenced by them. The origin of this conceptual system were the codes represented by pink boxes in the codebook. This part also indicates the stakeholders that precipitate the challenges, and the stakeholders mostly affected by them, in case this information could be apprehended through the coding process.

Finally, the codebook revealed that some actions of prevention are also affected by challenges. These are demonstrated in the second part of the model, with challenges placed as properties of the stakeholders and indication of the effect on actions of prevention.

2.6. Spatial analysis

To date, no methodology has proposed the integration of spatial data to system dynamics models. Nonetheless, the spatial dimension was important for understanding the general characteristics of the study. Furthermore, to answer RQ 6 (*How can the flows of plastic waste between local areas be demonstrated?*), a map of potential surface runoff was constructed.

2.6.1. Distinguishing urban and rural areas

Being able to distinguish urban and rural areas was relevant to this research due to the positive correlation of urban density and plastic waste generation (Nel et al., 2017; Ryan, 2020). Furthermore, urban areas close to the sea are critical contributors to marine plastic pollution (Jambeck et al., 2015). However, the spatial analysis was remarkably challenging due to institutional issues in Kenya (Mbaka, 2020).

On the one hand, one institution (Independent Electoral and Boundaries Commission – IEBC) holds a geo-spatial dataset with the administrative boundaries established by the Kenyan Constitution in 2010. On the other hand, the Kenya National Bureau of Statistics (KNBS) holds the updated population and housing data collected during the National Census carried out in 2019. Both institutions claim they should have exclusive mandate over the whole dataset. As a result, the shapefile with the most recent administrative divisions was never published and is not provided by any means by IEBC, while KNBS's data is only available in tabular format. Attempts to access the shapefile with updated boundaries were made for three months, with the support of a number of persons and institutions in Kenya, with unsuccessful results. Several datasets available online were also examined, but all of them are based in the 2009 boundaries. The most recent divisions are significantly different from the ones provided by the 2009 Census material, as illustrated in Figure 9.

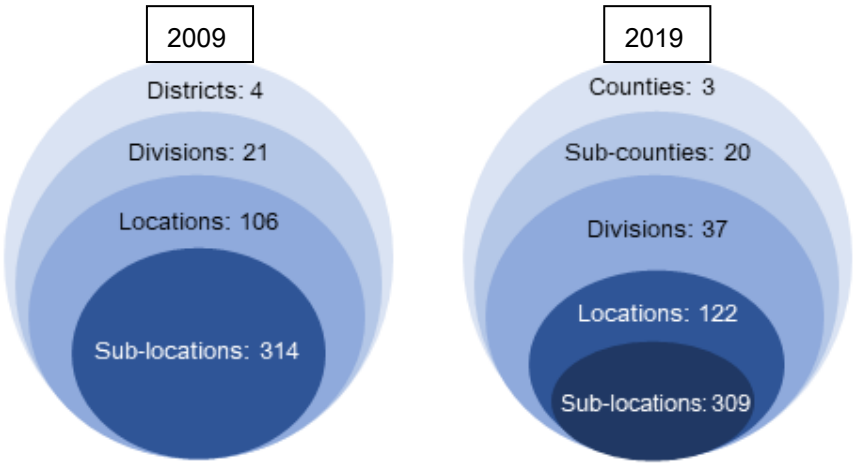


Figure 9. Comparison of Kenya's administrative boundaries in 2009 (before the administrative division stipulated in 2010), and 2019. Created with data from the National Population and Housing Census of 2009 and 2019, respectively (KNBS, 2009, 2019a).

Although a shapefile with the 2009 boudaries was provided by the Kenya Marine and Fisheries Research Institute (KMFRI), the attribute table does not include the rural/urban classification. Concurrently, the 2019 data does not include geo-spatial information. The strategies used to address the lack of updated datasets are presented in the next paragraphs.

First, a shapefile of the counties boundaries (HDX, 2021) was imported to Google Earth Pro and overlayed in the satellite image. Then, each of the 122 locations considered by KNBS in the 2019 Census were manually located in the satellite image and plotted with points in the boundaries shapefile. The newly created points layer was then exported from Google Earth Pro to ArcMap and overlayed in the 2009 shapefile.

With the 2009 sub-locations displayed in Arcmap, the 2019 tabular data was used to adjust the symbology of the 2009 shapefile according to information about urban, semi-urban (70-85% urban) and semi-rural (75 to 85% rural) areas. Consequently, all other areas (the majority) were defined as rural. This was done by locating the name of the place (town, settlement, or village) in the 2009 attribute table, with the assumption that the names were not modified in 2010. Out of 309 sub-locations (2019 data), 45 were not found in the 2009 attribute table. Therefore, they were determined by proximity (close to the other sub-locations belonging to that determined location). The resulting map is presented in Section 3.1.

The data provided by the 2019 Population and Housing Census (KNBS, 2019a) was also used as source of information about the main modes of solid waste disposal by households. Although the Census is published online, it presents aggregated results at country or county levels. For this reason, data at location and sub-location levels were requested to the Kenya Bureau of Statistics (KNBS) and sent by the Department of Population Statistics. With location and sub-location data, it was possible to identify the urban areas, which have higher population density, using recent data. In addition, by integrating the main modes of disposal to the classification of sub-locations into urban or rural, it was possible to see, in a graph, what are the typical patterns of solid waste disposal amongst the 302 sub-locations of the study area (Section 3.1).

2.6.2. Calculating the surface runoff

The level of surface runoff is a significant determinant of the flow '*transportation by rainwater*'. The higher the potential runoff, the higher is the risk of plastic waste being moved from one area to another. Furthermore, during rainy seasons, plastic waste can be transported within watersheds, transcending sub-counties and even counties' boundaries, as demonstrated by Lebreton and Andrady (2019). East Africa typically has a short rainy season, from October to December, and a long rainy season, from March to May (Rateb and Hermas, 2020).

The direct runoff was calculated in ArcMap (version 10.8.1) through the soil conservation service - curve number (SCS-CN) method, developed by the Department of Agriculture of the United States (Mockus, 1964). The SCS-CN method combines rainfall data to characteristics of soil and land cover type to determine the curve number (CN), a representation of the potential surface runoff. The method was slightly modified and did not take any particular rain event in consideration, since the goal was to determine the areas in which seasonal waterways have high potential of transporting plastic waste.

By overlaying the CN map to a river basins layer, it was possible to identify the watersheds in which plastic waste is more subject to transportation by rainwater. Besides the spatial datasets detailed in the previous section (2009 Census shapefile and HDX county boundaries shapefile), the datasets presented in Table 4 were used for the CN calculation:

Table 4. Datasets used to calculate potential surface runoff (curve number).

Data	Source	Description
River basins layer	ICPAC Geoportal	River basins as defined by Japanese International Co-operation Agency (JICA)
Global Hydrologic Soil Groups (HYSOGs250m) for Curve Number-Based Runoff Modeling	Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC)	Gridded dataset of hydrologic soil groups (HSGs), 250 m resolution
ESA WorldCover 2020 – Sentinel-1 and Sentinel-2 data	European Space Agency	Landcover raster layer, 10 m resolution
TR-55 report Urban hydrology for small watersheds	U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC)	CN Table

3. RESULTS

This chapter presents the findings for the three dimensions explained in the previous chapter (qualitative, quantitative, and spatial). Section 3.1. presents an overview of the system, with its general characteristics and the main differences between rural and urban areas. Sections 3.2 to 3.4 are the result of the thematic analysis conducted on qualitative data (semi-structured interviews) and aim to answer the following research questions:

1. What are the flows of plastic waste in the study area? (Section 3.2.)
2. What are the actions put in place to prevent marine plastic pollution? (Section 3.3)
3. What are the processes that contribute to plastic waste entering the sea? (Section 3.4)

Section 3.5. brings the previous results together and presents the structure of the system dynamics model, answering the fourth research question:

4. How can the system be described?

The results presented in Section 3.5. enable the answer to the fifth research question, presented in Section 3.6:

5. What is the extent of the data gap considering the determined model structure?

Finally, section 3.7 presents a map of the potential surface runoff in the study area, answering to RQ6:

6. How can the flows of plastic waste between local areas be demonstrated?

Furthermore, the thematic analysis generated a codebook that assembles all codes (except the quantitative ones) in a hierarchy diagram, presented in Annex 3. Due to the large volume of data, the sub-themes, sub-sub-themes and codes received unique IDs, as explained in the Methodology. These IDs were used to link the codes to the quotations that support the understanding of their meaning (Annex 4).

Some quotations were also distributed throughout this chapter, in order to confirm and substantiate the findings. As explained in Chapter 2, the interviews were pseudonymized and key informants received a code following the system *KI_number_stakeholder_(level)_county*. The 'level' was only used in case the key informant is a government representant.

3.1. General characteristics of the system

Some codes identified in the course of the thematic analysis reflect the characteristics of the system as a whole. Therefore, instead of being placed within a particular theme (e.g., flows, actions of prevention), they formed an additional theme (code G in the codebook).

One of the most significant characteristics of the system is the lack of separation, which causes the waste streams to be mixed, making recycling more difficult. Separation issues occur throughout the whole system and affect all flows. The exception is the collection performed by social enterprises, which promote separation in some households and hotels. However, despite this effort, the percentage of

separation in relation to the total plastic waste produced is close to zero. Moreover, the vehicles used by the government to execute public collection do not have compartmentation:

> Definitely it is not possible to calculate how much plastic waste is coming from each place – all waste come from all places, is mixed, and taken to a unique place *(the public dumping site)*. (KI_15_government_county_Kwale)

Although there are important initiatives that encourage separation, such as the green stations, which will be detailed in Section 3.3, the community is not always willing to follow the adequate procedures:

> Even in the stations in which we have the segregation bins, not all the stations are always well managed. Some of them are still mixed. These are some of the challenges that we face on the ground. (KI_9_Kwale Recycling Center_Kwale)

The lack of separation impacts the work of collectors that have their livelihood based on sales for recycling, as explained by this CBO:

> Not everyone accepts this *(separation)*. Some say “we don’t say have time to separate this”. Others put the garbage into the bins and say, “you come and collect it”. So, we have to do it by ourselves. (KI_8_CBO_Kwale)

Another characteristic that stands out is the lack of options for the appropriate disposal of solid waste. The public collection is based on containers distributed only in areas of high population density (Figure 10).

Figure 10. Public containers in Kilifi (left) and Kwale, next to Congo River (right).

Because there is no door-to-door public collection, the local community must carry their waste to the public containers, which are often far from their homes.

> What is clear to me after all those clean-ups is that if you don’t give people options, if you don’t put garbage bins, the problem will continue. So, give them recycling stations, give them options. The dumping site is not an option. (KI_10_NGO_Kwale)

> Choosing a strategy of talking to people, just talking to people, and you are not providing sorting bins, that will be a challenge (KI_7_NGO_Kwale).
>
> In most of the beaches we don't have garbage bins and if they are there, they are not several, they are not convenient. You don't want to walk 2 km or so with your waste, so if we positioned them correctly, that would work. (KI_16_government_county_Kwale)

The code '*lack of surveillance*' was mentioned by respondents in a number of topics, including separation issues. The positive impact of NGOs and social enterprises was also recurrent. Both are detailed along next sections.

Moreover, codes A3 and A9 were fundamental to comprehend the general characteristics of the study area. They disclose the differences between urban and rural areas regarding modes of solid waste disposal and production of plastic waste. These characteristics reverberate on the flows of urban and rural areas, whose differences were also demonstrated by observations.

Figures 11 and 12 offer an overview of the plastic waste system in rural and urban areas. The maps were created through the method explained in section 2.6.1 (Methodology – Distinguishing urban and rural areas), and the information about rural and urban population was provided by the Kenya Bureau of Statistics (KNBS) under request, in tabular format at sub-location level. Further pictures can be found in the Google map previously presented (https://bit.ly/Plastic_Coastal_Kenya).

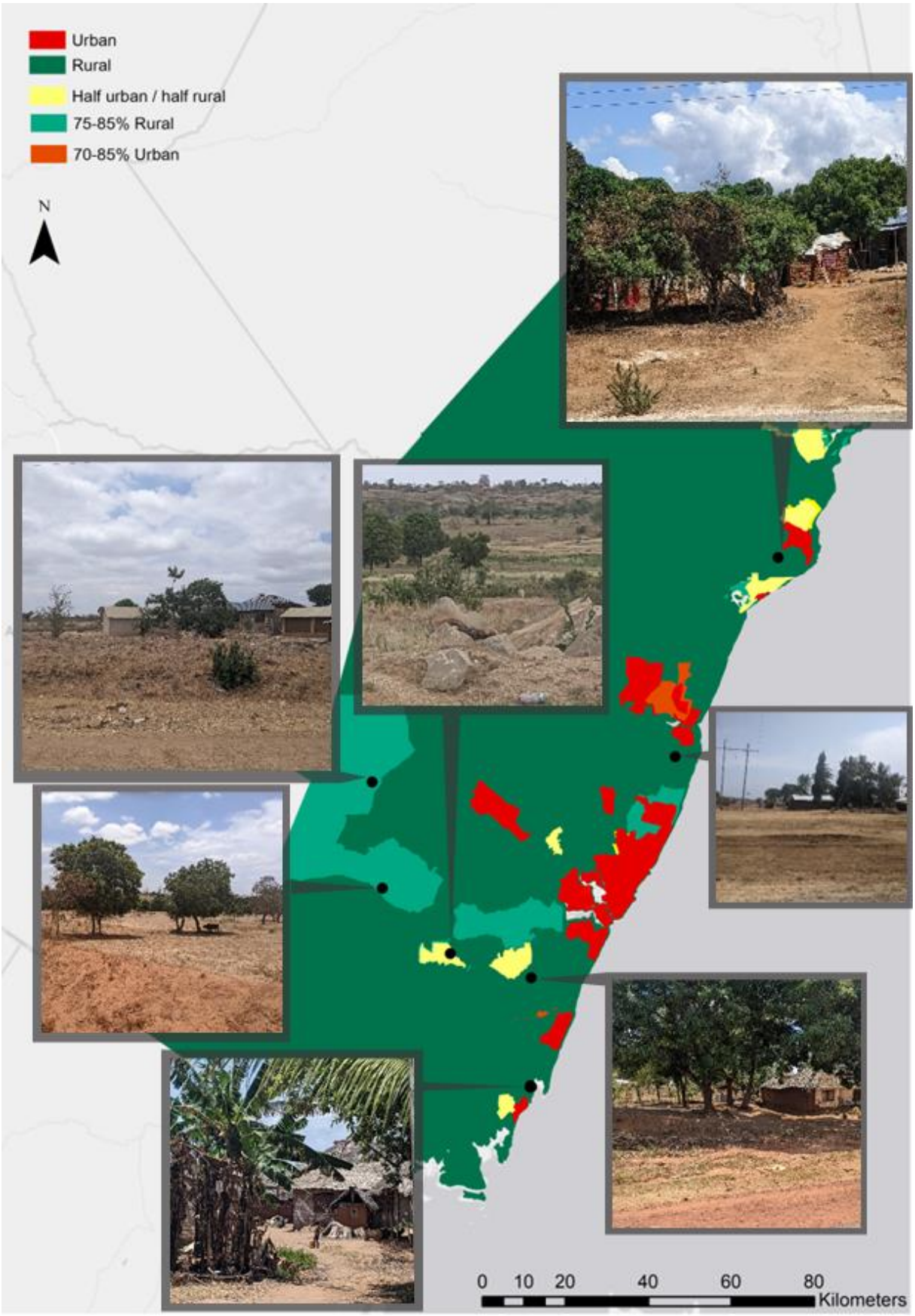


Figure 11. Rural landscapes in the study area. Pictures taken from February to April/2022.

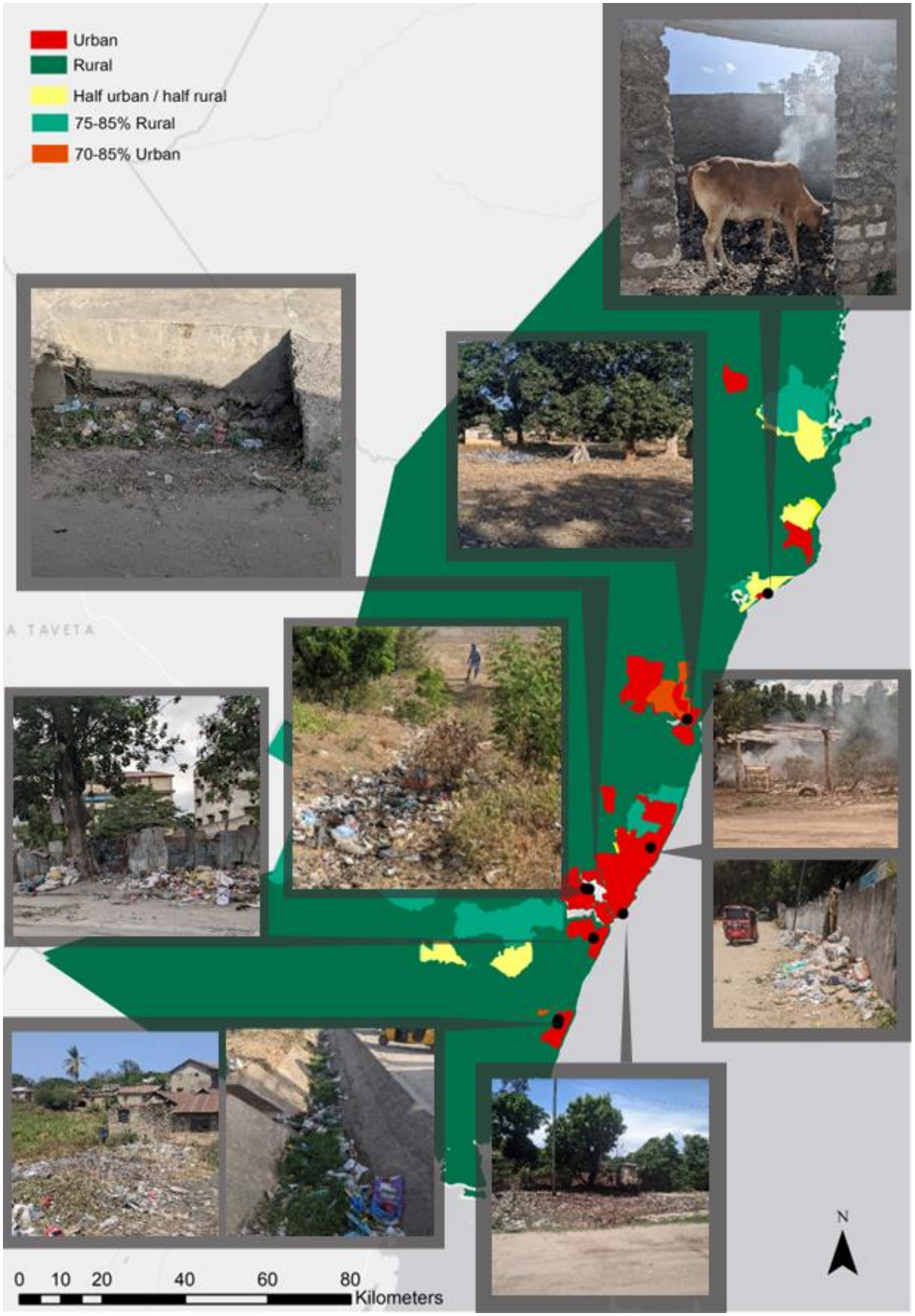


Figure 12. Urban landscapes in the study area. Pictures taken from February to April/2022.

The differences on modes of waste disposal in rural and urban areas are exemplified by Figures 13 and 14. Both graphs were created with data gathered by the Kenya National Bureau of Statistics (KNBS) during the 2019 National Census, which included a question about the main modes of solid waste disposal in households (KNBS, 2019c)

Figure 13 shows that, although the percentage is low overall, up to 10% of the households in the majority of urban sub-locations (64% of them) declared to have collection by the government as their main mode of solid waste disposal. In contrast, only 2% of the households in rural areas declared the same. In the other hand, figure 14 shows that in 46% of the rural sublocations (115 out of the 249), a range of 45% to 60% of the households mainly burn their waste, and this percentage reaches 95% in some rural sub-locations. Conversely, in urban areas, almost half of the sub-locations (25 out of 53) have less than 20% of households using fire as main mode of solid waste disposal.

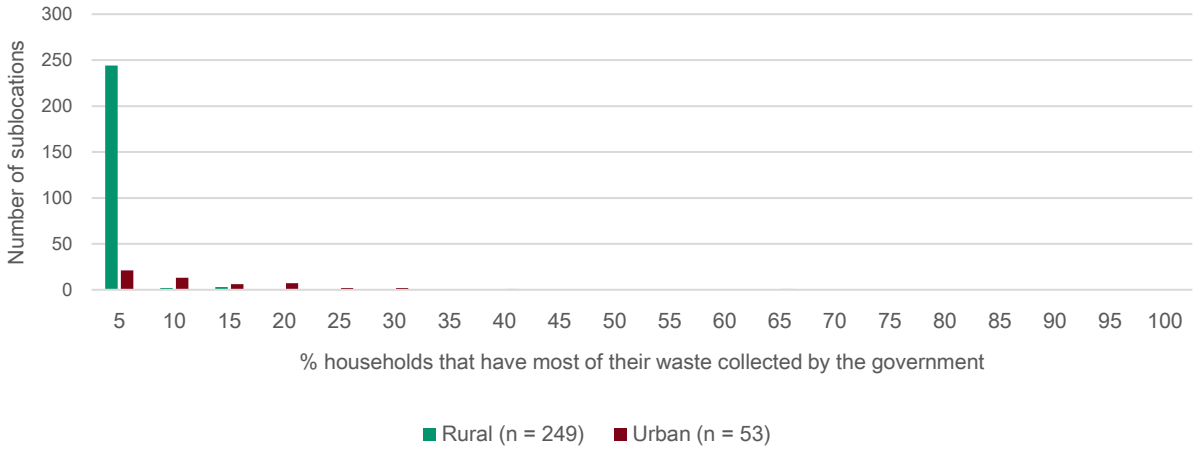


Figure 13. Frequency of households that declared that government collection is the main mode of solid waste disposal. Graph created by the author, with KNBS data (KNBS, 2019c)

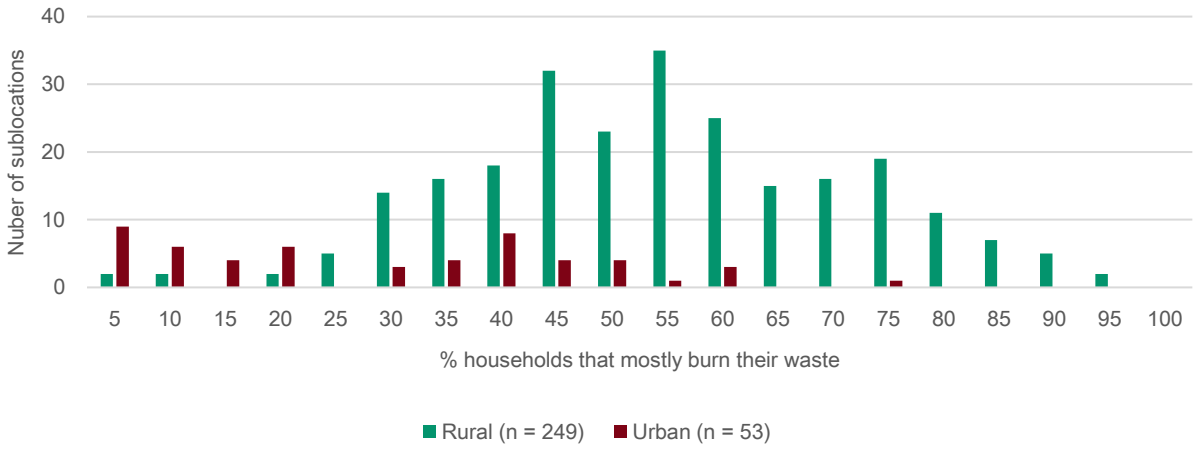


Figure 14. Frequency of households that declared to mostly burn their solid waste. Graph created by the author, with KNBS data (KNBS, 2019c)

Figure 14 was exhibited to a key informant from Kwale government, who provided an explanation:

> In rural areas, they manage the waste by themselves. The county has no containers or transfer stations. Because of the vast amount of land and limited options, it is easier: organic is given to animals, manure is produced. They manage it better. (KI_15_government_county_Kwale)

In the quote above, 'limited options' refers to the consumption profile of rural communities. Socio-economic level and the options available for purchasing are determinant for the volume of plastic waste produced. This view was echoed by a key informant that lives in a rural village in Mswambeni (Kwale):

> Most of the waste *(in rural areas)* is actually organic. Here, many of the houses have nothing inside. They don't have furniture, they don't have money to buy stuff that is wrapped in plastic or comes in plastic containers. They might have plastic from the washing powder, cooking oil, sugar and maybe rice. But we observe that in the villages in which there has been more income, more development, the structure of the houses has improved, and so there is more garbage. One that is really very obvious is, I would say it started about 3 years ago, that you see diapers laying. *(…)* That has really increased in the past 3, 4 years. I believe before people could not afford to buy diapers, or they were not available – the next supermarket is in Ukunda, we just have little stores here. There might be many reasons, it could be that they were more expensive and there are cheaper brands now. In any case, the environment has suffered a lot'. (KI_10_NGO_Kwale)

A common sense amongst the key informants was that urban areas are hotspots of plastic waste production. Because currently there is no quantification of plastic waste generation in Coastal Kenya, the speed with which garbage bins become full is a reference for hotspots identification, as detailed below:

> In *(mentions municipality)*, all bins are full in the end of the day. In the other areas, people call the municipality when the bins are full to be collected. Village administrators have a very important role on this because they are in charge of the supervision. This still happen in areas that are outside the municipality – they call and schedule the collection. They are usually very responsible, and the community expects them to be. (KI_14_government_municipality_Kwale)

Observations demonstrated that plastic waste littered in urban areas is ubiquitous. In all three counties, respondents considered marketplaces and business areas as hotspots for littered plastic waste due to the high number of people circulating. The physical structure of urban centres, usually with high built-up density, is an aggravating factor due to the surface runoff that creates seasonal waterways and conduct plastic waste to the sea (further information can be found in Annex 7).

3.2. Flows (RQ1)

Nine sub-themes were entailed by the theme 'Flows': collection, littering, illegal dumping, fishing material, natural transportation, burning, burying, disposal in a pit and overseas plastic debris. The criterium of frequency of codes was used to order the flows: collection is the most mentioned flow, while disposal on a pit is the least mentioned one, as demonstrated in Figure 15:

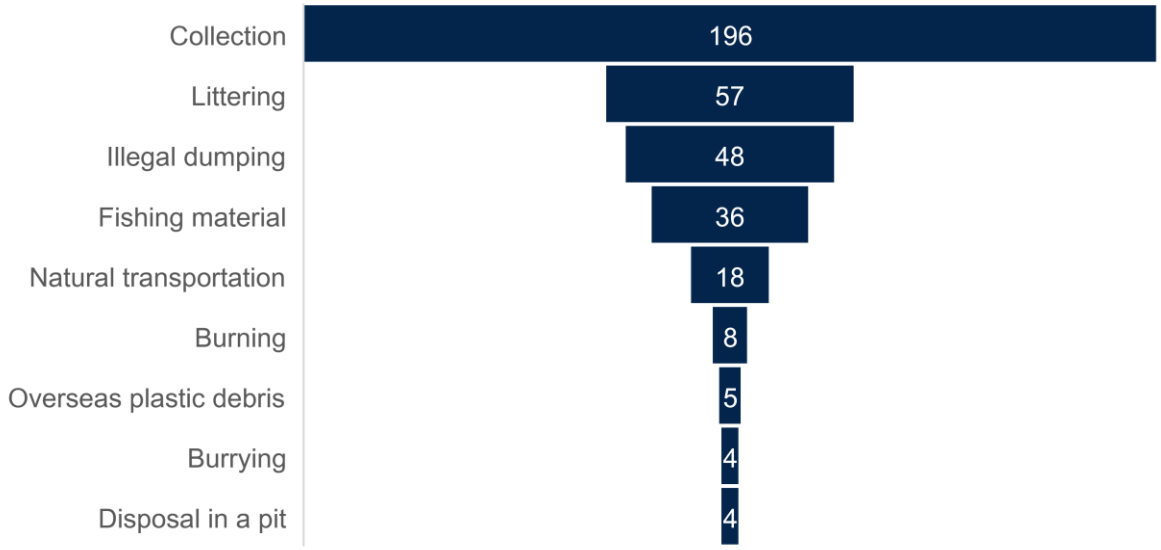


Figure 15. Frequency of codes for each flow.

Because each flow is a sub-theme in the codebook (clustered under Theme 1 - 'Flows', which answers RQ1), their ID is a capital letter, assigned according to the following legend:

- Collection = C
- Littering = L
- Illegal dumping = I
- Fishing material disposal = F
- Natural transportation = N
- Burning = B
- Overseas plastic debris = O
- Burying = R
- Disposal in a pit = D

The codes distributed under each sub-theme provided answers to the sub-questions a, b, c and d, and were identified by colors in the codebook:

a) What are the main characteristics of the flows? - yellow
b) Which stakeholders are part of each flow? - blue
c) What are the roles and functions performed by the stakeholders? - gray
d) What are the properties of the stakeholders? – light blue

The hierarchy diagram of flows is presented in Annex 3. As explained earlier, the challenges of the system (to be addressed by decision-makers) were signalled with a pink box. They answered RQ3.

Furthermore, for each flow a sub-system is exhibited. Although the sub-systems are excerpts of the final model, it is important to remark that their presention in this section does not follow the system dynamics' theory meticulously. As an example, some stocks do not have inflows, which violates one of the system dynamics principles. However, for the sake of clarification, some inflows, outflows, and relationships with other flows were omitted. Nonetheless, they will be displayed entirely in Section 3.5. In the model, plastic waste was denominated 'PW'.

3.2.1. Collection

Collection of plastic waste (sub-theme C) is performed by six stakeholders (sub-sub-themes): government, community-based organizations (CBOs), informal collectors, social enterprises, private companies, and non-governmental organizations (NGOs).

The collection made by the government (a responsibility of the county) is a flow from the public containers to the public dumping sites. There is one dumping site in Kwale, two in Mombasa and three in Kilifi. No separation is made neither at source nor during collection, hence streams remain mixed in the landfill. A great part is burned in the dumping site, as shown in Figure 16. Vulnerable families (informal collectors) work in precarious conditions at the dumping site, separating recyclable materials to sell. There is no equipment and children as young as 4 years-old are subject to serious health and security risks.

Figure 16. Kinondo dumping site, the only one in Kwale County.

Moreover, the county collects broken fishing nets from the BMUs (Beach Management Units), which are also taken to the dumping site. The subsystem of collection by the government is demonstrated in Figure 17:

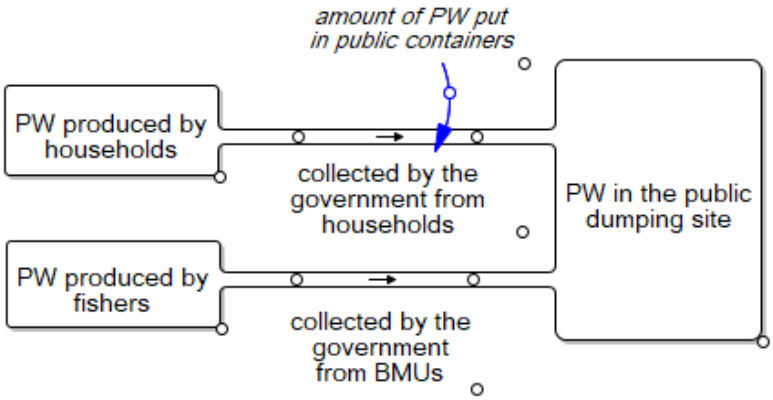


Figure 17. Subsystem model for ‘Collection by government’.

Typically, community-based organizations (CBOs) perform their activities either by collecting recyclable waste from the households for a fee or buying material from informal collectors to resell for recycling. Therefore, they need to store, sort by type and shred to reduce the volume of the material (Figure 18). For this reason, the flow caused by CBOs collection runs through three different stocks (Figure 19). The first stock is the plastic waste produced; the second is formed in the headquarters of the organization, where the material is processed. Finally, the third second stock is the plastic waste taken to recycling companies.

Figure 18. A CBO in Mombasa. In clockwise direction: Women sorting plastic by type and colour; plastic sorted by type and color, waiting to be sold (bought from individual collectors); the machine used to shred plastic, reducing the volume; hard plastic after being crushed.

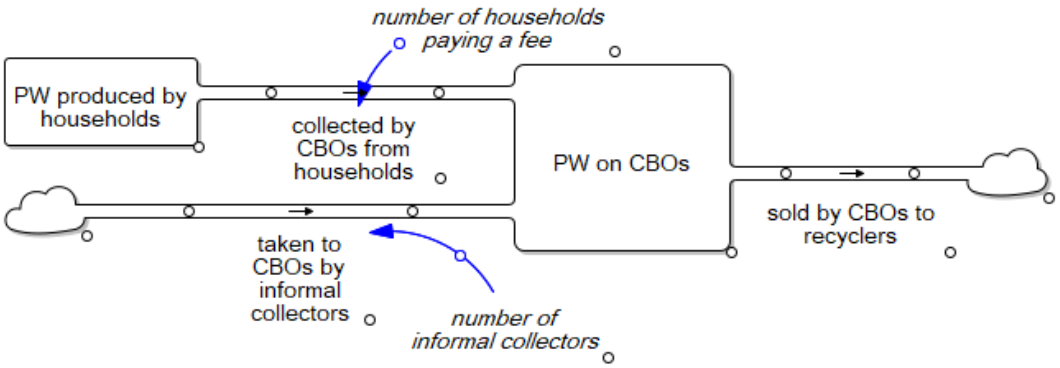


Figure 19. Subsystem model for ‘Collection by CBOs’.

The operations of social enterprises differ depending on the company, hence the flows are also different. The first type of flow executed by social enterprises is the collection from households and hotels (the case of EcoWorld's Watamu, in Kilifi). The second flow starts in the green stations, which are bins distributed in determined areas (the case of Kwale Recycling Center and, in smaller number, also EcoWorld's). Moreover, social enterprises receive great part of the plastic waste collected during street, beach and clean-ups. The flows related to social enterprises are represented in Figure 20:

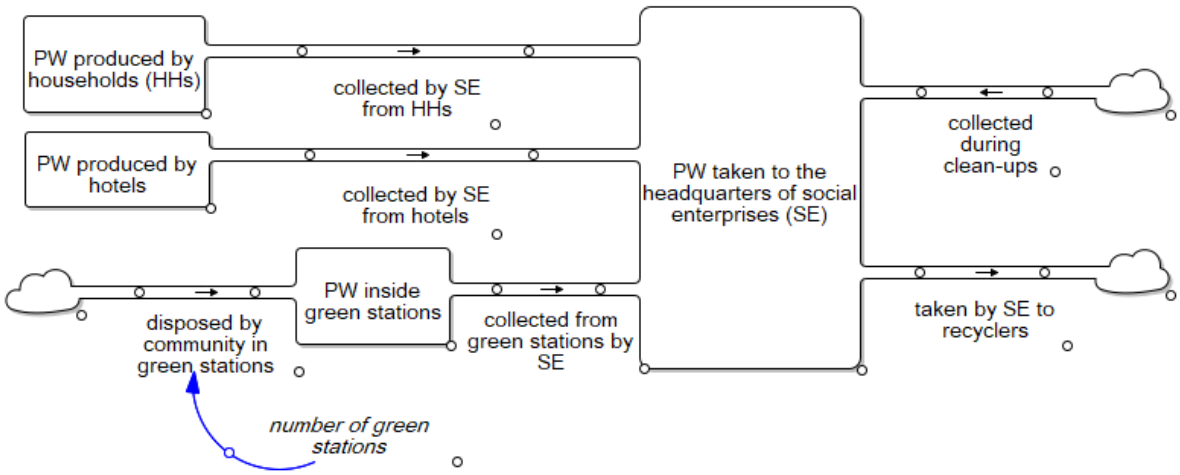


Figure 20. Subsystem model for 'Collection by social enterprises'.

The flows created by private companies carry many uncertainties, mainly because the informality is a strong characteristic of the system, as illustred by the following quotation:

> The problem is that some people engage in this business *(private companies of waste collection)*, but not officially. They do it only if they have work. Most of the times they do other businesses, but if they receive a call from someone that want the collection services, then they run and do it. (KI_31_government_sub-county_Kilifi)

Furthermore, the results revealed a significant relationship between illegal dumping and private companies of waste collection, which are considered unreliable, as explained by key informants 10 and 32:

> The first time I saw a pile of diapers laying under a tree, I thought it was from the hospital. I thought a collector had come and taken the nappies and dumped them in a place they were not supposed to be taken, which we see happening quite often. Identifying reliable service providers is not so easy. (KI_10_NGO_Kwale)

> Everybody knows that if you are using private vehicles, the chances of illegal dumping are high. The roads to the public dumping side are bad, 30, 40 minutes from here, and they are not going to go there. (KI_32_EcoWorld Watamu_Kilifi)

> You have these private services or tuk-tuks that say they are providing a service of collecting your waste to the dumping site, but they just go to the road side and illegally dump there when nobody is looking. (KI_32_EcoWorld Watamu_Kilifi)

Moreover, private companies do not always contribute to recycling. Besides practicing illegal dumping, they take a part of collection to the public dumping site, as explained by key informant 15:

> Private companies also take the waste to the dumping site, and they shouldn't. So, the amount taken there is higher *(than the amount taken by the government)*. And they are not charged for that, so they are using the dumping site for free. (KI_15_government_county_Kwale)

Figure 21 is a model of the flows created by private companies:

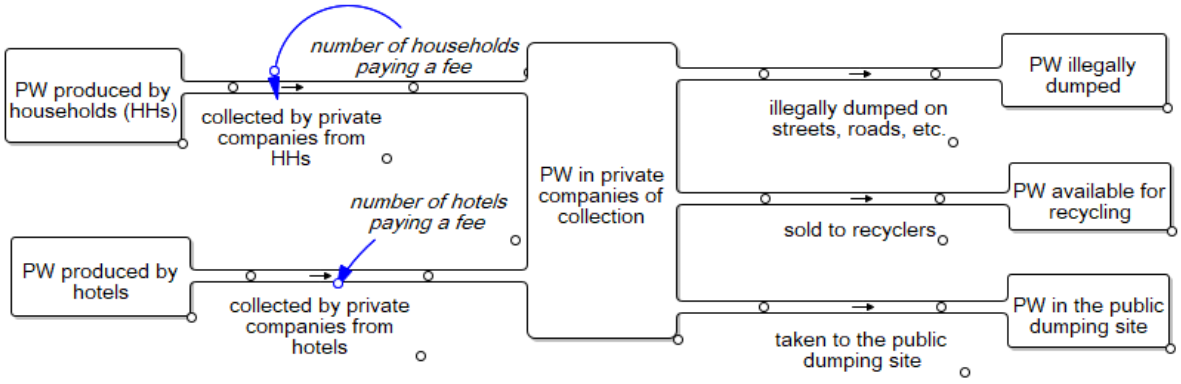


Figure 21. Subsystem model for 'Collection by private companies'.

Finally, the flows created by NGOs are related to clean-ups, particularly of the ocean and beaches. Some create a value chain for the plastic waste collected, by selling it to recycling companies and distributing the income in the community. Others donate the collection to social enterprises.

> The good thing is the community is collecting, reducing the amount of waste, and putting a value on it. Some communities take a boat, go to the ocean and collect plastics from the sea. They need some money. (KI_12_NGO_Kwale)

For this reason, the role played by NGOs is an action of prevention that impacts the clean-ups flows, as shown in Figure 22.

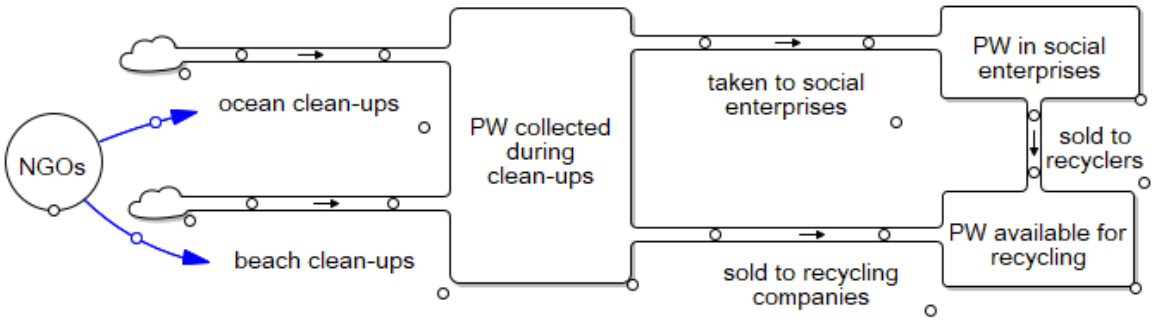


Figure 22. Subsystem model for 'Collection by NGOs'.

3.2.2. Littering

The sub-theme littering (L) was divided in three groups. The first assembles codes that provided information about the general characteristics of the flow. The second and third groups are related to the main areas in which plastic litter is deposited: streets and beaches.

Plastic waste is ubiquitous in the study area. There is plastic waste in drainage systems, along roads, at the beach and even in remote rural areas (Figure 23). PET bottles and lack of surveillance were mentioned as critical issues. The main stakeholder involved is the community, considered the main challenge related to this flow, as revealed by the following quotations:

> Community is the biggest problem. If you go to a hotel, you don't take a plastic bottle and they won't give it to you. They use glasses. You might find bottles here *(shows the water he is drinking)*. (KI_7_NGO_Kwale)

> Everybody has their own mind, own thinking. Maybe if you put a bin here, I can throw a bottle in the ground anyway. (KI_8_CBO_Kwale)

> And of course if you have a plastic bottle and you are riding a tuk-tuk or a matatu (*minibus used for public transportation*), you drink it and just throw them out of the window. (KI_10_NGO_Kwale)

Figure 23. Plastic waste in a drainage system in Ukunda, Kwale; PET bottles along a busy road in Likoni, Mombasa; a PET bottle in an isolated rural area of Kwale County; plastic litter in front of a house (division of Mombasa and Kwale).

At the beach, besides the PET bottles, small pieces of plastic are a critical issue in Kenya. Key informant 32 explained why:

> The number one offender is from Wrigley's PK *(a chewing gum brand)*, because the Swahili people use mara, or khat. Since khat has a bitter taste, people use the chewing gum to compensate the taste and leave the packaging on the beach. The alternative solution would be another material, a wax paper. (KI_32_EcoWorld Watamu_Kilifi)

A remarkable concern expressed by the respondents was the likelihood of plastic litter being transported by surface runoff and wind directly to waterbodies, sensitive areas such as mangroves, or up to drainage

systems. When the last occurs, rain will transport the plastic waste to rivers, and the final flow is towards the ocean.

Figure 24 shows how the littering flows can be modelled:

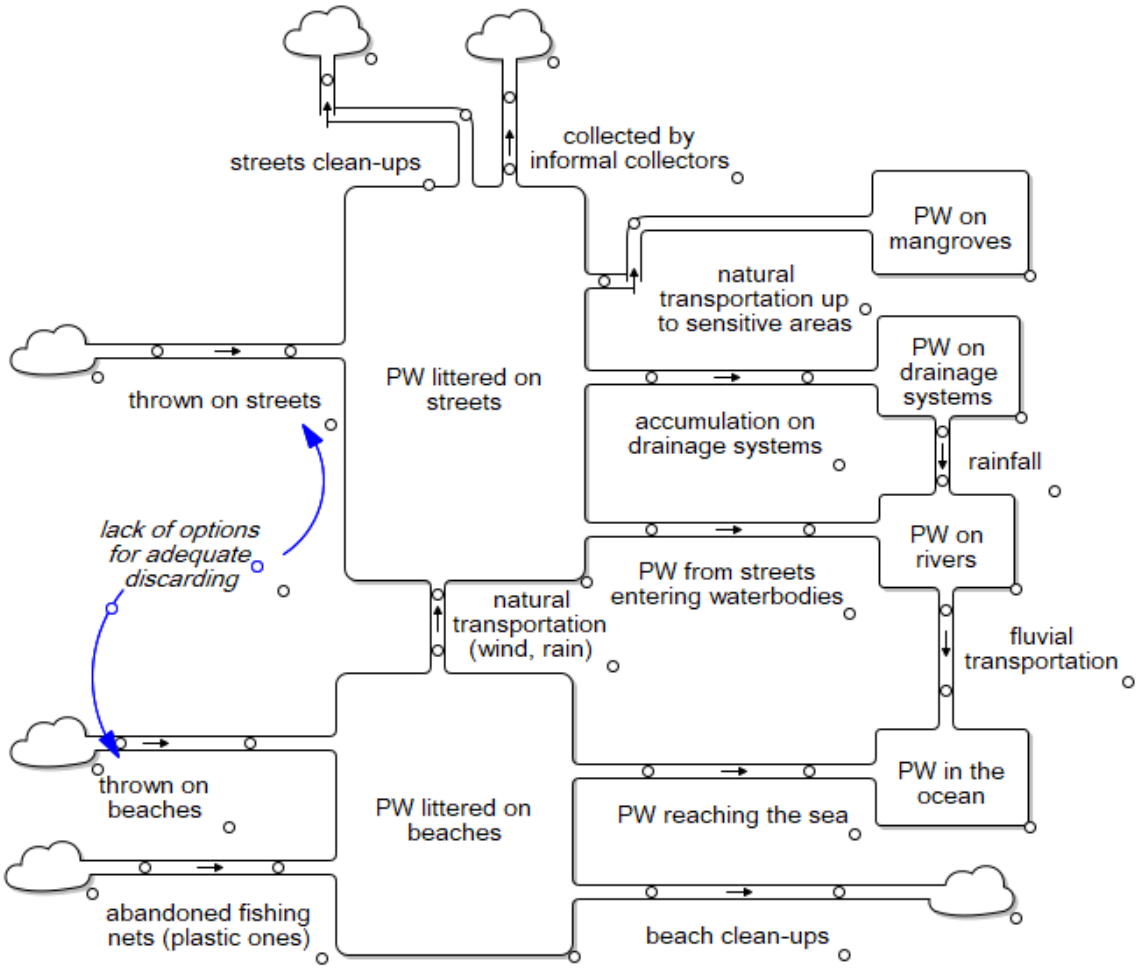


Figure 24. Subsystem model for ‘Littering’.

3.2.3. Illegal dumping

Observations demonstrated that illegal dumping is a very common mode of disposal in urban areas (Figure 25). The degree of illegal dumping of plastic waste is related to economic development, in the sense that the higher the income, the higher the purchasing power, hence more plastic waste is generated. The habit of illegally dumping waste in drainage systems also seemed to be a great source of concern among the interviewees.

> There are areas in which the waste is dumped on drainage systems because they know when the water comes, it will carry away. (KI_14_government_municipality_Kwale)

(The amount dumped) In drains and waterways is around 5% *(key informant's estimate)*. There is the issue of containers being far from their home, so they do not carry there. Awareness is being enforced to reduce that amount (KI_15_government_county_Kwale)

Figure 25. Areas of illegal dumping in Ukunda, Kwale (left), and at the entrance to Nyali Beach, Mombasa.

As previously mentioned, illegal dumping is also frequently practiced by private companies of collection, which are seen as unreliable for this reason. Moreover, key informants mentioned a relationship between illegally dumping and burned plastic waste. This will be further discussed in Section 3.2.6. - Burning.

Figure 26 illustrates the model of illegal dumping:

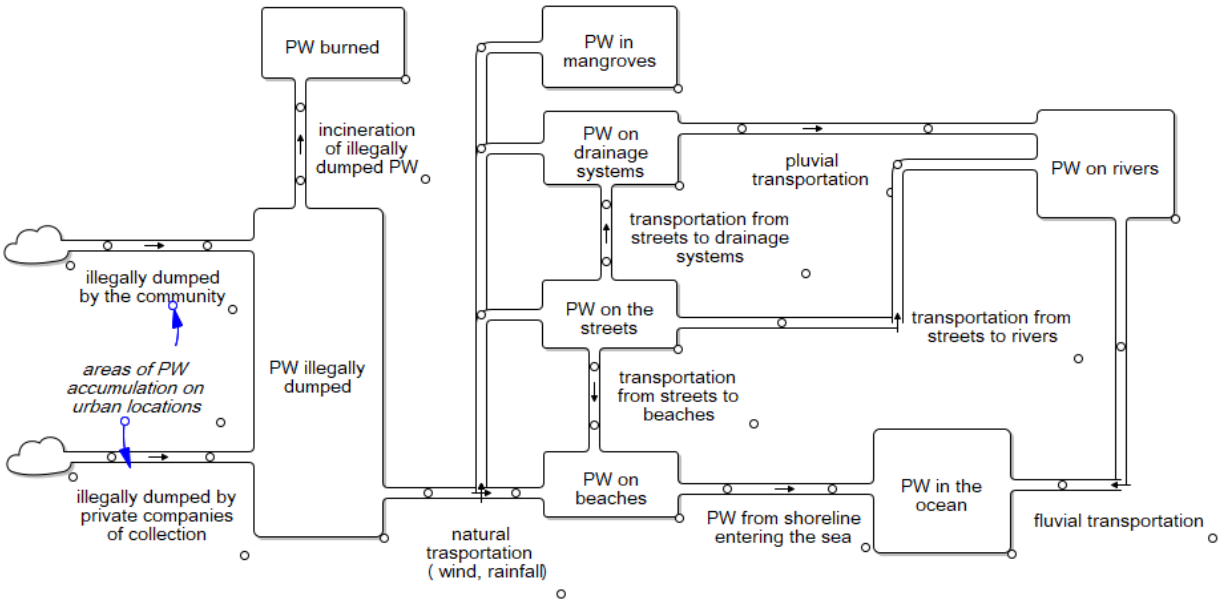


Figure 26. Subsystem model for 'Illegal dumping'.

3.2.4. Disposal of fishing material

The disposal of fishing material (plastic fishing nets and PET bottles) was grouped in a specific sub-theme due to being subject to different types of flows, as demonstrated by the following quotation:

> Sometimes, when a gear is lost, we talk to fishers from another BMU and they can be found. When we recover, we burn or take home to use for other stuff. The county collects some too. (KI_24_BMU 3_Kwale)

Fishing nets that break and go out of use are usually collected by the county or burned. However, the fishing material that breaks in the sea and cannot be recovered is a direct source of marine plastic pollution.

Although illegal, monofilament nets, which are made of plastic, are extensively used due to their efficiency in catching fishes. However, they represent a great threat to marine wildlife. This issue was discussed by researchers from the Technical University of Mombasa (TUM) and the Kenya Marine and Fishery Institute (KMFRI) during an event that occurred in Diani (Kwale), in March/2022. The event, called 'Partnerships in Plastic: Creating a Circular Economy for Plastics in the South Coast', was promoted by an NGO and gathered several stakeholders involved with plastic waste management in Coastal Kenya.

The use of illegal fishing nets is also recognized by the government, as demonstrated by the following quotation:

> As government, we are doing sensitization here and there and also giving them *(the fishers)* legal gears. The monofilament gears are illegal because of the plastic material, that takes years to degrade. So, once it is destroyed and lost in the sea, it becomes what we call ghost fishing: it will fish, nobody will collect, and it will keep swimming on the ocean. That's why it is illegal. So the county provides the legal gillnets, that degrade faster and the holes have two inches. We don't provide them every time. We provide a piece hoping they will buy the same type next time. (KI_16_government_county_Kwale)

Monofilament nets, however, are not the only plastic material used by fishers. Hook and line are also made of plastic, and fishers use PET bottles as buoys.

> We also have lots of plastic bottles. Fishers use a lot. For instance, when they use basket traps, they need to locate them. And for that they need a buoy. They use plastic bottles for that, because it is the locally available material. After using them, they are just going to dump them anywhere, and this means they are generating direct waste into the ocean. (KI_16_government_county_Kwale)

> For example, the hook and line. Why do they have to insist in plastic ones when there are other materials? They say the fish cannot see it, that it is invisible in the water, and it is the same thing with the gillnet *(monofilament, illegal net)*. They *(the legal ones)* are appropriate, they work the same way as plastic gears. The monofilament gears are already illegal, but the hook and line are legal regardless the material. (KI_16_government_county_Kwale)

Both government and fishers agree that improving the quality of the gears would reduce the amount of material directly entering the sea.

> The bad quality can also be related to the type of plastic used to fabricate that gear. There are all kinds of materials, and some are cheaper. Maybe the fisher doesn't want to buy a particular kind of gear, but it is a matter of price. (KI_16_government_county_Kwale)

> The quality is very bad, they *(fishing nets)* break more. More money would help. (KI_25_BMU 3_Kwale)

A fraction of the lost material, however, is recovered by the fishers.

> We use bottles as buoys, but we do not leave them in the sea, we always try to remove. Unfortunately, some we can't. From every 10 bottles, maybe 2 or 3 are lost in the sea *(per week*). Each bottle is used by two persons. (KI_23_BMU 1_Kwale)

Figure 27 shows the model for fishing material disposal:

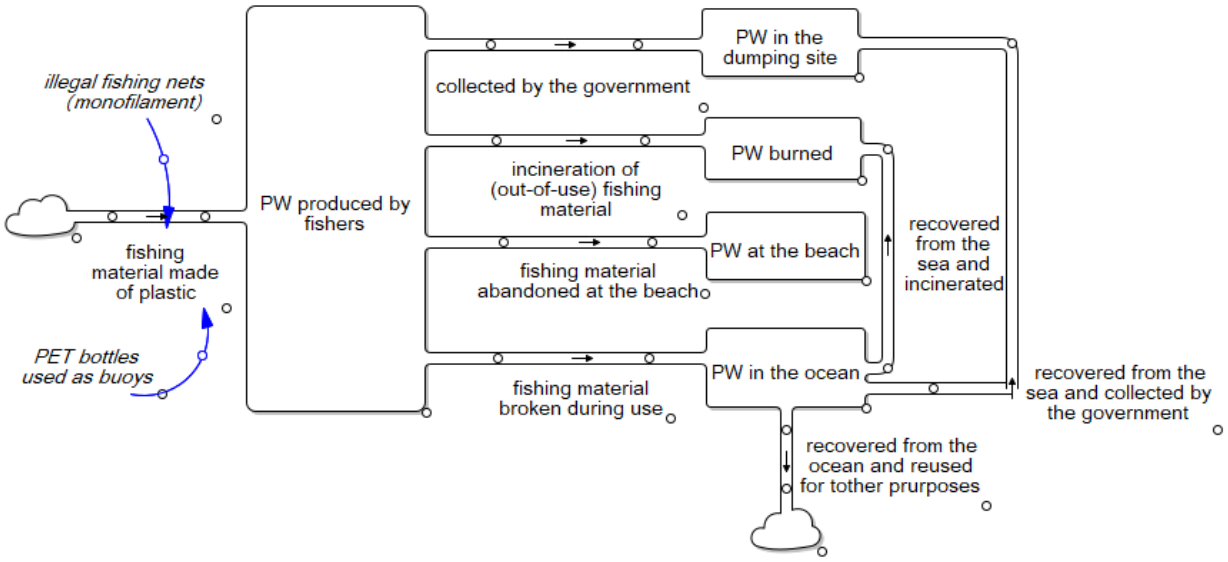


Figure 27. Subsystem model for 'Disposal of fishing material'.

3.2.5. Natural transportation

The flows created by natural mechanisms of transportation include the movement of plastic waste due to wind, rainwater and waterbodies. It is connected to other flows, namely littering and illegal dumping, and for this reason it is not a subsystem by itself.

Key informants demonstrated particular concern about the movement of plastic waste towards waterbodies during rainy season, that occurs from March to May and from October to December in East-Africa. The study area has two rivers: Congo River, in Kwale, and Sabaki River, in Kilifi.

> Most of the waste that is in the tunnels ends up in the ocean or Congo. In the bridge we have when you are crossing towards Tiwi, we have a small tunnel on the right-hand side. So, when it rains, that tunnel normally has a lot of waste, all kinds of waste: plastics, glass, paper, everything. Once it rains a bit, it flows into the river and the river can take it to the ocean. (KI_9_Kwale Recycling Center_Kwale)

3.2.6. Burning

Burning was considered by the key informants the most common mode of disposal. This sub-theme was divided in rural areas, urban areas, and a third group that includes dumping sites and fishing nets. The last was already discussed, in section 3.2.4. – Disposal of fishing material.

Because rural areas have their waste seldomly collected or not collected at all, residents opt for incineration. In urban areas, burning is a consequence of illegal dumping.

> Burning is the most common disposal. If you walk around Watamu or Malindi *(urban areas of Kilifi)*, you will see open dumping everywhere. And then somebody will burn it. So open dumping and burning are almost the same. You see this pattern repeated again and again. (KI_32_EcoWorld Watamu_Kilifi)

Figure 28 shows two examples of waste being burned in urban areas:

Figure 28. (Left): Waste being burned in an urban area (vacant plot), in Watamu, Kilifi; waste being burned on a road that connects Kilifi and Mombasa counties.

This flow can modelled as shown in Figure 29:

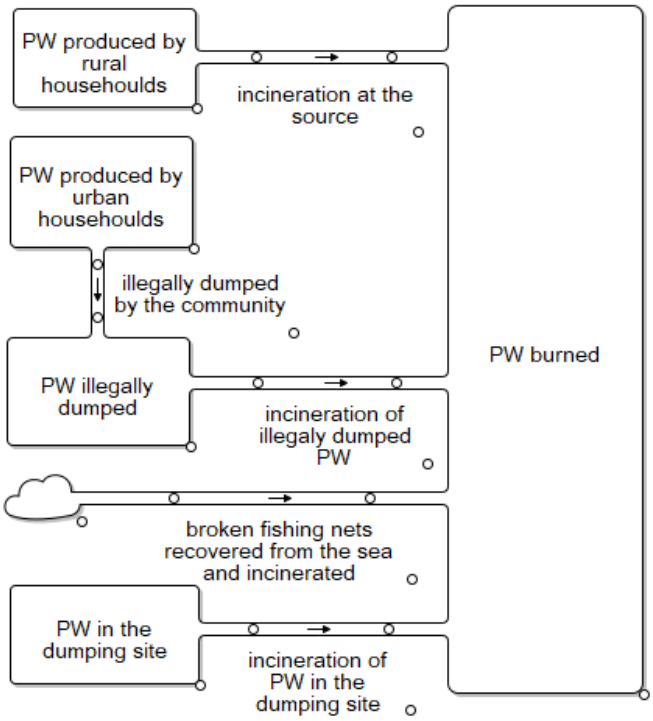


Figure 29. Model of the subsystem 'Burning'.

3.2.7. Overseas plastic debris

Part of the plastic waste found in Kenyan beaches has its origin in other countries. The source of the object can be traced back through the brand. However, there is some uncertainty about the amount, as shown by the contradictory statements below:

> Most of the plastic waste in the county comes from overseas: Madagascar, Somalia, Tanzania. (KI_15_government_county_Kwale)

> The majority of plastics found on beaches is from Kenyans, from littering, illegal dumping. This was quite a surprise. We used to believe that a lot of waste found on the beaches was washed off from the ocean. It is one of those tricks your eyes play on you: you see a bottle coming from the sea and think it's coming from Tanzania. But when you brand it, you see majority is from Kenya. (KI_32_EcoWorld Watamu_Kilifi).

Overseas plastic debris is part of the stock 'PW littered on beaches'. Nonetheless, it was not included as a flow in the model because actions of prevention conducted in Kenya are not able to influence it. Stocks and flows are only subject to internal dynamics, and therefore always have an endogenous point of view (Richardson, 2011).

3.2.8. Burying

Burying plastic is a typical habit in rural areas and can be modelled in a straightforward manner: a flow from the producers (rural residents) to the stock of buried plastic waste. There is a strong cultural aspect attached to it, as explained by the following quotations:

> Our people stick to traditional ways of doing things. Burying is one. (KI_14_government_municipality_Kwale)

> Many people are afraid waste can be used for other purposes, against you, like with diapers in some religions, for example, mainly in rural areas. (KI_15_government_county_Kwale)

3.2.9. Disposal in a pit

Disposing plastic waste in a pit is also more common in rural areas than in urban ones, as explained by respondent 14:

> Here, there are places we call “dzalas”. People dig a hole and dump things on it. This is traditional and still happens. (KI_14_government_municipality_Kwale)

A touristic facility located in an urban area declared that the plastic waste used in the hotel (especially PET bottles) is disposed in a pit.

> Plastic is a problem for us, we don’t know what to do with it. Sometimes collectors come and pick, but they take around two sacks and we have much more. So, we put it in a hole behind the swimming pool. (KI_20_2-star resort_Kwale)

Like the burying flow, disposal on a pit is a simple flow from the producers (mainly rural residents) to the stock of plastic waste in pits.

3.3. Prevention (RQ2)

The actions of prevention (P in the codebook) are related to the second research question of this study: ‘*What are the actions put in place to prevent marine plastic pollution?*. This RQ has two sub-questions, which will be addressed in the next pages.

First, quotations attached to the codes of theme P (a total of 196 quotations) were analysed in the light of the following sub-question:

- Which stakeholders are involved in the actions?

The results of the analysis were presented in Table 5. Furthermore, the quotations that yielded the results for each of the rows are indicated in Annex 4.

Table 5. Matrix of actions of preventions and stakeholders involved in their implementation.

		Stakeholders								
IDs	**Row number / Action of prevention**	Community	Social enterprises	Government	NGOs	CBOs	Fishers	Hotels	Private sector	Informal collectors
Pa119, Pa121, Pa122, Pa123	1. Awareness is being created by		■	■	■	■			■	
Pd140, Pd141, Pd142	2. Implementation of green stations by		■		■				■	
Pg153, Pg154	3. Zero-plastic environment adopted by							■		
Pi170, Pi172, Pi173	4. Implementation of EPR* planned by		■	■					■	
Pf148, Pf151	5. Implementation of PPPs** by		■	■					■	
Pc136, Pc138	6. Ban of plastic bags (put in place in 2017)			■						
Ph162, Ph166	7. Collection of pw is a source of income for	■						■		■
Pb128	8. Beach clean-ups are promoted by	■	■	■	■			■		
Pb127	9. Ocean clean-ups are carried out by	■			■		■			
Pb129	10. Street clean-ups are carried out by	■		■				■		
Pf150	11. Projects to fill in data gaps developed by		■	■	■					
Pg156	12. Separation of waste streams executed by		■		■	■		■		■
Ph163	13. Reuse is adopted by	■								
Pf152	14. Research conducted by		■	■						

* Extended Producer Responsibility

** Public-private partnerships

The second sub-question of RQ2 was:

- Which flows are affected by the actions of prevention?

The results for this question were presented in Table 6, in descending order of frequency of mentions (maximum 23, minimum 2). The rationale for each row is presented below the table and was based on information provided by the 196 quotations of Theme P.

Table 6. Cause and effect matrix for actions of prevention. The minus sign indicates a decrease in the flow, while the plus sign indicates an increase in the flow.

Frequency bar (mentions)	Row number / Actions of prevention (cause)	Flows affected by the actions (effect)							
		Collection	Littering	Burning	Illegal dumping	Burying	Disposal on a pit	Abandoned fishing material	PW naturally transported
23	1. Awareness creation		-	-	-			-	-
13	2. Implementation of green stations	+	-	-	-				-
10	3. Zero-plastic environment	-	-	-	-	-	-		-
9	4. Implementation of EPR*	+							
8	5. Implementation of PPPs**	+	-		-				
5	6. Ban of plastic bags		-	-	-	-	-		-
5	7. Collection is a source of income	+	-	-	-				-
4	8. Beach clean-ups		-					-	
4	9. Ocean clean-ups							-	
2	10. Street clean-ups		-						
2	11. Reuse	-	-	-	-	-	-	-	

* Extended Producer Responsibility

** Public-private partnerships

Rationale:

1. **Awareness creation** was mentioned by the key informants as an important cause of reduction on littering, illegal dumping and burning. Consequently, natural transportation of plastic waste is also a result of this reduction. Among fishers, the increasing level of awareness is important to reduce the use of illegal fishing nets and encourage the collection of broken material, both from beaches and in the ocean, as exemplified by this quotation provided by a fisherman:

> We know the negative impacts of the nets in the ocean. We gather 4 or 5 men, then go in a boat to try and recover the broken pieces. (KI_23_BMU 1_Kwale)

2. **Green stations** (Figure 30) are garbage bins distributed in areas of high population density, usually with four compartments for separation of plastic, metal, glass and paper. The county government also has separation containers, but in small number. Kwale Recycling Center is responsible for 19 green

stations along the approximately 13 km of the road in its area of operation (Diani, Kwale). In the case of EcoWorld, a project called 'Plastic Recycling Point' is developed in partnership with the Kenya PET Recycling Company (PETCO), as explained by key informant 32:

> With PETCO we put some bottle bank containers, which we put in Marine Parks in Watamu and Mombasa, and some town centres. That's what we call a green station, a public plastic waste container where people can drop their plastic. So, this is a small project, but it's the first time we have that kind of engagement with the industry. It is a beginning. (KI_32_EcoWorld Watamu_Kilifi)

The plastic waste deposited in the green stations is collected by social enterprises and subsequently recycled. Furthermore, green stations are an option for the adequate disposal of plastic waste, hence reduce the amount of plastic waste littered, burned, and illegally dumped. Because green stations are placed in urban areas, they do not affect flows typical from rural areas, namely burying and disposal in a pit, and flows created by fishing activities.

Figure 30. Clockwise direction: Green stations implemented by an NGO, by the government, by EcoWorld Watamu and by Kwale Recycling Center.

3. Results suggested that hotels are seen as very sustainable both by themselves and by all other stakeholders, as the following quotations demonstrate:

> Most of the hotels have a special agreement either with the county or with private dealers. Most of them deal with private sector. Hotels are not a problem for the plastic pollution. (KI_31_government_sub-county_Kilifi)

> They *(hotels)* are very aware of best practices and want to be seen as excellent. So, they are going to use the best available service. (KI_32_EcoWorld Watamu_Kilifi)

> Hotels do realize their business rely on a clean environment, so even in terms of regulation, licensing, making sure that waste is collected. Many hotels have their own garbage collection centres. (KI_6_government_county_Mombasa)

Approximately 70% of the hotels adopt a **zero-plastic environment**, thus eliminating the flows related to plastic waste management.

> We *(5 star-resort)* don't have plastics. Not at the restaurant, not at the bedrooms. If guests bring PET bottles with them, they are asked to dispose them in a garbage bin. The owners respect sea creatures. I believe 70% of the hotels and resorts in the coast do that. In the last years, you see much less *(PET)* bottles on the beach. (KI_19_4-star resort_Kwale)

4. Although still in the very first stages of planning, **implementation of EPR** is expected to increase the responsibility of producers of plastic waste with collection.

> We are hopeful about the EPR regulations, that they will be implemented, that the industry will be complied. Because it is good for the industry too, it is good to show that you are part of the solution. It is a good opportunity for responsible business, for CSR *(Corporate Social Responsibility)*, it is a good opportunity to invest in recycling. I think we are going to see some progress more than ever before this year. (KI_32_EcoWorld Watamu_Kilifi)

5. **PPPs** (public-private partnerships) are conducted by the government and social enterprises, which sometimes use the county's vehicles to collect plastic waste, and by the government and private companies:

> The county has a partnership with the private sector, with *(mentions the company)* to develop education/awareness projects in schools, and they have been seeing a positive change on disposal of waste, recycling. (KI_15_government_county_Kwale)

6. The **ban of plastic bags** was very successful in Kenya (not only the Coast) due to the support from local community:

> When we banned plastic bags, we literally didn't know how to substitute them. We were 250, 300 technical officers trying to enforce this plastic ban in a population of 47 million people. It was actually the people who made our work quite easy. Because if they continued to use plastics bags, they would probably still be in the environment. Even with other organs to assist, like police and county government, it was the public that decided. So, attitude really helps and is also the biggest challenge. They really assisted us on carrying on the plastic bags. (KI_6_government_county_Mombasa)

By eliminating the plastic bags, the government was also able to reduce the volume of plastic waste at risk of becoming part of mismanaged flows.

> Before the ban, many activities made use of plastics – for example, fishes were sold ready to cook, in plastic bags. The ban was very effective, but now the bottles are a huge problem. (KI_3_Research Institute_Kwale)

7. Because plastic waste can be sold for recycling companies, **collection is a source of income** for CBOs, NGOs, social enterprises, and informal collectors (waste pickers). The higher the degree of collection, the less plastic waste will remain littered on the environment, being burned, illegally dumped and transported by natural mechanisms.

8. During **beach clean-ups,** plastic waste (including fishing nets) is collected from the shore.

9. **Ocean clean-ups** are a strategy used to reduce the stock of plastic waste in the sea. Fishers try to recover material lost during fishing. Moreover, NGOs encourage the community to collect plastic waste from the sea.

10. **Street clean-ups** reduce the amount of plastic waste littered on urban areas.

11. **Reusing** plastic products reduces the amount of material at risk of becoming mismanaged. However, this reduction is momentary, since at some point the object will become waste, as detailed by key informant 9:

> People try to reuse it *(plastic containers)* for seedbeds, flowerpots and stuff like that, but it is not that sustainable, because a part of them, if you are using for seedbeds, when you transplant what was inside, you have to cut it open. The challenge is, after you cut it open, now it has no use and it will be dumped. So, people try to reuse them, but it not really sustainable. (KI_9_Kwale Recycling Center_Kwale)

Figure 31 shows an example of plastic bottles being reused for planting.

Figure 31. An example of reuse: PET bottles used as flowerpots for sale in Diani (Kwale).

3.4. Challenges (RQ3)

As previously explained, the challenges always have an effect on other elements of the system. For this reason, they were not considered in isolation, but distributed throughout the codebook. The challenges are related to the following research questions:

RQ3: What are the processes that contribute to plastic waste entering the sea?

- What are the challenges that affect the flows?
- What are the challenges that affect the stakeholders?
- What are the challenges that affect actions of prevention?

To answer these questions, a cause and effect matrix was created. The rows contain all challenges identified during the thematic analysis (accompanied by IDs, so they can be found in the codebook), and the columns contain the flows, stakeholders and actions of prevention affected by the challenges. The relationship between the challenges and the flows, stakeholders and actions of prevention that are impacted by them (the coloured cells) was defined through the content of the quotations to which the code (challenge) was attributed. To clarify this methodology, an example will be used.

The code '*PET bottles have low value when sold for recyclers'* (IDs Cb35, Cc35, Cd35, Cf35) was used three times during the thematic analysis process. This means that the code had three quotations:

- You see, for flip flops we get 30 Ksh *(Kenyan schillings, Kenya's currency)* per kilo. Plastic bottles, only 16 Ksh per kg. And it started at 10 *(Ksh per kg).* An institution in Shimoni, which is part of the committee, is responsible for shredding the PET bottles to sell the buyers in small pieces, so they can carry more in the lorry. I hope we can set the price higher because of that. (KI_12_NGO_Kwale)
- The problem is plastic bottles do not have the highest demand *(for recycling)*, that is why we don't collect many. For us it is better to collect the hard plastic, because the demand is high. But for plastic bottles, we can get maybe 1 Ksh per bottle, is very little. We do bring them *(PET bottles)* because they are needed by people who sell juice, for instance. Then they are reused, not recycled. They are used by people who drink juice, cold water. (KI_8_CBO_Kwale)
- The PET bottles still have a very low value in the market. One of our goals is working with the industries to try and increase the value, so we get more of it. We *(social enterprise)* get around 10 Ksh for a kilo of PET. The more informal dealers are given 1 or 2 Ksh a kilo. So that doesn't incentivize people to collect them. (KI_32_EcoWorld Watamu_Kilifi)

Together, these quotations provide information about how the low value of PET bottles affects collection (a flow); NGOs, CBOs, social enterprises, and informal collectors (stakeholders); recycling; and circular economy (little collection and PET bottles that do not return to the market as recycled materials). As explained in the Methodology chapter, the selection of quotations presented in Annex 4 was based on the extent to which it supports the comprehension of the code. In this example, the quotations selected for Annex 4 were the first and second ones. The third quotation, although providing important contextual information, is self-explanatory in relation to the code '*PET bottles have low value when sold for recyclers'* and for this reason was not included in te Annex. Nonetheless, it is accessible in the software of qualitative coding (ATLAS.ti) and can be easily retrieved.

Table 7 shows the challenges with more than two mentions, in descending order of frequency. Annex 5 contains the codes that were only mentioned once or twice.

Table 7. Matrix with challenges (with respective code IDs) and indication whether they affect flows, stakeholders and/or actions of prevention.

		Flows affected											*Stakeholders affected*								*Prevention affected*						
ID(s)	*Challenges and frequency of mentions*	Collection	Littering	Burning	Illegal dumping	Burying	Disposal on a pit	Fishing material	Natural transportation	PW directly entering sea	Dumping site capacity	PW in sensitive areas	Community	Government	Social enterprises	CBOs	NGOs	Fishers	Informal collectors	Hotels	Plastic bags ban	Clean-ups	Green stations	Recycling	Circular economy	Zero-plastic env.	*COUNT*
G4, Fc104	People do not have options for adequate discarding (16)	■	■	■	■	■	■	■	■			■	■									■		■	■		13
G1	Separation is almost zero (14)	■									■			■	■	■			■			■	■	■	■		10
G14, X174, X175, X178, X179, X180	Data gap (13)	■									■		■	■	■									■	■		7
Lb74, Lb76, Ic74, N74, N76	PW is transported by water and wind (11)								■			■	■									■					4
G6, Ia85, Ia86, Fa97	Lack of surveillance (10)		■	■	■			■	■		■	■	■	■				■						■	■		12
La66	Littering is a built-in behaviour (9)		■						■			■	■							■			■		■	■		8
La67, Ia85	Lack of awareness (9)		■	■	■	■		■	■	■		■	■	■	■			■					■	■	■	■		16
G8, La70	Creating awareness takes time (7)	■	■	■	■			■		■				■	■		■						■	■	■	■		13
Ca24	Rural areas do not have collection (7)			■		■	■						■											■	■		6

		Flows affected											*Stakeholders affected*								*Prevention affected*						
ID(s)	*Challenges and frequency of mentions*	Collection	Littering	Burning	Illegal dumping	Burying	Disposal on a pit	Fishing material disposal	Natural transportation	PW directly entering sea	Dumping site capacity	PW in sensitive areas	Community	Government	Social enterprises	CBOs	NGOs	Fishers	Informal collectors	Hotels	Plastic bags ban	Clean-ups	Green stations	Recycling	Circular economy	Zero-plastic env.	*COUNT*
Cb37 Cc44, Ce57 Cf65	Informality (7)															■			■								2
La69	PET bottles are a critical issue (6)		■		■				■				■	■								■					6
Cb36 Cb39 Cf64	Economic difficulties (5)	■														■											2
Ra112 Da114	Cultural aspects and traditions (5)					■	■																				2
Fa96	Illegal fishing nets are used (5)									■																	1
Fa98	Some fishing nets are lost in the sea and cannot be recovered (5)									■																	1
G10	Urbanization is a driver of plastic waste pollution (4)	■	■	■	■	■	■	■	■				■	■								■					11
Cb34 Cc34	Plastic value has low value when sold for recyclers (4)	■														■	■							■			4
Cb40 Pb134	Volunteer work is a challenge (4)	■																				■					2
La68 Ia68 N68	PW gets trapped in mangroves (4)											■															1

		Flows affected											*Stakeholders affected*								*Prevention affected*						
ID(s)	*Challenges and frequency of mentions*	Collection	Littering	Burning	Illegal dumping	Burying	Disposal on a pit	Fishing material disposal	Natural transportation	PW directly entering sea	Dumping site capacity	PW in sensitive areas	Community	Government	Social enterprises	CBOs	NGOs	Fishers	Informal collectors	Hotels	Plastic bags ban	Clean-ups	Green stations	Recycling	Circular economy	Zero-plastic env.	*COUNT*
Ib87	Illegal dumping creates areas of accumulated PW (4)								■			■	■	■													4
Ib88	Use of disposable diapers has been increasing (4)				■	■							■														3
Db115 Pg159	Water bottles are more expensive, therefore some hotels still use plastic (4)						■													■							2
Ca25 Ba106	Public collection is insufficient (3)	■	■	■	■	■	■	■	■				■	■											■		11
Cb38	Impact of the scrap metals ban (3)	■														■			■								3
Cb35 Cc35 Cd35 Cf35	PET bottles have very low value when sold for recyclers (3)	■													■	■	■		■					■	■		7
Cd52 Pd52	Green stations are expensive (3)		■														■						■				3
Ce56 Ib56	Private companies of collection are seen as unreliable (3)				■						■																2
Lb75 N75	PW is transported by rivers (3)								■			■		■													3

Lc79 Fa79	Fishing nets are abandoned at the beach (3)																										1
Ph167	Social enterprises must achieve a regular flow to recycle locally (3)																										2
Ib89	Illegally dumped PW arrives at the beach (3)																										4
	COUNT	11	10	7	9	7	6	6	10	5	4	8	13	10	6	6	4	3	4	3	1	9	4	11	10	1	

Table 7 demonstrated that the five challenges with the highest frequency of mentions were:

- people do not have options for adequate discarding (16 mentions)
- separation is close to zero (14 mentions)
- data gap is extensive (13 mentions)
- plastic waste is transported by water and wind (11 mentions)
- lack of surveillance (10 mentions)

The challenges with the highest frequency of effect (impacting more flows, stakeholders, and actions of prevention) are:

- lack of awareness (affects 16)
- people do not have options for adequate discarding (affects 13)
- creating awareness takes time (affects 13)
- lack of surveillance (affects 12)
- urbanization is a source of plastic waste (affects 11)
- public collection is insufficient (affects 11)

The most affected flow is collection (11 challenges), followed by littering and natural transportation (10 challenges) and illegal dumping (9 challenges). Furthermore, three codes are common to these four flows:

- people do not have options for adequate discarding
- urbanization is a driver of plastic waste pollution
- public collection is insufficient

Due to the lack of direct relationship with the scope of this study, some challenges were coded, but not included in the codebook. They are:

- Organic waste (10 mentions)
- COVID-19 (4 mentions)
- Encroaching and corruption related to constructions in riparian areas (2 mentions)

3.5. Model structure (RQ4)

As explained in Chapter 2, the structure of the system dynamics model presented in this section was built in an inductive approach, through the results presented in the previous sections of this chapter. The model is presented in three parts. The first is the structure of a quantifiable model that illustrates the different stocks and flows of plastic waste in the study area. The second part includes the actions of prevention currently in place, whereas the third indicates the challenges faced by the system.

3.5.1. Stocks and flows model structure (quantifiable model)

Figure 32 follows a colour coding (randomly selected) to facilitate the comprehension of the elements of the model and their relationships. The meaning of these colours is presented in the next paragraphs.

Yellow represents the stocks and flows related to production. These are the points in which plastic products are discarded, thus becoming plastic waste. Because these points were defined through the analysis of interviews, it is possible that the system contains production stocks that are not displayed in the model. For instance, plastic waste produced by industries or by aquaculture were not mentioned by respondents when they were asked about sources of plastic waste. A probable explanation is that the number of industries is low in Coastal Kenya. However, this fact should be contemplated in future studies that might consider the model.

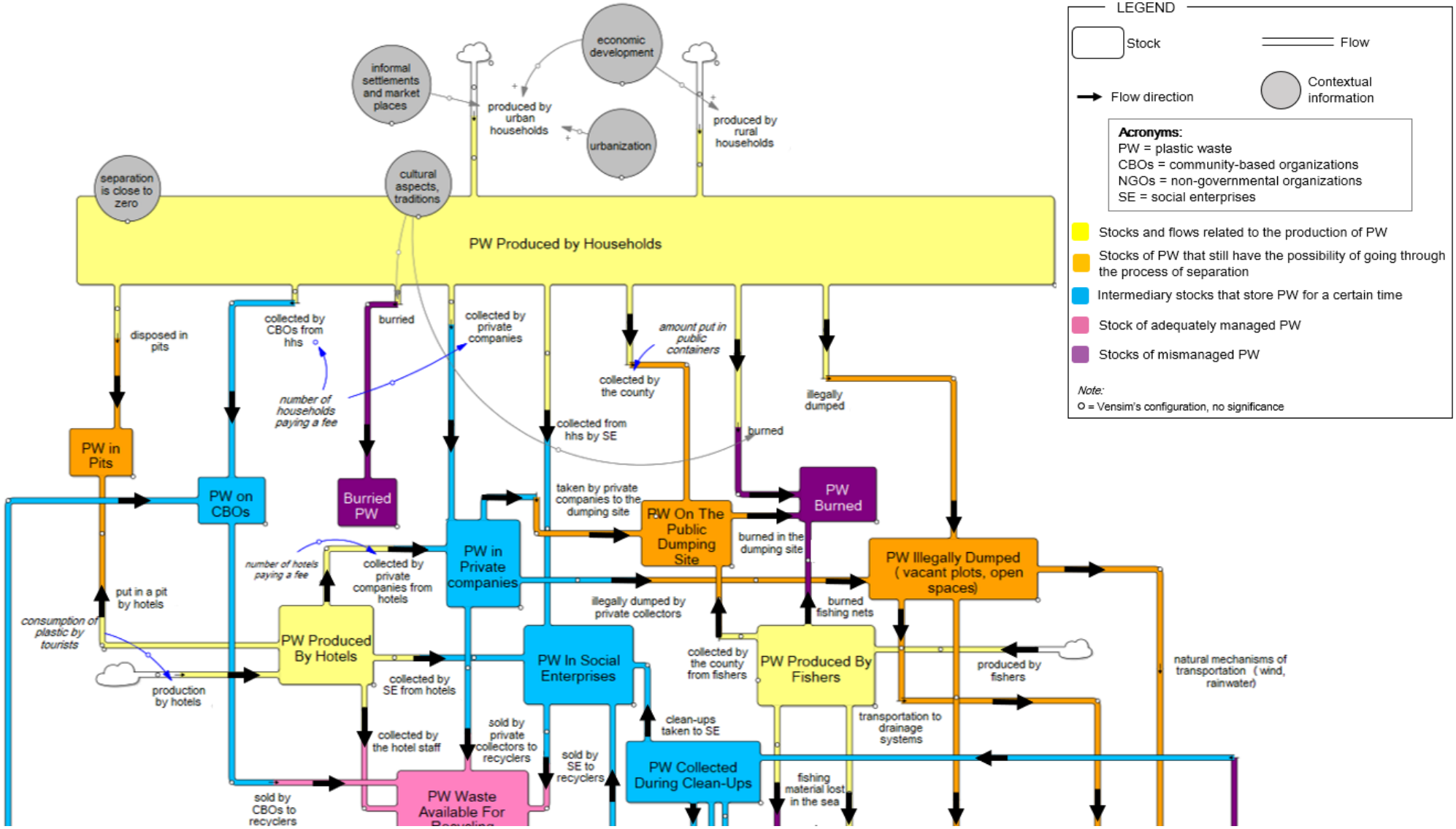
Orange represents stocks of plastic waste that still have the possibility of going through the process of separation (e.g., via clean-ups). Plastic waste accumulated in areas of illegal dumping and drainage systems are examples of this type of flow.

Blue stocks can be seen as intermediary stocks, in which the plastic waste is stored for a certain amount of time. These stocks are usually located in the headquarters of stakeholders that perform collection, namely social enterprises, CBOs and private companies of collection.

Pink was used for the stocks and flows formed by adequately managed plastic waste. The model has two pink stocks: the one formed by the material that can be recycled, and the stock of plastic waste inside the green stations, which will be collected by social enterprises.

Finally, purple represents stocks of mismanaged plastic waste that will likely not be recovered anymore. These stocks are formed by burned and buried material, by the plastic waste that have already reached rivers (hence will enter the sea at some point), and by the plastic debris that are already in the ocean. Although there are manners to retrieve plastic waste from the ocean and rivers, the processes conducted in the study area are very punctual and able to retrieve a very small number of plastic debris, in comparison to the amount that enters waterbodies (e.g., two or three persons in a boat to collect PET bottles during ocean clean-ups, as explained by the quotations linked to code Pb127).

In addition, two other elements are part of the model. The first is contextual information, represented by the gray circles. This information is neither a challenge nor an action of prevention, nonetheless is relevant for understanding the system. An example of contextual information is the code '*cultural aspects, traditions'*, which supports the comprehension of flows typical from rural areas, namely '*burying*' and '*disposal on a pit*'. The second element entails variables that were not extracted from the codes presented in the codebook, yet are necessary in the model. These variables are in italic and connected to a flow by a blue arrow. An example is '*number of hotels paying a fee*'. Although this was not a code, the thematic analysis showed that private companies collect plastic waste from hotels for a fee. Therefore, the number of hotels paying a fee is determinant for the magnitude of the flow '*collected by private collectors for a fee*'.


LEGEND
Stock
Flow
Flow direction
Contextual information
Acronyms:
PW = plastic waste
CBOs = community-based organizations
NGOs = non-governmental organizations
SE = social enterprises
Stocks and flows related to the production of PW
Stocks of PW that still have the possibility of going through the process of separation
Intermediary stocks that store PW for a certain time
Stock of adequately managed PW
Stocks of mismanaged PW
Note:
O = Vensim's configuration, no significance
economic development
informal settlements and market places
produced by urban households
urbanization
produced by rural households
separation is close to zero
cultural aspects, traditions
PW Produced by Households
disposed in pits
collected by CBOs from hhs
number of households paying a fee
burried
collected by private companies
amount put in public containers
collected by the county
collected from hhs by SE
illegally dumped
burned
PW in Pits
PW on CBOs
Burried PW
taken by private companies to the dumping site
PW On The Public Dumping Site
PW Burned
burned in the dumping site
number of hotels paying a fee
collected by private companies from hotels
PW in Private companies
PW Illegally Dumped (vacant plots, open spaces)
put in a pit by hotels
consumption of plastic by tourists
illegally dumped by private collectors
burned fishing nets
PW Produced By Hotels
PW In Social Enterprises
collected by the county from fishers
PW Produced By Fishers
produced by fishers
natural mechanisms of transportation (wind, rainwater)
production by hotels
collected by SE from hotels
clean-ups taken to SE
transportation to drainage systems
collected by the hotel staff
sold by private collectors to recyclers
sold by SE to recyclers
PW Collected During Clean-Ups
fishing material lost in the sea
sold by CBOs to recyclers
PW Waste Available For

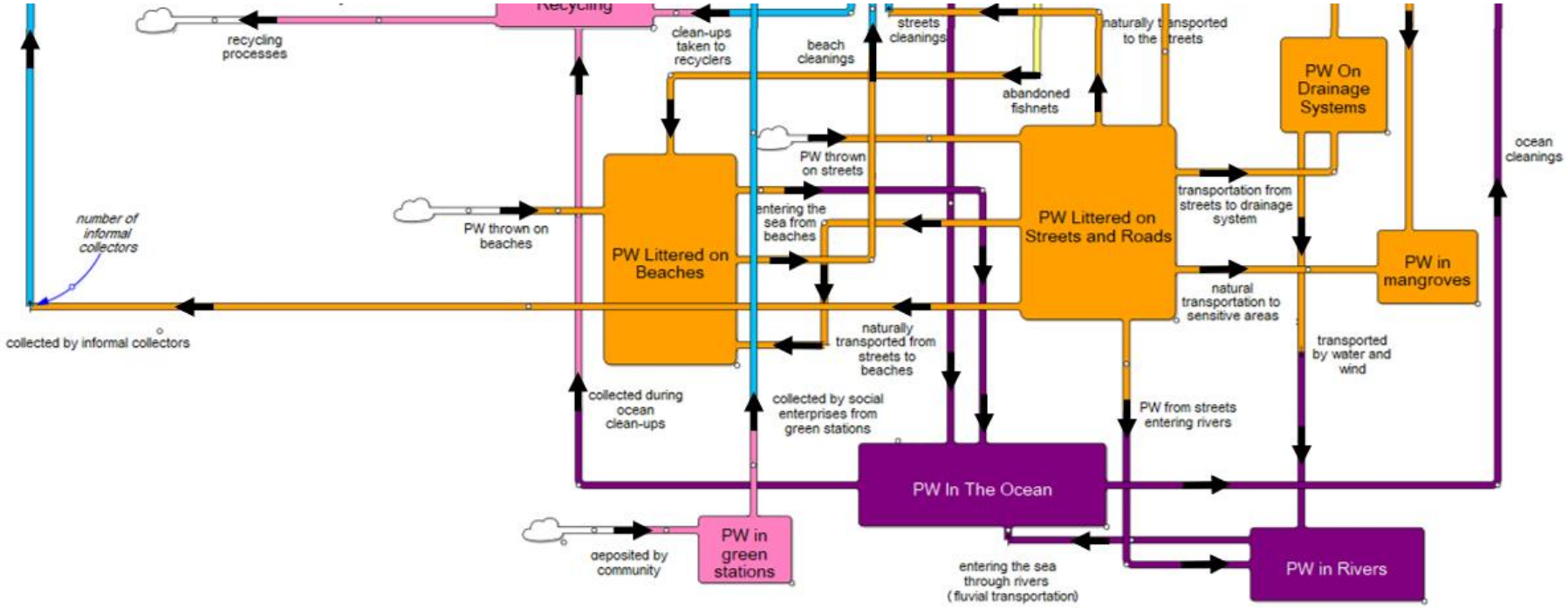
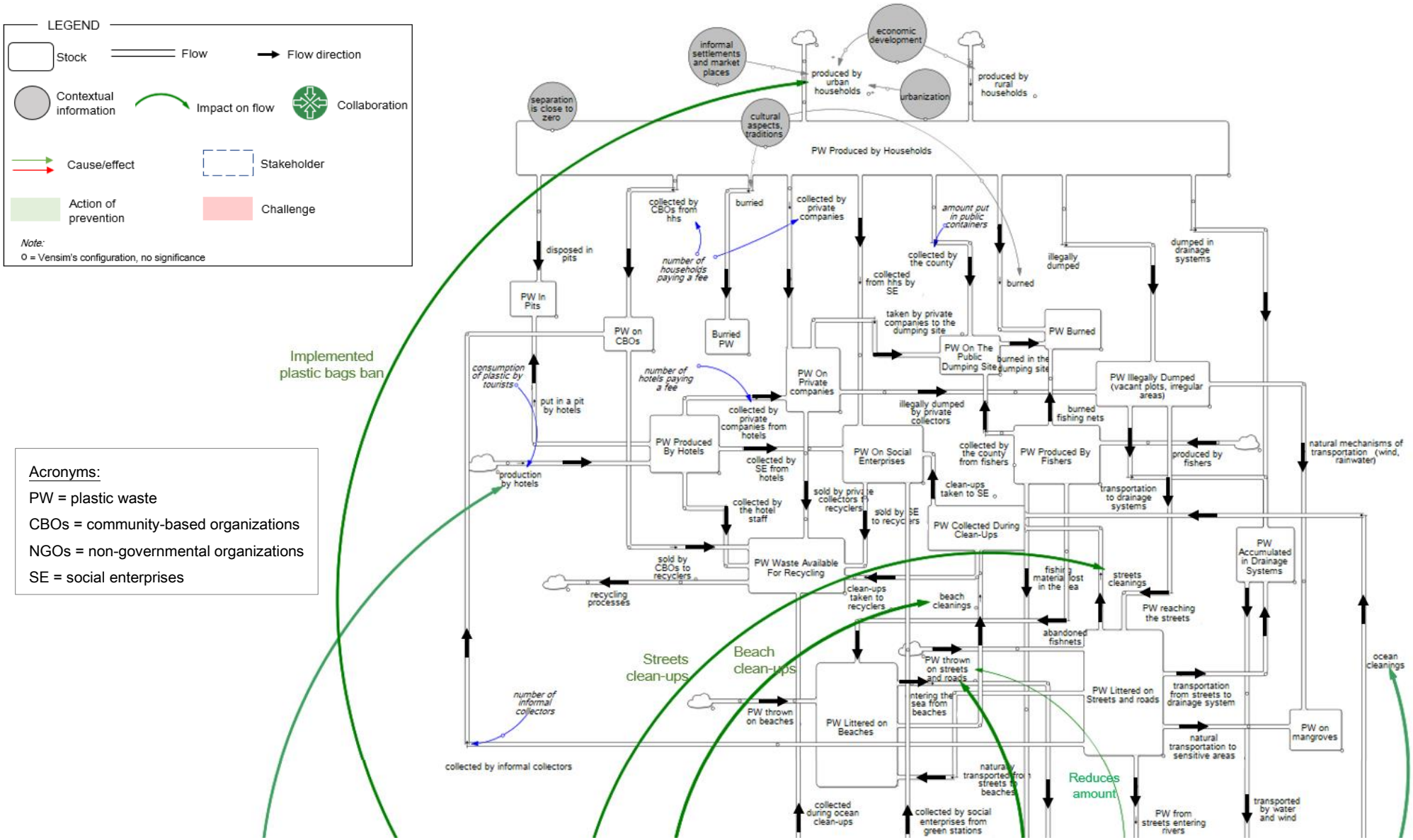


Figure 32. Structure of the stocks and flows model (system dynamics model). The same figure is displayed in A3 size in Annex 8.

3.5.2. Conceptual system model of actions of prevention

The conceptual system model displayed in Figure 33 is part of Theme 2 in the codebook (code P). As explained earlier, the image presents the actions of prevention as properties of stakeholders. The green arrows indicate the effect of these properties on flows and in other actions of prevention, whereas the red arrows indicate the effect of a challenge in a stakeholder's property.



Acronyms:

PW = plastic waste

CBOs = community-based organizations

NGOs = non-governmental organizations

SE = social enterprises

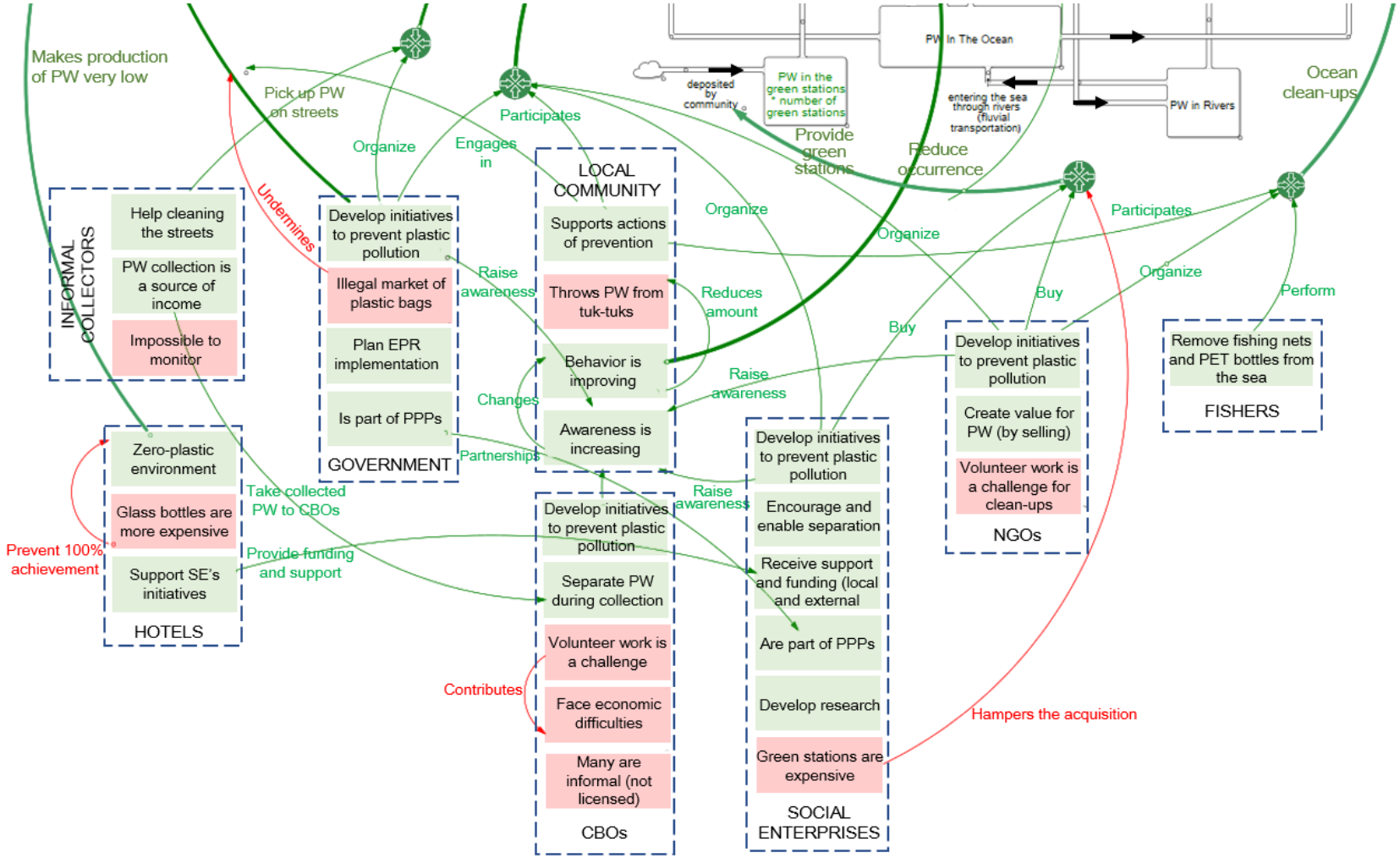
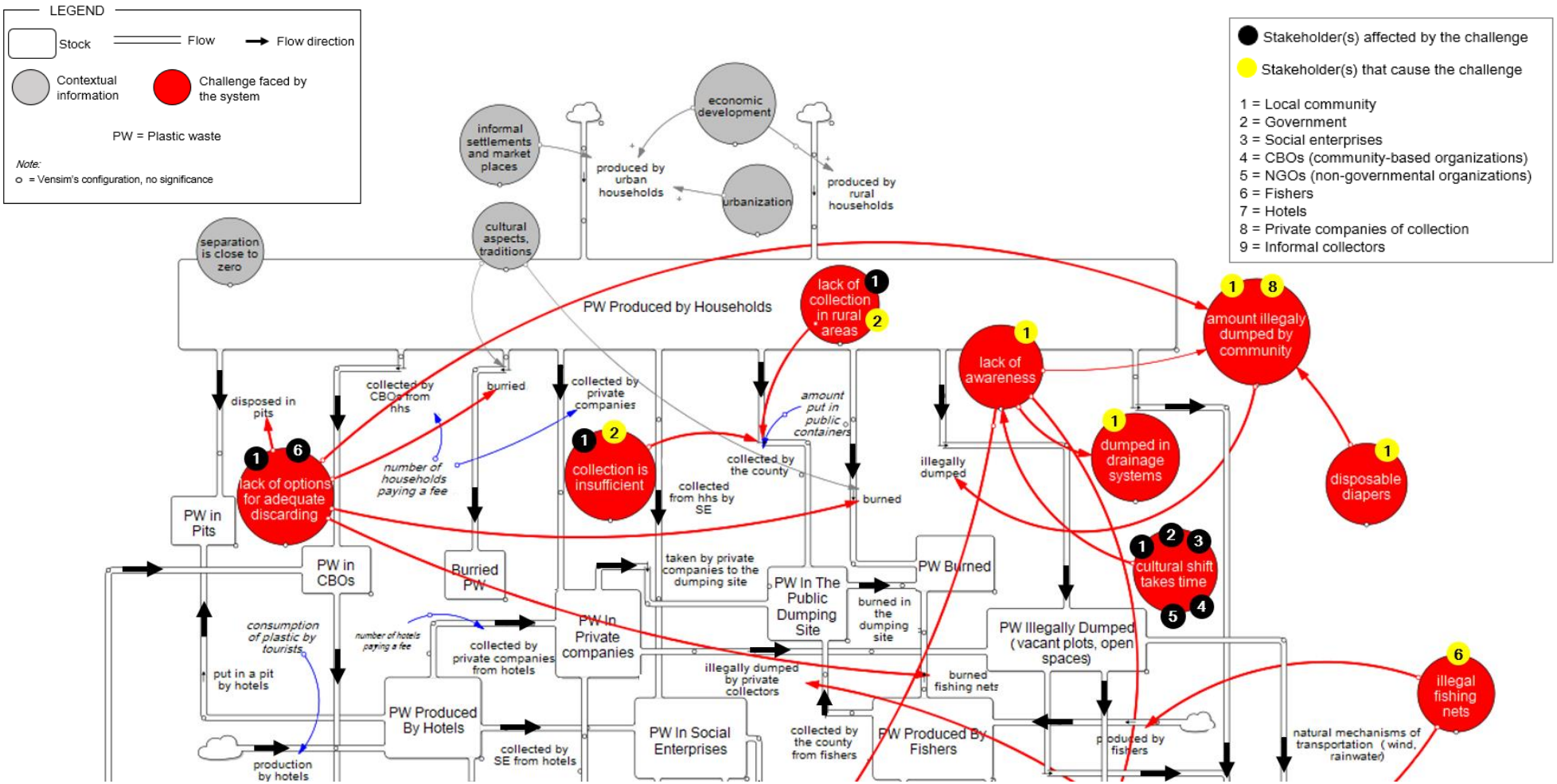


Figure 33. Conceptual System Model showing stakeholders and their properties, the effect of the properties on flows and the effect of challenges on properties. The same figure is displayed in A3 size in Annex 9.

3.5.3. Conceptual system model of challenges

Finally, Figure 34 is the conceptual system model of challenges, represented by the red circles. The effect of the challenges is represented by red arrows. Furthermore, the red circles have information about the stakeholder(s) that trigger the challenge and that are affected by the challenge (in case these information could be apprehended from codes and quotations).



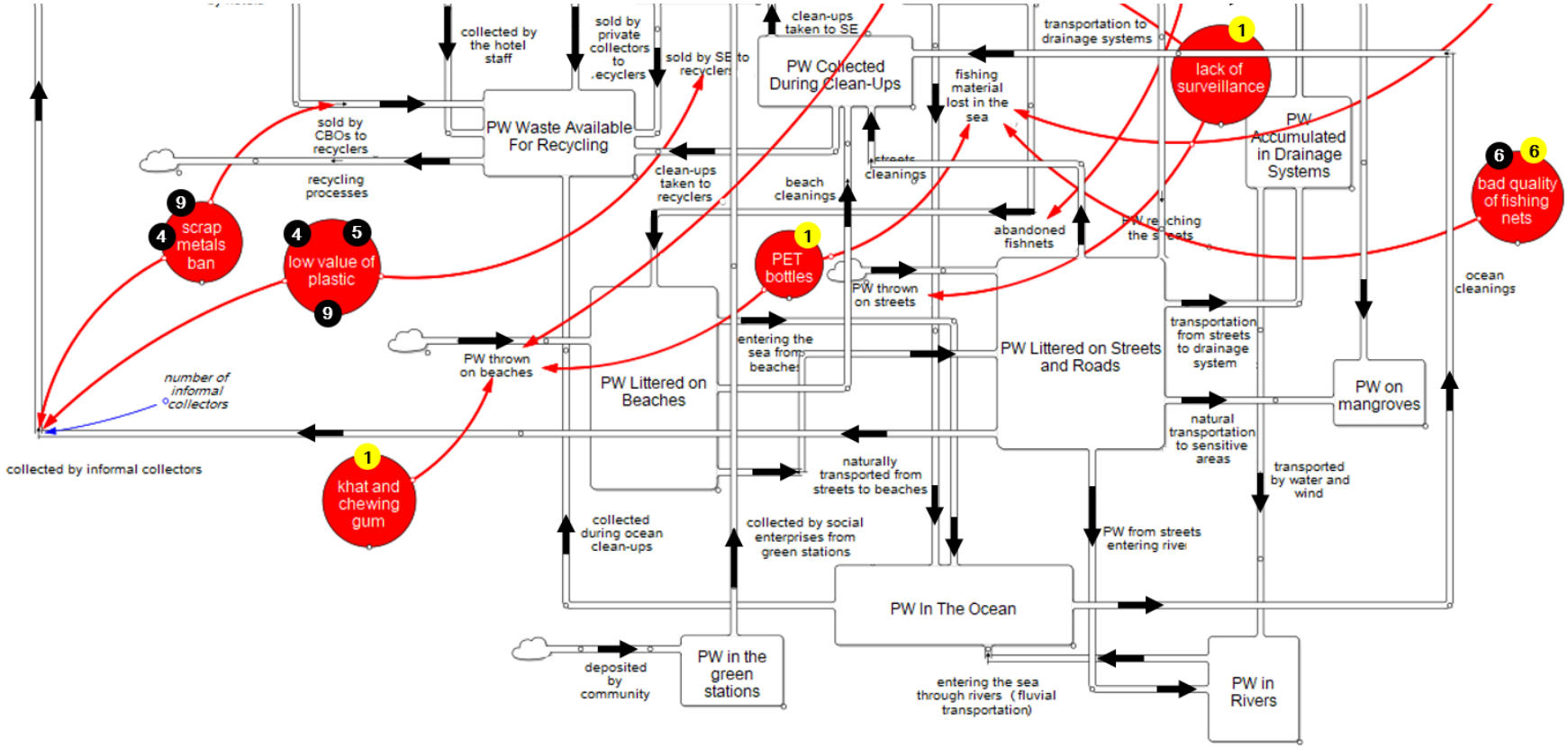


Figure 34. Conceptual System Model showing the challenges faced by the system (red circles), their impact on flows, and the stakelholder(s) that create and/or are affected by the challenge(s). The same figure is displayed in A3 size in Annex 10.

3.6. Data gap (RQ5)

Two groups of codes revealed information about the extent of the quantitative data gap in the study area. The first group was formed by codes that labelled quotations regarding data gap issues (Theme X in the codebook). These codes are summarized below:

- Characteristics of data gap:
  - it is critical (3 mentions);
  - there are challenges to fill in the gap (3 mentions);
  - there are ongoing and future projects aiming to fill in the data gap (2 mentions).
- Gap on data about plastic waste production - per capita and total (5 mentions).
- Gap on data about the volume of plastic waste that is littered and illegally dumped (2 mentions).
- Gap on data about the local community's perception about mismanaged plastic waste (1 mention).
- Gap on data about types of plastic consumed (1 mention).
- Gap on data about how to handle disposable diapers (1 mention).

The second group was formed by codes that label numerical data collected during interviews, as pointed out in the Methodology chapter. Annex 6 presents a summary of these codes, along with the quantitative data collected through review of scientific and gray literature.

3.7. Surface runoff calculation

Figure 35 shows the potential runoff in Kilifi, Mombasa and Kwale. The potential runoff is represented by curve number (CN), as explained in the methodology chapter. The curve number ranges from 30 to a maximum potential runoff of 100. Further information about the CN calculation can be found in Annex 7.

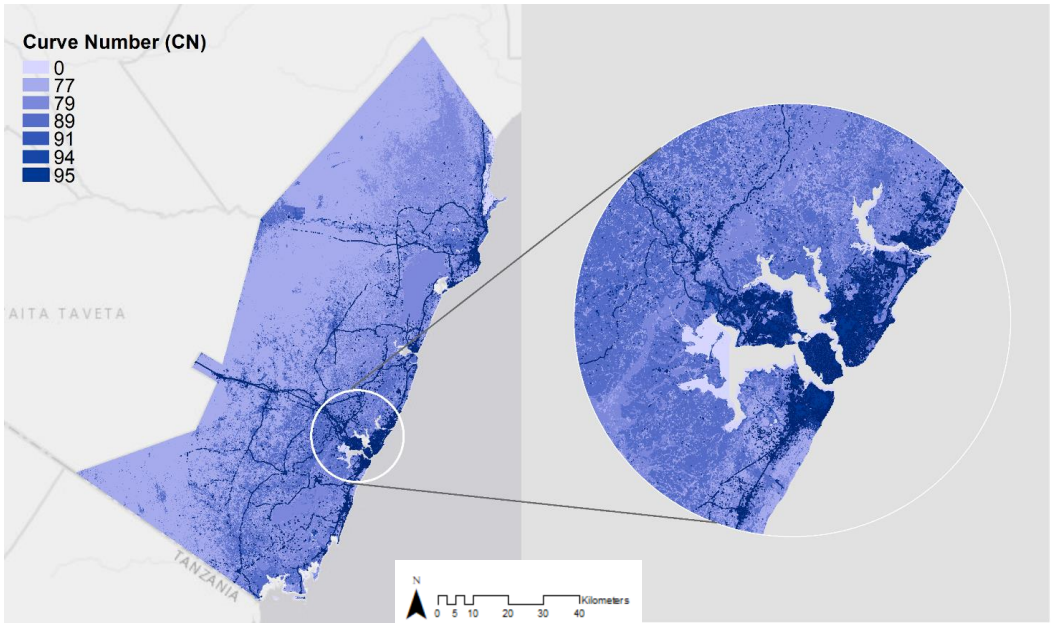


Figure 35. Potential runoff map (curve number - CN) map. The CN ranges from 30 to 100 (maximum potential runoff). The detail on the right shows a zoom in Mombasa.

Figure 36 adds the demarcation of river basins to the CN map.

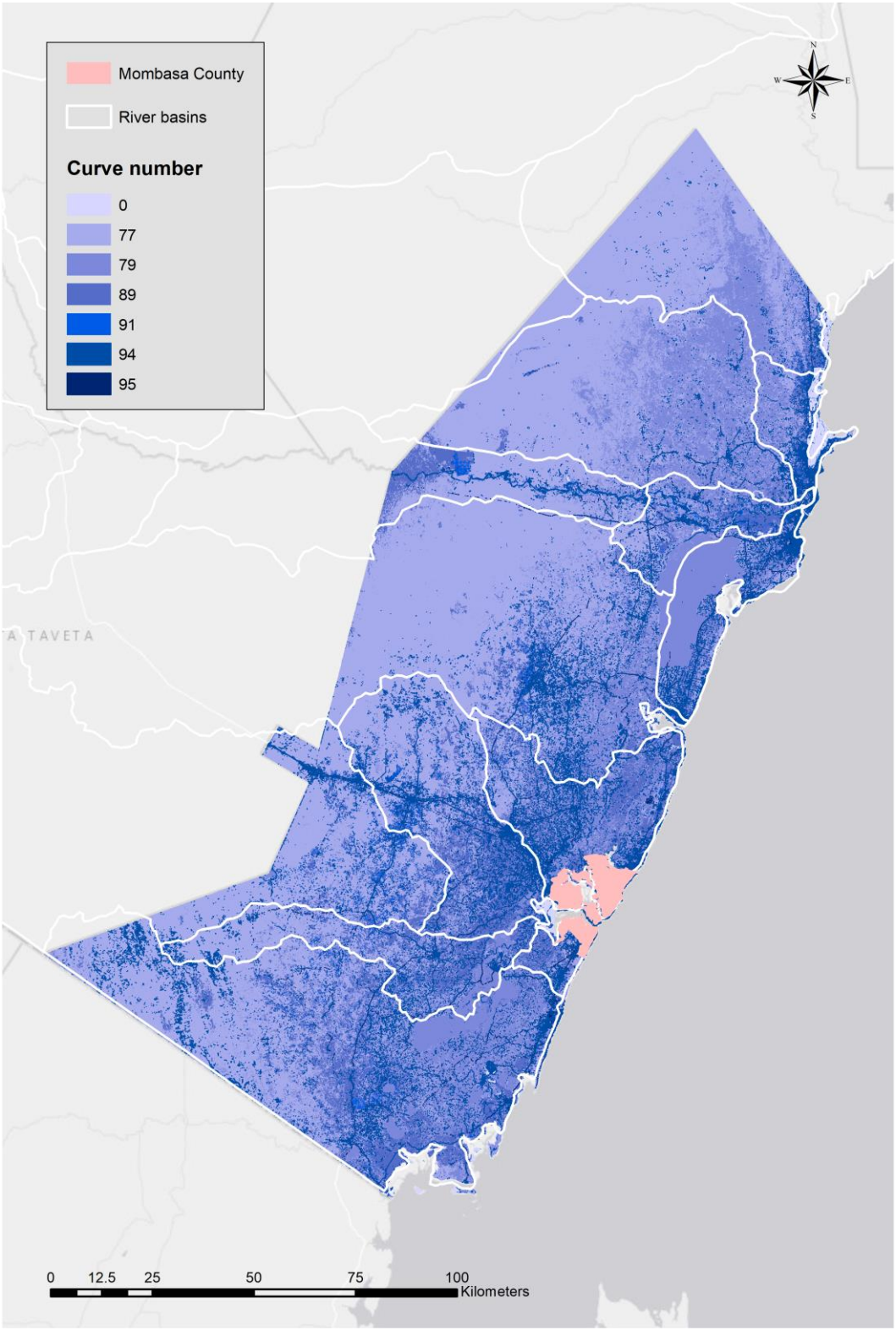


Figure 36. Potential runoff map (represented by the curve number – CN) and river basins demarcation.

4. DISCUSSION

This research presented the structure of a model that captures the dynamics of the plastic waste system in three counties of Coastal Kenya. The thematic analysis of qualitative data collected through semi-structured interviews yielded a codebook that assembles information about the stocks, flows and stakeholders involved with the system, the actions of prevention currently put in place to avoid marine plastic pollution and the main challenges faced by the system. These results were brought together in a system dynamics model conceptualization that depicts the following information:

- The flows that increase and decrease the stocks.
- The stakeholders responsible for creating the flows, actions of prevention and challenges.
- The relationships between flows (how a flow can increase or decrease other flows).
- The flows that are increased or decreased by the actions of prevention.
- The flows that are increased or decreased by the challenges.
- The flows that are traversed by plastic waste until it reaches the ocean.

Furthermore, the thematic analysis, along with the review of scientific and gray literature, provided information about the extent of the gap on quantitative data, whereas images produced through non-participant observation supported the comprehension of the general characteristics of the system. Finally, the calculation of potential runoff in the study area indicated the rivers basins in which plastic waste is at higher risk of being transported between locations.

This chapter offers a reflection about the selection of methods, generation of results and usability of tools developed in this study.

4.1. Framing the research questions

The structure of the quantifiable model of stocks and flows (Figure 32) successfully summarized the answers to research questions 1 (*What are the flows of plastic waste in the study area?*) and 4 (*How can the model be described?*). The stocks show where plastic waste can be found in different moments of its cycle – production, disposal, and management/mismanagement. In addition, the photographs produced during non-participant observations (displayed throughout Chapter 3 and on the Google map) are visual representations of the stocks.

Moreover, the colour scheme informed whether a stock is a starting point (yellow: production); an intermediary point (blue: stored plastic waste; orange: plastic waste that can be recovered; pink: plastic that will be recycled); or an end point (purple: plastic waste that can no longer be recovered). A note of caution is due here since the characteristics represented by the colours may vary depending on the location in which the model was built. For instance, although stocks in rivers and ocean are marked in purple, this might not always be the case. As mentioned in the Introduction chapter, there is technology available to remove plastics from fluvial and marine environments (Helinski et al., 2021; The Ocean Cleanup, 2022). Nevertheless, because this model was constructed in an inductive approach and no such technology is currently applied in Coastal Kenya, rivers and the ocean were considered end points for plastic waste.

Furthermore, the model's flows indicate the pathways of plastic waste within the system. By analysing the flows it is possible to classify the plastic waste according to the two post-consumer categories

considered by Geyer et al. (2017): managed or mismanaged. The material available for recycling is an example of the later, whereas burned plastic waste is an example of the last.

Figure 33 (actions of prevention model), in turn, provided answers to research question 2 (*What are the actions put in place to prevent marine plastic pollution?*) and revealed which stakeholders are responsible for implementing actions of prevention. Furthermore, the model indicated how the processes resulting from the actions impact the stocks flows (e.g., initiatives taken by NGOs include the promotion of beach clean-ups events, which decrease the stock on the beach and reduce the flow that move plastic waste to the ocean).

Similarly, Figure 34 aimed to answer research question 3 (*What are the processes that contribute to plastic waste entering the sea?*). These processes were synthetised by the challenges, represented by red circles, and by arrows that indicate the cause and effect relationships between challenges and flows. Additional information placed on the red circles created a link between stakeholders that trigger the challenges and/or are affected by them (e.g., fishers are directly affected by the bad quality of fishing nets).

Lastly, a brief reflection about the entirety of the results. The findings yielded by the thematic analysis convey a significant amount of information that is not included in the model. The reason is that a high volume of information harms the visualization, making the comprehension of the model more difficult. This issue can be addressed with the use of the codebook (Annex 3) and the quotations to which the codes are attached (Annex 4). Because all elements of the model are also codes and can be retrieved from the interviews, the codebook and quotations provide details about stakeholders, flows, stocks, actions of prevention and challenges, clarifying their meaning. Ideally, all three tools should be used together for a better comprehension of the system.

4.2. Framing the actions of prevention

The model revealed that a small number of actions of prevention are currently conducted in Coastal Kenya, considering the possibilities available for implementation. The problem-based selection tool created by Alpizar et al. (2020) for developing countries, as mentioned in the literature review (Table 3), will be used as a reference to illustrate this statement.

From the 28 actions suggested by Alpizar et al. (2020), only five were part of the results presented in Section 3.3 of this research. Among those five, only one is fully adopted in Kenya (the ban of light-plastic bags). The other actions seem to be either in very initial stages or are insufficient, as detailed below:

- Extended Producer Responsibility (EPR): as demonstrated by the codes with ID ‘Pi’ and their respective quotations, the implementation of EPR is in very initial stages.
- Provision of waste collection that promotes separation of waste for recycling: in Coastal Kenya, these are the green stations (codes with ID ‘Pd’ in the codebook and respective quotations). However, since they are a project developed by social enterprises, the area covered by the green stations is still very small in relation to the extension of the Coast. In addition, green stations are only placed in high population density areas.
- Education, information campaigns: codes with ID ‘Pa’ show that awareness is being created by government, social enterprises, and NGOs, but the cultural shift is considered a very slow process (code G8).

- Finally, the face-to-face information facilitating the adoption of recycling is mainly developed by social enterprises, through the green stations and the work developed by EcoWorld Watamu with hotels and some households that receive labelled bags to separate their solid waste (quotation of code Cd49). Like the green stations project, the area covered by the project is extremely small if compared to the study area.

Nevertheless, Alpizar et al. (2020) fails to address actions that aim to repair flows of mismanaged plastic waste, such as the beach clean-ups frequently promoted in Coastal Kenya. The reason is likely because the referred study is not focused in coastal areas. This is a good example of a dynamic that is particular of coastal locations.

4.3. Framing the challenges faced by the system

The analysis of Table 7 (Matrix of challenges and their effect) showed that the frequency of mentions of a code by the key informants during the interviews is not necessarily an indication of the number of flows, stakeholders and actions of prevention affected by it. For instance, '*lack of awareness'* has the sixth higher frequency (9 mentions), nevertheless it is the challenge with the highest frequency of effect (8 flows, 4 stakeholders and 4 actions of prevention). Likewise, the code '*Plastic waste is transported by water and wind*' was mentioned 11 times during the interviews, but only affects two flows (*natural transportation* and *plastic waste in sensitive areas*).

A possible explanation for this might be the semantic approach used in the thematic analysis (Braun and Clarke, 2006) and the descriptive characteristic of the coding (Tesch, 1990). In other words, no interpretation was carried out during the thematic analysis, and because of this, some nuances might have been overlooked. For instance, it can be hypothesized that '*plastic waste is transported by wind and water*' is a flow that affects hotels, since having a clean environment is important for this stakehoder, especially for the ones located at the beach front (Code PG154). However, because no key informant mentioned that, the codebook does not present a relationship between transportation by wind/water and hotels.

Something that must also be noted about the challenges is the extent to what they can be modified by decision-makers. While some challenges can be clearly targeted, such as '*collection by the government is insufficient*', others cannot be directly influenced. The code '*plastic waste is transported by rainwater*' is an example of the last. However, decision-makers can influence preceding flows, such as '*plastic waste thrown on the streets*' (the lesser plastic waste in the environment, the lesser material will be transported by rainwater). A similar example is the code '*use of disposable diapers is increasing'*. In this case, it is unlikely that the use of disposable diapers will be reduced in the future, nevertheless decision-makers can elaborate strategies to adequately manage them after disposal occurs.

The findings about challenges corroborated data demonstrated by previous studies, as presented in Chapter 1. First, they confirmed that urbanization and its implications, such as the growth on number of supermarkets, are indeed significant drivers of plastic pollution (Deloitte, 2014; Wiedenhofer et al., 2013). Second, they supported evidence from publications that stated that the increasing production and consumption of plastics are not followed by the improvement of infrastructure in developing countries (Akindele and Alimba, 2021; Ghaffari et al., 2019; Jambeck et al., 2015). Third, they reinforced the fact that data gap is a critical issue in African countries (Jambeck et al., 2018). And, finally, they corroborated the view that low awareness about the consequences of plastic pollution is critical in Africa (Akindele and Alimba, 2021).

4.4. Usability and recommendation for further studies

The main outcome of this study – the structure of a system dynamics model - was designed to support decision-making processes related to plastic waste management in a local coastal area of Kenya.

A possible use of the model is as a tool for identifying priorities in the system (e.g., targeting all flows that directly contribute to the stock '*plastic waste in rivers')*. In other cases, the model indicates a chain of possible actions. An example is the flow '*plastic waste thrown on streets*', which must be reduced. The model shows that a crucial driver of this flow is '*lack of awareness*', a challenge that can be addressed with '*awareness creation*' (an action of prevention). Elevated awareness changes human behaviour (also a code related to actions of prevention), which ultimately reduces the amount of plastic waste inadequately disposed on streets by the community, hence reducing the stock of plastic waste on streets.

Furthermore, the tool can play a role in planning actions that are not part of the model at the moment. For instance, besides the ocean clean-ups executed by fishermen to remove plastic fishing material that was lost in the sea, no other action of prevention is currently targeting fishing communities. Nevertheless, the model indicates that broken fishing nets are frequently abandoned at the shoreline, becoming part of the stock of plastic waste on beaches, and prone to become part of the flow that transports plastic waste into the ocean. This information suggest that new actions such as the distribution of garbage bins close to BMUs or the implementation of a return fee project for fishing nets would be effective at reducing the flow '*fishing material abandoned at the beach'*. Furthermore, the new actions can be added to the model, which is freely available for use and editing.

The stocks and flows model (Figure 32) can be further developed with the inclusion of equations. Once the model is quantified, it can be used to project the behaviour of the system over time. The stocks must have their initial levels quantified (e.g., the current weight of plastic waste in the dumping site), and the rates of all flows must be defined for a certain period of time. Due to the extensive data gap, however, the initial quantification of stocks is a great challenge to be addressed in the future.

Currently, for instance, there is no precise information about per capita or household production in Coastal Kenya. Moreover, measuring flows such as illegally dumping and littering are rather challenging. Nevertheless, the government can provide estimates about collection; flows of adequately managed plastic waste can provide information about the volume of recycled material; and flows like '*deposited in green stations*' can be weighted, in the same manner as the plastic waste collected by CBOs, NGOs, private companies of collection and social enterprises can have their weight quantified (which is not done currently). Annex 6 provides more information about the quantitative data and offers some insights about how the gap can be filled in the future.

4.5. Discussing the spatial dimension

To date, no methodology has been able to translate a system dynamics model into a spatial decision-support model. Nonetheless, Figures 35 and 36 were an effort to demonstrate how plastic waste might be transported by rainwater within watersheds, thus answering RQ6. Mombasa County is used as an example for this discussion.

Mombasa is the ending point of four river basins, thus is prone to receive plastic waste produced in all four basins. In basins with a high curve number, the volume of transported material is probably higher.

Moreover, as shown in Figure 35, Mombasa has high potential runoff, which means that once plastic waste reaches Mombasa, it is also likely to reach the ocean.

These findings indicate that the model can be improved with the inclusion of a spatial dimension. First, data about surface runoff would support the identification of areas that receive plastic waste from other locations. Second, spatial coordinates can be attributed to pits, drainage systems, beaches, streets, green stations and every other stock. Likewise, flows have coordinates in space, since plastic waste is always transported from one stock to another.

In conclusion, decision-making processes would benefit from the inclusion of a spatial dimension in the model. For instance, the government might incentivize the establishment of CBOs in communities with the highest population density within a sub-location. In the same vein, the number of green stations could be distributed on streets that have more circulation of people, and campaigns of education could be reinforced in areas with the highest rates of illegal dumping.

4.6. Lessons learned with the methodology selected

The findings yielded by this research indicate that semi-structured interviews analysed through an inductive approach are legitimate methods for structuring a system dynamics model. However, some cautious is advised for two reasons.

First, this study assumed that all statements made by the key informants were true. Even codes that were mentioned only once were taken as an accurate reflection of reality, which might not always be the case. Second, the interviews were registered in audio, and the presence of a recording device may influence the answers provided by the key informants. For instance, government representatives may inflate numbers to portray a situation in a more positive way, or key informants may want to avoid certain topics. This possibility was perceived during interviews with fishers, who demonstrated some level of discomfort when asked about the illegal fishing nets, likely due to the apprehension of being held accountable by regulation agencies.

Furthermore, the design of the thematic analysis enabled the construction of a codebook with well-defined themes and sub-themes. The documentation of the dataset's richness of detail was possible through the selection of quotations and by the inclusion of additional details in the codes, namely: (i) the question it is answering (whether it is a characteristic of the flow, a stakeholder, a stakeholder's role, a stakeholder's property, a challenge, or an action of prevention); (ii) the number of times the code was mentioned; and (iii) if the code appears in another sub-theme. These details are presented in the beginning of Annex 3 (codebook).

Nonetheless, a limitation of the thematic analysis performed in this study was the lack of validity procedures. Due to the large amount of data (more than 17 hours of audio), a cross-coding would be beneficial for the data analysis, since multiple coders avoid individual biases and reduce the variance in interpretation of code definitions (Guest et al., 2012).

Finally, as previously mentioned in this chapter, the inductive and semantic design of the thematic analysis might implicate on data being overlooked, since no interpretation was carried out.

5. CONCLUSION

This research has developed the structure of a model that described, for the first time, the dynamics of plastic waste in a local coastal area of Kenya, a lower-middle income country. Different from other system dynamics models presented in the literature, the design of this study did not include prior assumptions about the system, and all elements were inductively generated by information provided by the stakeholders. Furthermore, images produced through non-participant observation provided a visual representation of the stocks and flows.

Besides indicating where plastic waste is accumulated (stocks) and the pathways traversed by the material (flows), the model demonstrates how flows connect to each other. In other words, it shows how a flow related to one stock can indirectly contribute to flows connected to other stocks. Moreover, the actions of prevention and challenges that affect the flows are properties of the stakeholders, thus the model indicates how stakeholders can influence the flows and, consequently, the stocks.

These characteristics suggest that the model structure can be a powerful tool to support decision-making processes that aim to reduce marine plastic pollution in local coastal areas. Understanding the dynamics of the system and identifying priorities are crucial to develop assertive strategies and policies at local scale. Furthermore, the impact of actions of prevention can be assessed through the measurement of flows over time. Likewise, the impact of modifications on challenges can be quantified if flows are measured over time. Hence, the model might be a useful monitoring tool as well.

A number of strategies to prevent marine plastic pollution are suitable to the context of Coastal Kenya, although not yet explored. Therefore, the outcome of this research may support not only the identification of priorities and actions to be reinforced but may also be a starting point for innovation and implementation of new projects.

Finally, the dynamic nature of the system makes the model suitable for constant modifications. The implementation of new strategies of prevention, for instance, would add new variables in the model, transforming the flows. This research favors Open Science, thus the dissemination of information and improvement of the model are possible and recommended. End-users can modify and improve the model (adding equations, for example) through Vensim, the software used in this study.

APPENDIX

ANNEX 1: Example of the semi-structured interviews (government representative)

Notes:
As typically occurs in semi-structured interviews, the following questions were merely used as a guide. They were adapted to each type of stakeholder (e.g., questions about public containers were not asked to NGOs), which ultimately means that 32 different interviews were conducted. The guide does not assure that all questions were asked, and information already provided in previous answers were excluded. In the same vein, several other questions were made when the conversation opened space for that – for instance, if a person mentioned 'community is the biggest problem', further questions were asked to explore the topic. Overall, questions that aimed to gather quantitative data (per capita production, for instance), professional responsibilities related to plastic waste and perceptions about the system were asked to all participants.

SECTION 1 – Responsibilities and general information

1. What is the area under (XXX) management/jurisdiction?
2. Is there information about the amount of solid/plastic waste produced at the following levels: household, neighbourhood, area, municipality, location, sub-county, county?
3. How many public dumping sites are there in (XXX)?
4. Do you believe the per capita/total production is the same in all (XXX)'s locations/areas?
5. Which socio-economic indicators do you consider having impact on the plastic waste production?
6. Who is responsible for the solid waste collection/management in (XXX) jurisdiction? Can you please explain the process?
7. How many tons are collected by the government in (XXX)?
8. Which percentage of the total solid waste produced does this amount represent?
9. What is the equipment used for waste collection in (XXX)?
10. What is the frequency of collection in (XXX) and the criteria used to define it?
11. What is the itinerary of collection in (XXX)?
12. How many public containers are there in (XXX)?
13. How much of the total solid waste in (XXX) is actually taken to the container?
14. What happens to the part that is not taken to public containers?

SECTION 2 – NGOs, CBOs, private companies, and social enterprises

1. Is there official register about the number of individuals working with plastic waste collection?
2. Same as above for NGOs/CBOs/private companies/social enterprises.
3. Please tell me about the operations of CBOs that work with plastic waste (collection, recycling, clean-ups) in (XXX).
4. Same as above for NGOs, private companies, and social enterprises.

5. How do you see the role of NGOs/CBOs/private companies/social enterprises within the plastic waste system in (XXX)?
6. What is the relationship of (XXX) government with NGOs/CBOs/private companies/social enterprises?
7. Are there clean-ups in (XXX)? Who participates? What is the frequency?
8. How much in average is collected during these clean-ups?

SECTION 3 – Modes of disposal

1. How do the households dispose the plastic waste they produce?
2. What is the level of separation of different streams of solid waste in (XXX)?
3. Is disposal of plastic waste in (XXX River, if any) common? How much of the total plastic waste produced?
4. Same as above for vacant plots and road drains.
5. (show the graphic with the main modes of disposal (2019 Census) in the respondent's jurisdiction) Do you believe these numbers properly reflect the reality?

SECTION 4 – Overall perception of the system

1. Considering the mismanaged part of plastic waste that we talked about (not collected), how much reaches the sea, in your opinion?
2. What is the path travelled by plastic waste until it reaches the sea?
3. What do you consider the biggest challenges in the plastic waste management system?
4. And the positive ones?
5. How do you evaluate community's engagement with initiatives that aim to reduce maine plastic pollution?
6. Does (XXX) conduct any project related to awareness about waste disposal, specially related to plastic waste?
7. If you could change something in the system right now to reduce marine plastic pollution, what would that be?

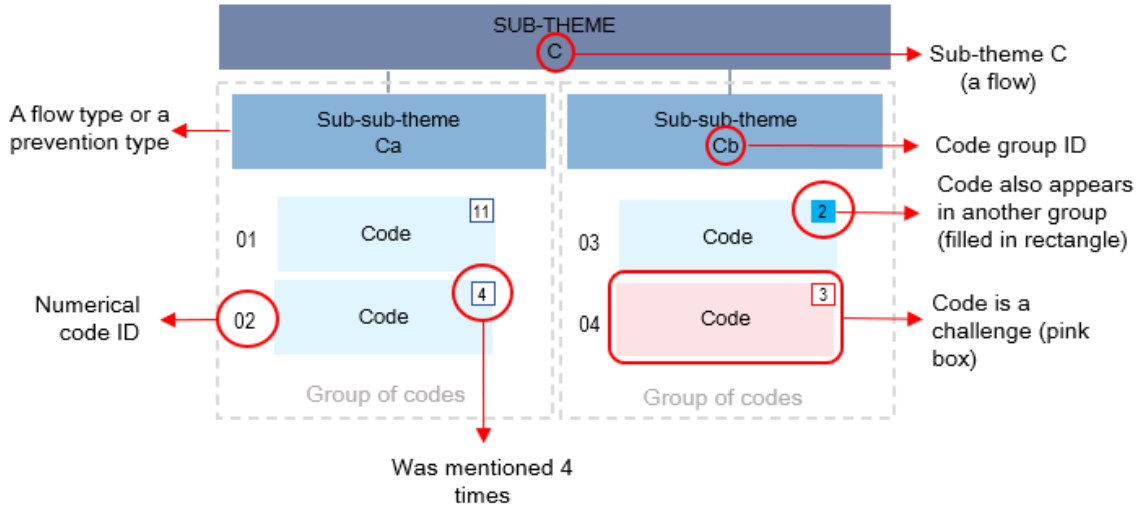
ANNEX 2: List of interviews and key informants

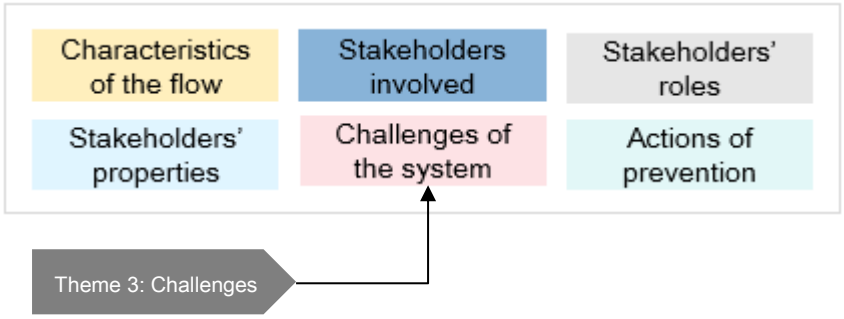
KI = Key informant
ACAD = Academy / GOV = Government / NGO = Non-Governmental Organization / PRIV = private sector / BMU = Beach Management Unit
TOUR = organization in the tourism industry / INDEP = Contact made independently, by the researcher
FtF = Face to face interview | ON = online interview | PH = Interview by phone

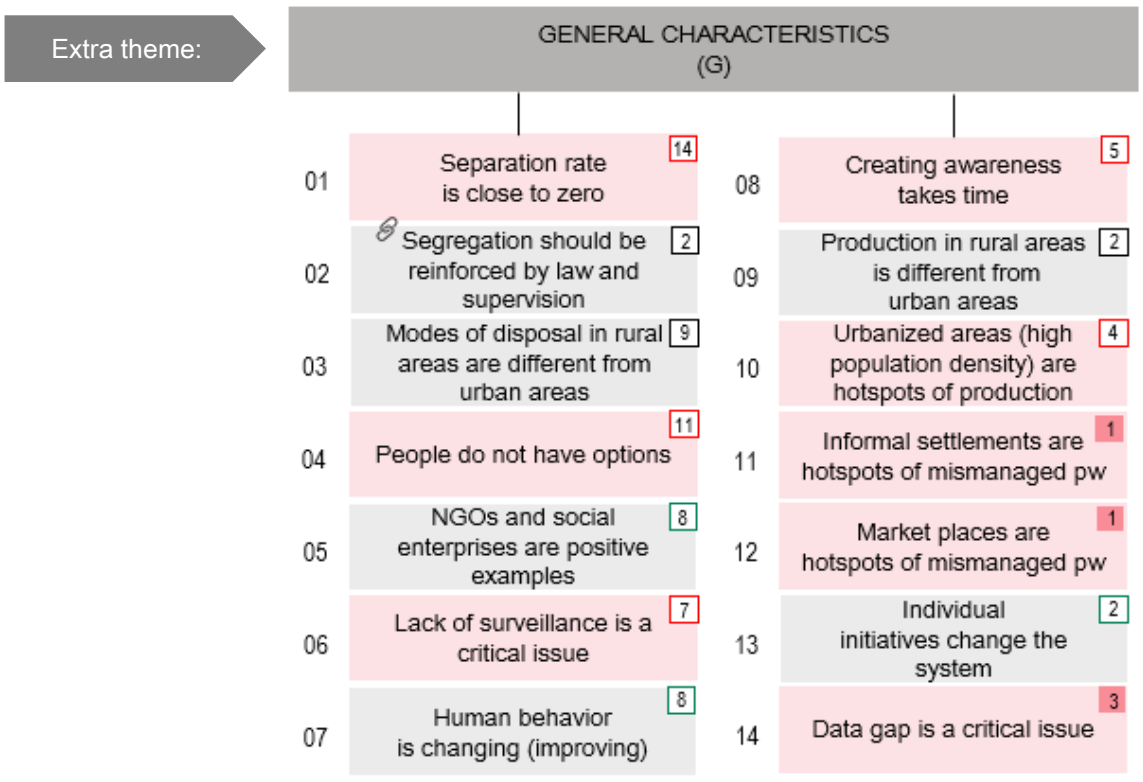
County	KI	Code	Type	Indication by	Interview date	Mode
Mombasa	1	KI_1_Kenya Marine and Fishery Institute_Mombasa	GOV	Starting seed	14 February	FtF
	2	KI_2_Technical University of Mombasa_Mombasa	ACAD	Starting seed	25 February	FtF
	3	KI_3_Research Institute_Kwale	GOV	1	17 February	FtF
	4	KI_4_NGO_Mombasa	NGO	1	18 February	FtF
	5	KI_5_CBO_Mombasa	CBO	1	18 February	FtF
	6	KI_6_government_county_Mombasa	GOV	22	22 April	FtF
Kwale	7	KI_7_NGO_Kwale	NGO	2	2 March	FtF
	8	KI_8_CBO_Kwale	CBO	7	4 March	FtF
	9	KI_9_Kwale Recycling Center_Kwale	SE	7	4 March	FtF
	10	KI_10_NGO_Kwale	NGO	7	4 March	FtF
	11	KI_11_CBO_Kwale	CBO	7	4 March	FtF
	12	KI_12_NGO_Kwale	NGO	3	8 March	FtF
	13	KI_13_CBO_Kwale	CBO	7	9 March	FtF
	14	KI_14_government_municipality_Kwale	GOV	12	14 March	FtF
	15	KI_15_government_county_Kwale	GOV	14	15 March	ON
	16	KI_16_government_county_Kwale	GOV	6	17 March	FtF
	17	KI_17_5-star resort_Kwale	TOUR	INDEP	25 March	PH
	18	KI_18_4-star resort_Kwale	TOUR	INDEP	25 March	FtF
	19	KI_19_4-star resort_Kwale	TOUR	INDEP	25 March	FtF
	20	KI_20_2-star resort_Kwale	TOUR	INDEP	25 March	FtF
	21	KI_21_5-star resort_Kwale	TOUR	INDEP	25 March	PH
	22	KI_22_3-star resort_Kwale	TOUR	INDEP	25 March	FtF
	23	KI_23_BMU 1_Kwale	BMU	16	28 March	FtF
	24	KI_24_BMU 2_Kwale (*not recorded*)	BMU	16	28 March	FtF
	25	KI_25_BMU 3_Kwale	BMU	16	28 March	FtF
	26	KI_26_government_county_Kwale	GOV	15	29 March	FtF
	27	KI_27_government_municipality_Kwale	GOV	26	29 March	FtF
Kilifi	28	KI_28_Pwani University_Kiifi	ACAD	INDEP	30 March	FtF
	29	KI_29_government_county_Kilifi	GOV	28	04 April	FtF
	30	KI_30_government_county_Kilifi	GOV	26	06 April	FtF
	31	KI_31_government_sub-county_Kilifi	GOV	28	14 April	FtF
	32	KI_32_EcoWorld Watamu_Kilifi	SE	5, 28, 29, 31,	15 April	FtF

ANNEX 3: Codebook

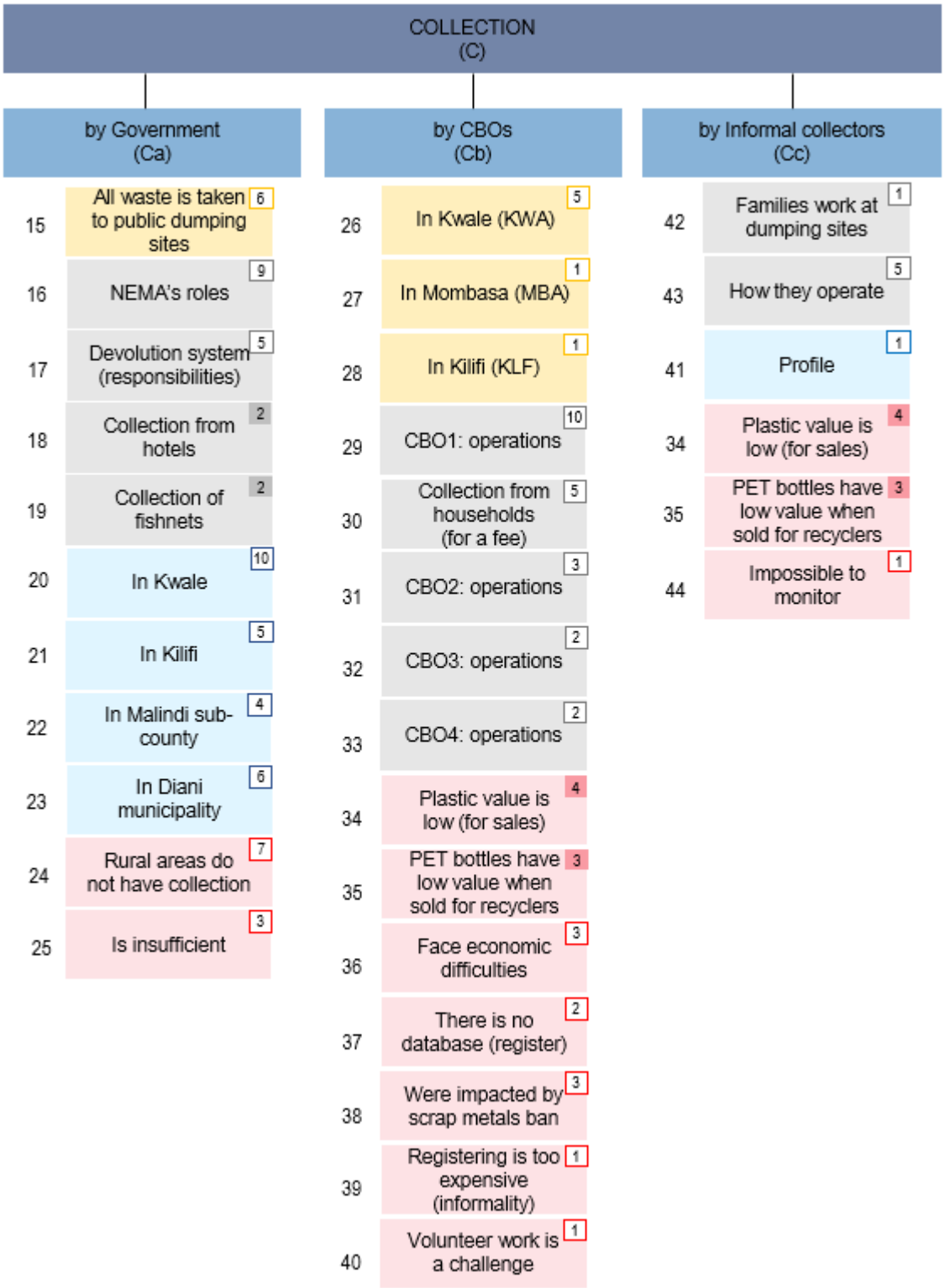
LEGEND:



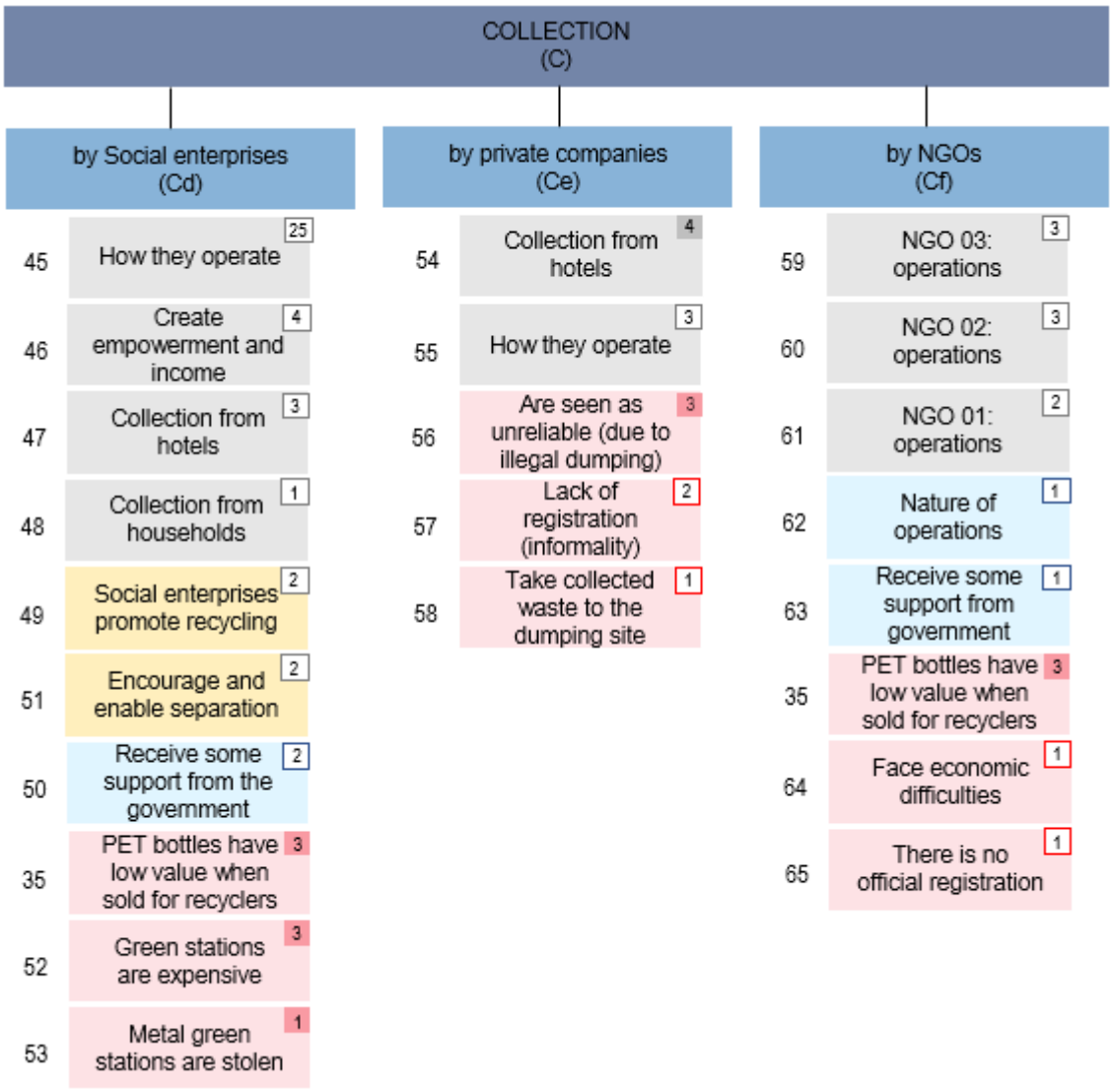




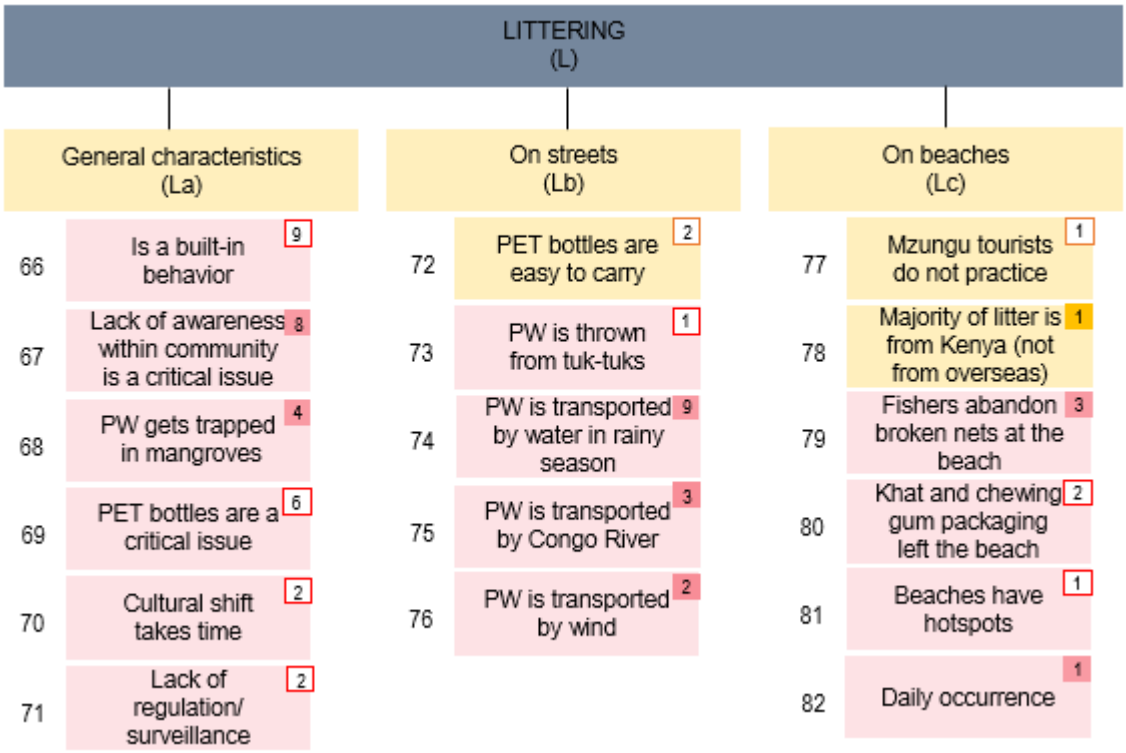
Theme 1: Flows

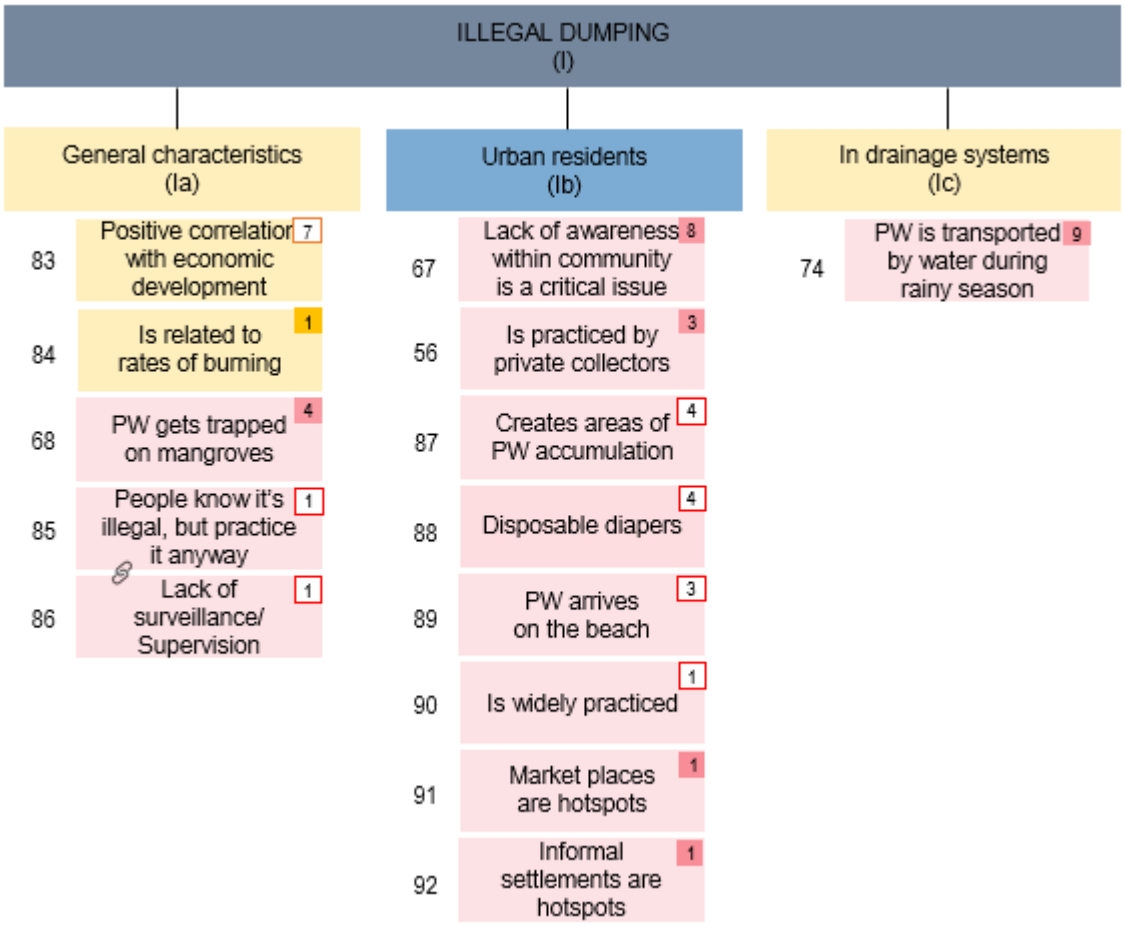


Theme 1: Flows

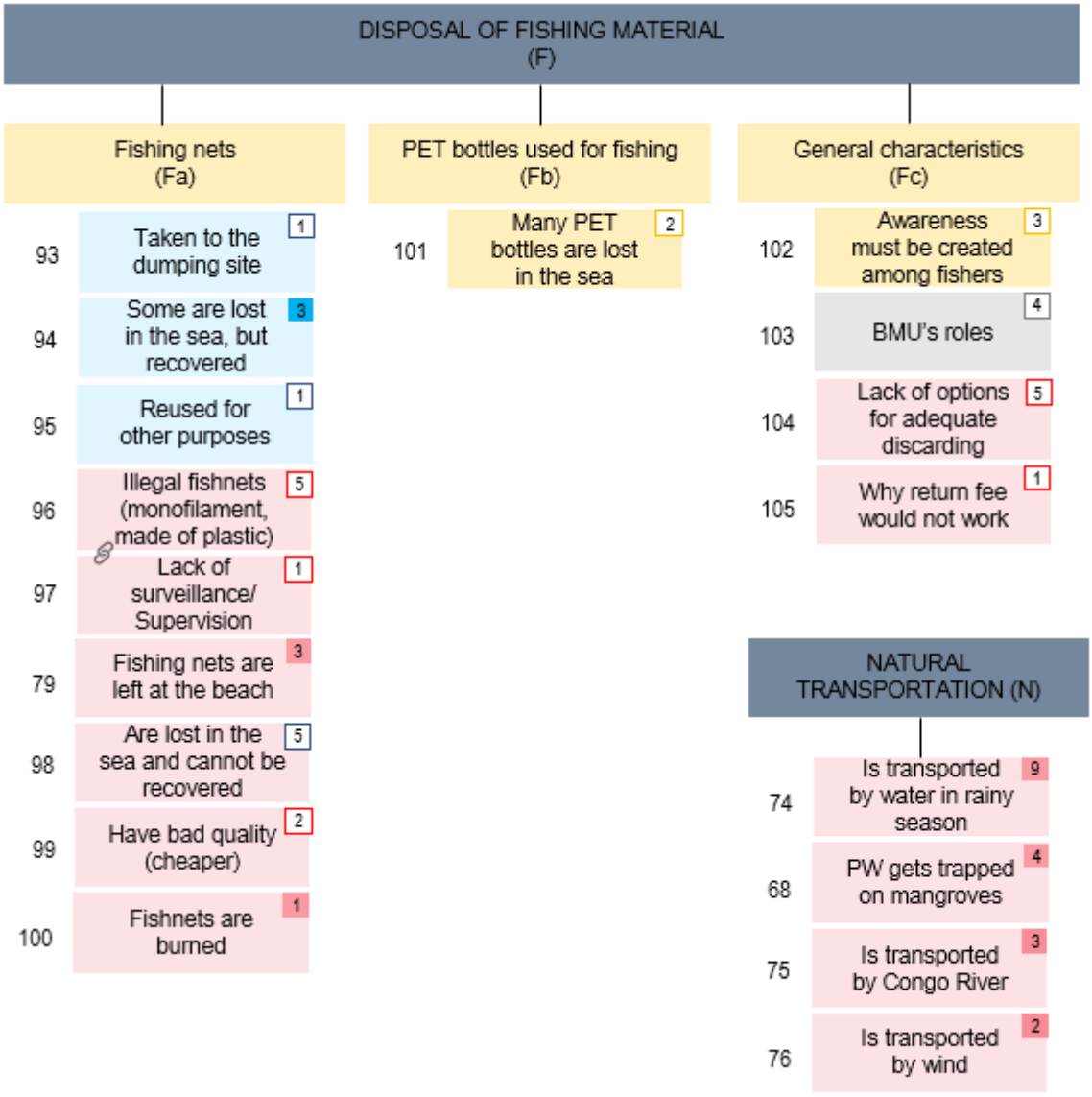


Theme 1: Flows

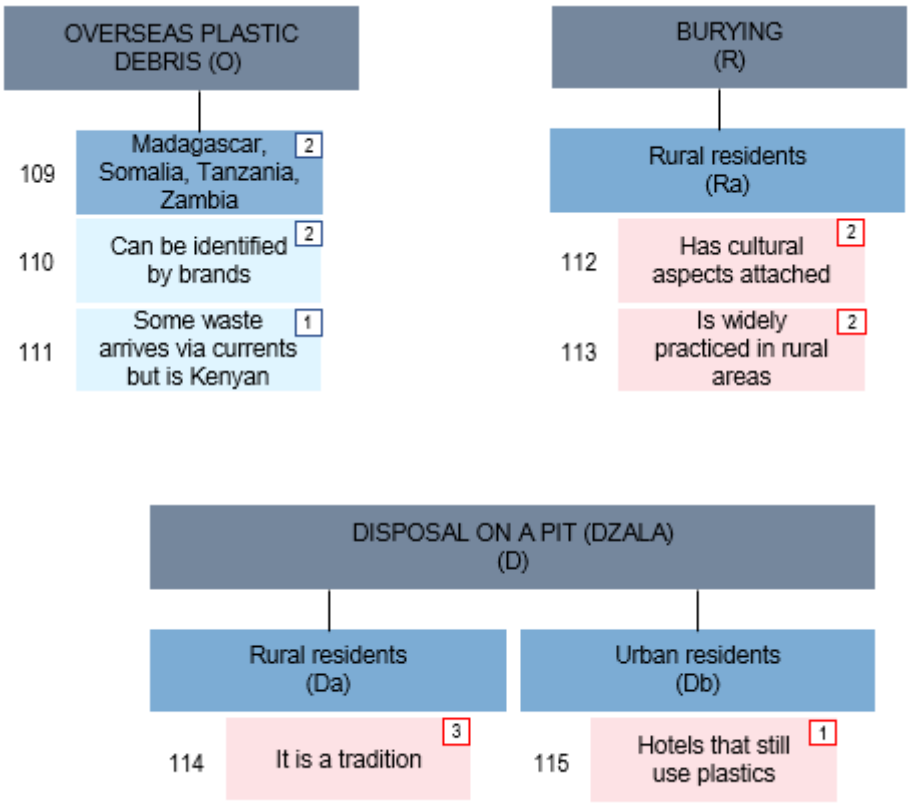




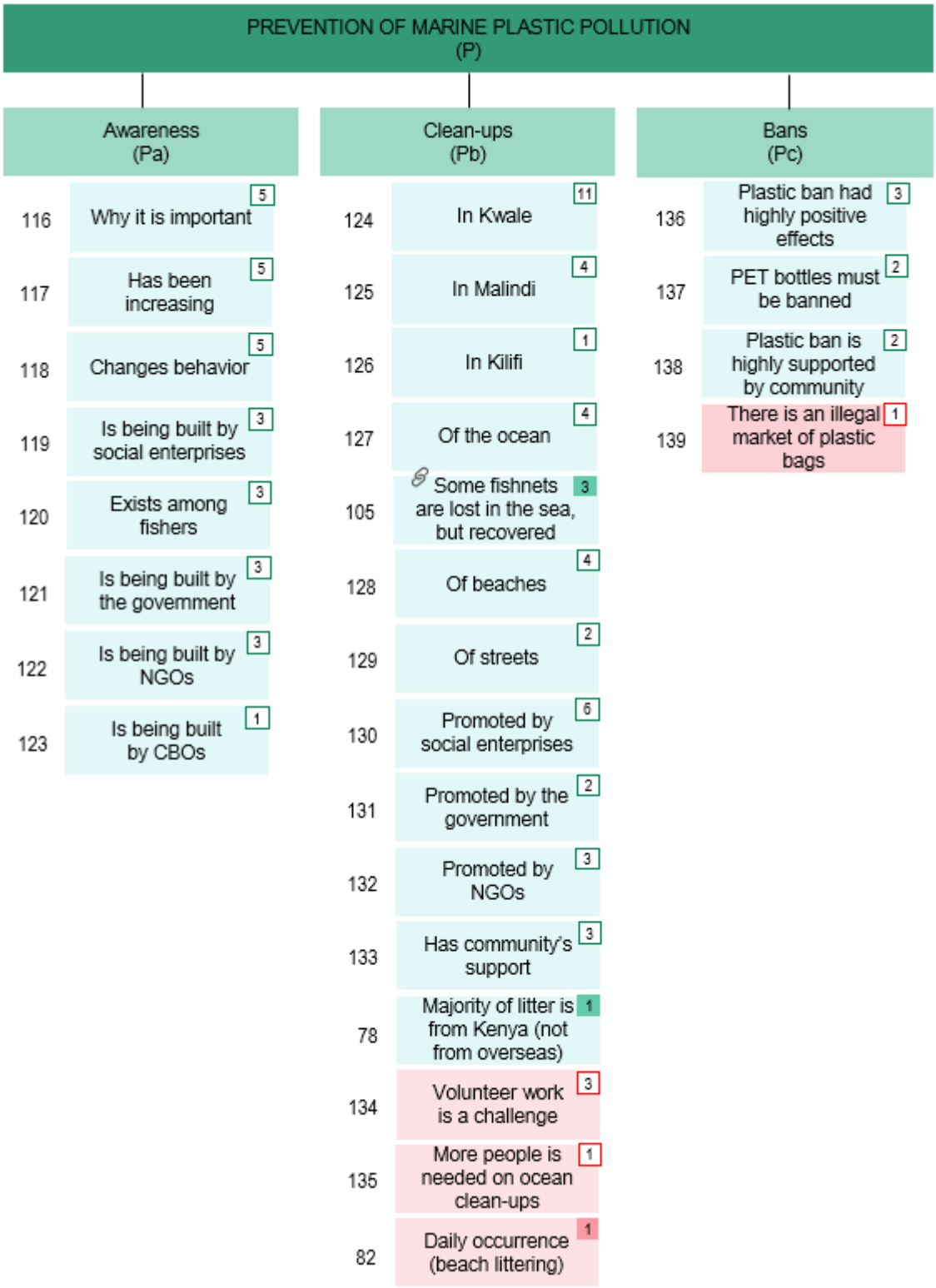
Theme 1: Flows



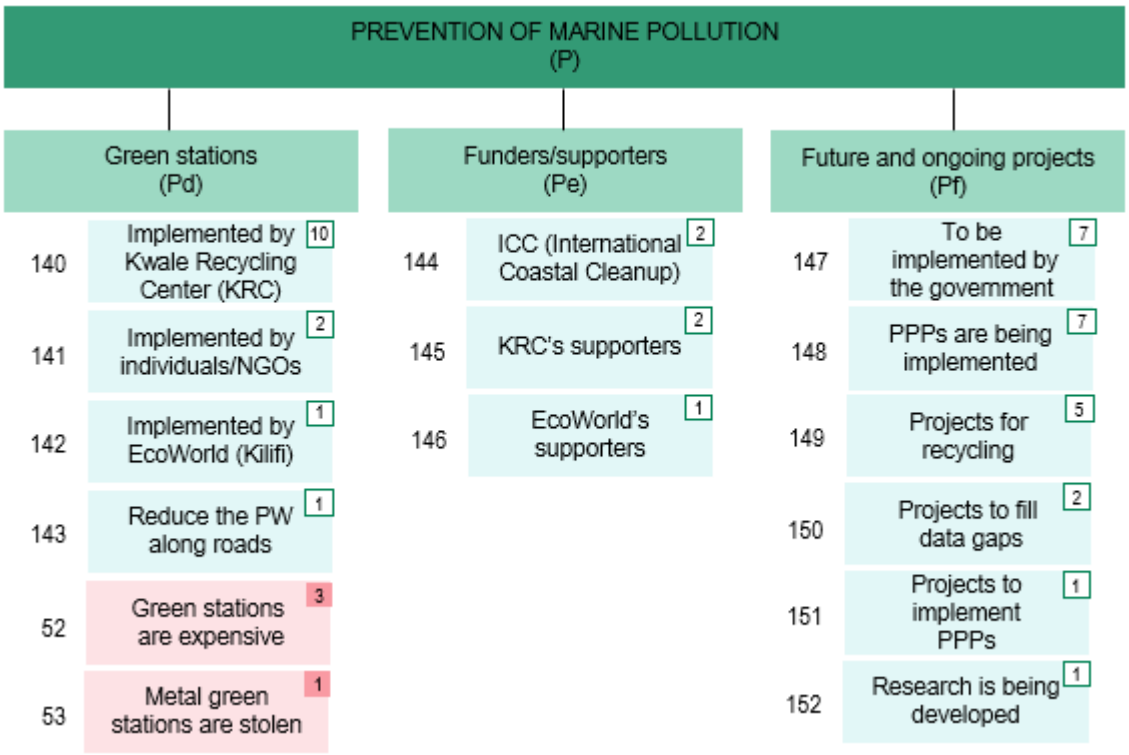
Theme 1: Flows



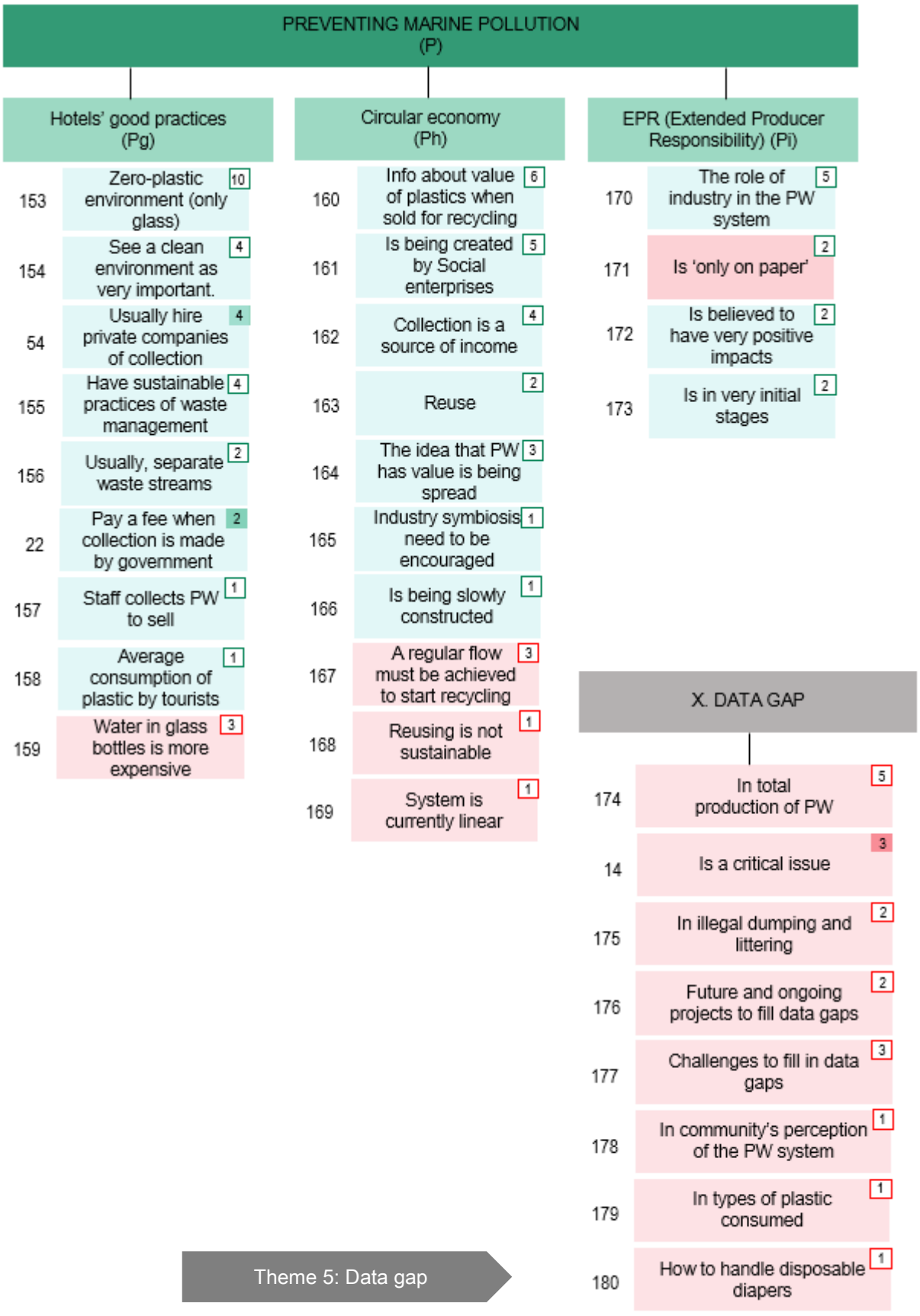
Theme 2: Actions of prevention



Theme 2: Actions of prevention



Theme 2: Actions of prevention



Theme 5: Data gap

ANNEX 4: Quotations selected to support the comprehension of the codes

The following table exhibits 140 quotations (30.6% of a total 458) selected to provide further information about the codes' meaning. The excerpts were extracted from the semi-structured interviews conducted with 32 key informants from Kwale, Mombasa and Kilifi from February to May of 2022 (see Sections 2.3 and 2.4). The text is verbatim the statement provided by the key informants. Changes were only made in case more context was needed for comprehension, and are marked in parenthesis and italic. The column in the left indicates the code(s) to which the quotation is attached. These codes can be found in the codebook (Annex 3), through their IDs.

Code(s) ID(s)	Selected quotations that support the comprehension of the code(s)
G1	Even in the stations in which we have the segregation bins, not all the stations are always well managed. Some of them are still mixed. These are some of the challenges that we face on the ground. (KI_9_Kwale Recycling Center_Kwale)
G1	Plastic waste is very difficult to separate from other types of waste. Because of lack of segregation, you will find a lot of plastics mixed to other types. (KI_6_government_county_Mombasa)
G1	Not everyone accepts this *(separation)*. Some say "we don't say have time to separate this". Others put the garbage into the bins and say, "you come and collect it". So, we have to do it by ourselves. (KI_8_CBO_Kwale)
G1 La67 Ca25	These challenges are what drive the plastic pollution: people are not responsible and throw the plastics out, we don't have enough capacity to be able to collect all the plastic, and we don't segregate the plastics on the environment. (KI_6_government_county_Mombasa)
G2	One of the solutions is creating awareness and law enforcement for sorting. There is no other way. (KI_29_government_county_Kilifi)
G2	We still have challenges on policies and regulations. Even for the segregation, we should be able to enforce and regulate. (KI_6_government_county_Mombasa)
G4	What is clear to me after all those clean-ups is that if you don't give people options, if you don't put garbage bin (*the problem continues)*. So give them recycling stations, give them options. The dumping site is not an option. (KI_10_NGO_Kwale)
G4 Fc104	In most of the beaches we don't have garbage bins and if they are there, they are not several, they are not convenient. You don't want to walk 2 km or so with the waste, so if we positioned them correctly, that would work. (KI_16_government_county_Kwale)
G4 Ca70	Choosing a strategy of talking to people, just talking to people, and you are not providing sorting bins, that will be a challenge. (KI_7_NGO_Kwale)
G4 G5	But at least there are some movements. There is the initiative of Kwale Recycling Center, that started 4 years ago. But of course this is in Diani, you are not going to carry your waste from here *(Mswambeni)* to Diani. So it is not a solution for the household level. (KI_10_NGO_Kwale)
G5 Ph164	Impact of the green stations implemented by Kwale Recycling Center is showing that plastic is not waste, plastic has a value to people that can take it to recycling. So it's very positive, because it means less plastic mixed to the whole amount of waste in the dumping site. (KI_29_government_county_Kilifi)
G5	We are also trying to act as a model so if it is successful in Kwale, we can then look into other counties and we can actually be a good example to the rest of the country. (KI_9_Kwale Recycling Center_Kwale)

G6	Often here in Kenya, we have policies *(of waste management)*. The enforcement is a big issue, and also community awareness. The importance of proper disposal, how bad it is for the environment, these are the big issues. I am not saying the policies are perfect, and maybe there are a few that may need to be refined, but mostly the enforcement and community awareness are the big, big problems. (KI_7_NGO_Kwale)
G7	New learnings are a process, a long process, and it takes time. But the community is taking it well. It is improving every now and then. (KI_9_Kwale Recycling Center_Kwale)
G7	It's really working *(the green stations)*. Now we are having guys that are conscious. We are not employing them, but we are growing awareness out of the passion they have for the environment. They also try to pick up every once and while and dump it inside our bins. (KI_9_Kwale Recycling Center_Kwale)
G8	*(About the use of green stations by the community)* We have to talk, we have to teach, we have to repeat. You have to repeat a million times. (KI_9_Kwale Recycling Center_Kwale)
G8	You see how it happens…In school, a kid cannot learn one plus one in one day. You will have to come again tomorrow. And if you ask: 1 plus 1? Somebody will still tell you that 1 plus 1 is eleven. And then someone says: but he told us it was two. It's like that. (KI_4_NGO_Mombasa)
G10	Mwtapa, Kilifi, Malindi are hotspots because of the density, hotels and urbanization. (KI_29_government_county_Kilifi)
G11 G12 Ib91 Ib92	The hotspots are the areas that normally generate illegal dump sites. And these are informal settlements, it's where we have marketplaces, these are the hotspots when you move away from the ocean. So, they vary. These are basically the places that are densely populated or busy areas. They are hotspots. (KI_9_Kwale Recycling Center_Kwale)
G13 Pe144	In 2018 ICC *(International Coastal Cleanup)* lead my interest on waste. After that, Kwale Recycling Center created a committee, and I was part of it. After ICC, we started an awareness project about beach clean-up, and it was turned into a competition: who collects more and makes the best segregation receives an award. Also, who brings more people for the clean-ups, not only the beach, all community. The event grew and in 2021, instead of beginning in September to December, we started in July. And now we also bring the buyers. (KI_12_NGO_Kwale) - **ROW 7 TABLE 5**
G14 L14 L174 L177	NEMA wants the county to quantify the amount of waste, but it is being difficult. Figures are still lacking, we want to be able to identify the most problematic streams of waste in 10 years, but we cannot do so yet. We need funding to do that, the time to put the house in order is now. (KI_26_government_county_Kwale)
Ca15	NEMA's role is to regulate all the players in the system and ensure that the county is doing what it is supposed to do. They regulate the vehicles (including county's ones) to know where the waste is being collected from and being taken to. Also regulates the private sector – types of waste collected, where and to where. (KI_26_government_county_Kwale)
Ca15	NEMA is responsible for the coordination and implementation of policies related to the environment. This is mostly compliance, and this is done through licensing. The Environmental Management and Co-ordination Act downwards the regulations. There is an environmental impact assessment, regulation, water quality regulation, air pollution regulation, etc. And there is a regulation for waste management. We created under pressure by an international agreement that Kenya signed, and that is based on a global convention. (KI_6_government_county_Mombasa)
Ca25	I was completely aware that there is nothing coming from the national government or county government. I wouldn't say nothing, but very little. A couple of things have changed in the last couple of years as well. One of them is the bin containers for general waste, the

	ones that can be loaded to the truck and taken to the dumping site. First there were just a few, then they became more and more, and now we have 3 in Mswambeni – we are talking about a population that estimate to be about 15 thousand people *(it is 22.517 according to KNBS)*. I am talking about Mswambeni town, I am not even talking about the villages. They have nothing at all. If you go a little bit more rural there is nothing. (KI_10_NGO_Kwale)
Cb27	We have three villages. In Mwaroni we have 40 households. In Mwamambi B we have 67 households. In Mwamambi A we have almost 90 households. So almost 200 hundred households within Gombato. (KI_8_CBO_Kwale)
Cb26 Cb27	Our organization offers opportunities for the community, but also works training them and establishing even other sources of livelihood. We have four sectors: waste management, where the community is involved with activities with the waste. Not all the waste, but there is waste that is a resource. It is the chain, it is how they can benefit of this waste. We have an aspect of livelihood – like for example, when you come to mangroves, they play along with fisheries, because you can't have one without the other. So, we have activities for livelihood inside the mangrove, as I told you. We have beehives inside the mangrove, because they are very productive and attractive to bees. We have seedbeds, we collect the seeds and raise them somewhere. And then the aspect of fisheries: we have fisheries and we train the fishermen on the importance of the fish, because you cannot fish everything. We do check the gears, because you cannot come with a mosquito net and start fishing. You will have exploited everything. We need this generation to be back to life, because if you fish today, in two months that fingerling will be grown and can be fished again. So they have a group on their own by which they meet, we come and visit them, see where they have reached. If there are issues we try to help them. If it is beyond us, we invite KMFRI, then the government assist us further in the livelihood of fisheries and mangroves. And another aspect is child development. We have a partner who assist us, because they miss things that are needed for the kids to grow up. Nutrients, education. So, we have a partner from the World Vision who assist us in those problems. So, this chain, how the kid, he or she grows up, is being provided food, education, a place where they can sleep, all of that. (KI_4_NGO_Mombasa)
Cb28	We don't receive any external funds. We buy the material from collectors, 20 to 30 collectors, all from Likoni. They collect in the South Coast – Kwale and Mombasa. We have a shredding machine that crashes 5 tons per day. We put in sacks and take to the companies. They are all from Mombasa. The material is taken by the CBO to the companies. (KI_13_CBO_Kwale)
Cb34 Ph160	*(About plastic waste collected)* Sometimes we get 15 Ksh per kilo, sometimes 10. Plastics do not have a lot of weight. (KI_8_CBO_Kwale)
Cb35 Ph160	You see, for flip flops we get 30 Ksh per kilo. Plastic bottles, only 16 Ksh per kg. And it started at 10 *(Ksh per kg).* An institution in Shimoni, which is part of the committee, is responsible for shredding the PET bottles to sell the buyers in small pieces, so they can carry more in the lorry. I hope we can set the price higher because of that. (KI_12_NGO_Kwale)
Cb35 Ph163	The problem is plastic bottles do not have the highest demand, that is why we don't collect many. For us it is better to collect the hard plastic, because the demand is high. But for plastic bottles, we can get maybe 1 KSh per bottle, is very little. We do bring them *(PET bottles)* because they are needed by people who sell juice, for instance. Then they are reused, not recycled. They are used by people who drink juice, cold water… (KI_8_CBO_Kwale)

Cb36 Cf64	For NGOs and CBOs we used to have a unit group, but it didn't last for too long. The nature of this work also needs some resources, support from the government. They cannot support themselves. (KI_31_government_sub-county_Kilifi)
Cb37 Pf147 Pf150	There are quite many *(CBOs)*, but NEMA doesn't have a database. The reason is that CBOs and NGOs have various interests. For example, you can have a CBO focused on mangroves, but they are still working with plastics; some are particularly working with transport from the households to the collection centre. The registration of all these CBOs and NGOs is still in process, NEMA is working with the county government to develop a policy framework. (KI_6_government_county_Mombasa)
Cb38	*(about the scrap metals ban)* The reason for this is that you should not buy scrap metals because they have been robing infrastructure projects such as electricity wires, metal in bridges, transformers. They steal those to sell to dealers. And that is the challenge: scrap metal dealers are facing challenges and that has also impacted plastics. (KI_7_NGO_Kwale)
Cb38	The facility is suffering with the ban of scrap metals. Collectors are bringing less than needed. It reduced almost half. It is hard to get 15 tons. (KI_13_CBO_Kwale)
Cb39	It is difficult because the government has no consideration for our welfare. It charges an exorbitant price for licensing – 250.000 Ksh for the license and offers very little support. There is an organization that is trying to reduce for 20 thousand, so we might be able to afford *(the Kenyan Association of Recyclers).* (KI_13_CBO_Kwale)
Cb40	We started with 64 people, but right now there are 15. They quit because everybody has their own goals, their own thinking. So, the only objective of this group was dealing with environmental issues. But they come here looking for jobs. When we say to members that we are here for environmental issues, to clean up our community areas, they say "these people are joking, I will not stay here, I will go away". Because they are not paid, they want money. (KI_8_CBO_Kwale)
Cc41	Most collectors are drug users. Collecting waste is the easiest thing they can do. (KI_7_NGO_Kwale) ROW 7 TABLE 5
Cc44	*(About informal collectors)* We have no idea of how many, but most of them are drug addicts and take *(the collection)* to the centres *(CBOs).* (KI_14_government_municipality_Kwale)
Cd45	Kwale Recycling Centre was first known as Kwale Plastics Plus. It started in 2018. At first, the dream was to try and take away plastics from the environment, because that was a major challenge we were facing in Kenya and also in Kwale County. We changed the name last year *(2021)* because we realized you cannot take care of just one section of waste. So, we changed the name from Kwale Plastics Plus to Kwale Recycling Centre because we want to partner with anybody who is involved with conservation and waste management, so we can manage waste sustainably in Kwale. (KI_9_Kwale Recycling Center_Kwale)
Cd45 Pb128 Pb130 Pe144 Pe146 Pf152 Ph161	The work related to waste management started in 2010. Started with beach clean-ups, as a Watamu Marine Association to get the community, hotels, tourism industry and environmentalists working together to protect the beaches. This led to the creation of EcoWorld Recycling, which turned into a social enterprise and charity company. It is a result of a recognized need, a recognized problem in the community. Now, years later, EcoWorld is a recovery material facility, also involved in research, but the primary goal is to develop plastic circular economy opportunities to expand throughout Kilifi county. In one level, EcoWorld is involved with beach clean-ups and research. In other level, EcoWorld is targeting the plastic waste produced in the county, so it can be recycled. (…) The Blue

	Team is a group of 20 people, the original beach cleaners when the program started. After the first beach clean-ups, the group realized the work should be continuous, got the first funding, which kick-started everything. This is when we went to the hotels and said “this is a team effort, we all have to work together here. It is our community, our marine park, you’ve got a lot of advantages in the hotel industry on how you present yourselves”. So, they came together and sponsored the Blue Team. So, after the fund raising, the hotels started funding the Blue Team over the years. Some hotels more, some hotels less. The sustainability of the Blue Team is on providing what we call environmental services, meaning cleaning the beach, so the hotels benefit, their guests benefit from having a cleaner beach, and everybody can see the value of that. So that has been going since 2010, but we have special events. During the height of COVID, back in 2020, we set a Covid relief project called Trash for Cash. We raised 10 thousand dollars and managed to keep the beach clean for 3 months having cleaning members to go out and get an income during those really hard times, when nobody had jobs and income. So, we target the community, but the marine litter as well. We’ve been working with the ICC (International Coastal Cleanup) for years, and have been getting funding to target marine litter. So big clean-up events such as ICC, World Ocean’s Day, World Environment Day, that’s when we gather 5, 10 tons in one day from the beaches. (KI_32_EcoWorld Watamu_Kilifi) – ROW 14 TABLE 5
Cd46 Ph161	We need to empower the youth who don’t have jobs, we need to empower the women groups, we need to empower the BMUs. So, we are really trying to go deep into them, trying to educate them on the importance of waste management. Because the target is trying and incorporate a circular economy in Kwale County, so the waste generated in Kwale County can be recycled and managed in Kwale County, so we can have products from the recycled materials being used in Kwale. (KI_9_Kwale Recycling Center_Kwale)
Cd47	Not all hotels, but most of hotels that use plastic bottles have an agreement with EcoWorld to send their plastics there. Most of the hotels have a special agreement either with the county or with private dealers. Most of them deal with private sector. Hotels are not a problem for the plastic pollution. (KI_31_government_sub-county_Kilifi)
Cd47	EcoWorld has been working with six marine park hotels over the years, actually helping them to develop their waste management policies. They are very aware of best practices and want to be seen as excellent. So, they are going to use the best available service. And all the plastic waste from these marine park hotels comes to EcoWorld. And they will only use county vehicles. (KI_32_EcoWorld Watamu_Kilifi)
Cd48 Bd50	With the houses, we give them labelled bags, they give us the bags, we give them back. This happens in Watamu and we are now spreading to Malindi and Kilifi. (KI_32_EcoWorld Watamu_Kilifi) – ROW 12 TABLE 5
Cd50	We also have the bins, which we call green stations. They are segregating bins, separated into four different sections that are glass, plastic, metal, and paper. We are trying and place these stations along the community, near roads, small marketplaces. (KI_9_Kwale Recycling Center_Kwale)
Cd53 Pd53 Pd140	We started with around 33 *(green stations)*, but last year we had to reduce them a bit, because the design that we had come up at first was not sustainable, and people were actually stealing the metal roads. So now we are building new ones. (KI_9_Kwale Recycling Center_Kwale)
Ce54 Ib56 Pg22	There are private companies that make the collection, specially from hotels and resorts. When the hotel is very big and private collectors are not able to collect, the municipality does it. But is not for free, there is a monthly fee. (KI_14_government_municipality_Kwale)

Ce56	Everybody knows that if you are using private vehicles, the chances of illegal dumping are high. The roads to the public dumping side are bad, 30 40 minutes from here, and they are not going to go there. (KI_32_EcoWorld Watamu_Kilifi)
Ce56	You have these private services or tuk-tuks that say they are providing a service of collecting your waste to the dumping site, but they just go to the roadside and illegally dump there when nobody is looking. (KI_32_EcoWorld Watamu_Kilifi)
Ce57	The problem is that some people engage in this business *(private companies of waste collection)*, but not officially. They do it only if they have work. Most of the times they do other businesses, but if they receive a call from someone that want the collection services, then they run and do it. The ones that are doing it officially are three. They are responsible for about 2% in the whole sub-county *(Malindi sub-county). (*KI_31_government_sub-county_Kilifi)
Ce58	Private companies also take the waste to the dumping site, and they shouldn't. So the amount taken there *(to the public dumping site)* is higher. And they are not charged for that, so they are using the dumping site for free. (KI_15_government_county_Kwale)
Cf60	Clean Green Mswambeni is a project with 3 pillars: tree planting, tree protection and the third of them is sustainable garbage management. (KI_10_NGO_Kwale)
Cf60	We saw we needed someone from the community to talk to the community. So, I've been heading emergency projects, for a German NGO, so I knew a bit about the set ups I wanted to use, which is really community-based, to understand the community, and it has to come out of them. (KI_10_NGO_Kwale)
Cf63	We have already the land in Shimoni, given by the county government, and we are thinking about how to get it going. We are now focusing in getting new buyers/recyclers. (KI_12_NGO_Kwale)
R112	Our people stick to traditional ways of doing things. Burying is one. (KI_14_government_municipality_Kwale)
La66 Ba106	A lot of course is being burned, some is being dug up, some is just wiped outside. (KI_10_NGO_Kwale)
La66 Lc77	Mzungu *(word used in Kenya to describe a white person)* tourists are usually very much aware of environment matters. If they come with a bottle, they keep it on their backpacks to discard them correctly. The same does not happen with local people – they usually throw bottles wherever they can. (KI_19_4-star resort_Kwale)
La67	Community is the biggest problem. If you go to a hotel, you do not take a plastic bottle and they won't give it to you. They use glasses. You might find bottles here *(shows the water he is drinking)*. (KI_7_NGO_Kwale)
La67 La69	And of course if you have a plastic bottle and you are riding a tuk-tuk or a matatu (*minibus used for public transportation*), you drink it and just throw them out of the window. (KI_10_NGO_Kwale)
La67 La71	Everybody has their own mind, own thinking. Maybe if you put a bin here, I can throw a bottle in the ground anyway. So, we need monitoring on this also. (KI_8_CBO_Kwale)
La67	The biggest problem is the community and the businesspeople on the streets. This is a bit difficult to control – they drink water and throw the bottle on the street. We really need more awareness and also law enforcement. (KI_29_government_county_Kilifi)
La68 N76	We have these areas that are local and they are not occupied by the beach areas. Maybe mangroves, maybe places that have coral rocks. They are not places that people visit regularly, but these are areas where we have wind blowing and the currents, and they trap a lot of plastics. It's a lot of plastics, but people don't care about these areas. So, we are

	trying to come up with small beach management units, so we can once in a while just do clean ups. People don't pay attention to them because tourists don't go there, but they also need cleaning. (KI_9_Kwale Recycling Center_Kwale)
La69 Pc136	Before the ban, many activities made use of plastics – for example, fishes were sold ready to cook, in plastic bags. The ban was very effective, but now the bottles are a huge problem. (KI_3_Research Institute_Kwale)
La69	Our biggest challenge is the PET bottles! You see, the blue ones we have here, and the next ones are the clear ones. These ones are many. They are basically covering the largest area of waste we are keeping here. The PETs. (KI_9_Kwale Recycling Center_Kwale)
Lb74 Lb75 N74 N75	Most of the waste that is in the tunnels ends up in the ocean or Kongo. In the bridge we have when you are crossing towards Tiwi, we have a small tunnel on the right-hand side. So, when it rains, that tunnel normally has a lot of waste, all kinds of waste: plastics, glass, paper, everything. Once it rains a bit, it flows into the river and the river can take it to the ocean. (KI_9_Kwale Recycling Center_Kwale)
Lb68 Lb75 Ia68	The trash that normally gets into the ocean is not only generated by the people that live around the beach. Most of it comes through the rivers. So Congo River plays a major role in bringing plastics, but again a big percentage of it will be trapped in the mangroves. So, we need to have people managing those areas so that they can go deep into the mangrove areas and just to try and take away all the trash we have there. But yes, it *(fluvial transportation)* plays a major role in taking plastics into the ocean. Not only Congo River, but also the other rivers that we have. (KI_9_Kwale Recycling Center_Kwale)
Lc80	The number one offender is from Wrigley's PK *(a chewing gum brand)*, because the Swahili people use mara, or khat. Since khat has a bitter taste, people use the chewing gum to compensate the taste and leave the packaging on the beach. The alternative solution would be another material, a wax paper. We didn't have the time to do it, but we got to get in touch with these companies. (KI_32_EcoWorld Watamu_Kilifi)
Ia83 Ib56 Ib88	Most of the waste (in rural areas) is actually organic. Here, many of the houses have nothing inside. They don't have furniture, they don't have money to buy stuff that is wrapped in plastic or comes in plastic containers. They might have plastic from the washing powder, cooking oil, sugar and maybe rice. But we observe that in the villages in which there has been more income, more development, the structure of the houses have improved, and so there is more garbage. One that is really very obvious is, I would say it started about 3 years ago, that you see diapers laying. The first time I saw a pile of diapers laying under a tree, I thought it was from the hospital. I though a collector had came and taken the nappies and dumped them in a place they were not supposed to be taken, which we see happening quite often. Identifying reliable service providers is not so easy. But then I realized it is actually the community itself. Well, part of them, it's not everyone. But part of them is somehow not aware that it is open defecation. That has really increased in the past 3, 4 years. I believe before people could not afford to buy diapers, or they were not available – the next supermarket is in Ukunda, we just have little stores here. There might be many reasons, it could be that they were more expensive and there are cheaper brands now. In any case, the environment has suffered a lot'. (KI_10_NGO_Kwale)
Ia85	The biggest challenge is human behaviour. It's not even awareness. People are aware. They know it is against the law, but they still do it. But it is the biggest challenge, but it is also the biggest achievement at the same time. That is way I say human behaviour. (KI_6_government_county_Mombasa)

Ia86	Especially when it comes to the diapers, people seem really fed up with them. We even had some elders suggesting 'let's just prohibit them'. But what is lacking is supervision. (KI_10_NGO_Kwale)
Ib87 Pa117	Last time we checked there were 11 dump sites *(areas of plastic waste illegally dumped in Diani)*. At first there were many and they were bigger, but right now, after the awareness and the installation of green stations, the waste in illegal dump sites is actually going down. (KI_9_Kwale Recycling Center_Kwale)
Ic74 N74	It is littered *(the non-collected amount, estimate 70%)*. There are areas in which the waste is dumped on drainage systems, because they know when the water comes, it will carry away. (KI_14_government_municipality_Kwale)
Ic74	*(The amount dumped)* In drains and waterways is around 5%. There is the issue of containers being far from their home, so they do not carry there. Awareness is being enforced to reduce that amount (KI_15_government_county_Kwale)
Fa194 Fc103 Pa120 Pb127 Pb105	We know the negative impacts of nets in the ocean. We gather 4 or 5 men, then go in a boat to try and recover the broken pieces. (KI_23_BMU 1_Kwale)
Fa195 Ph163	The ones recovered are burned, taken home to be reused or taken to the dumping site. (KI_24_BMU 2_Kwale)
Fa96	As government, we are doing sensitization here and there and also giving them *(the fishermen)* legal gears. The monofilament gears are illegal, for instance, because of the plastic material, that takes years to degrade. So, once it is destroyed and lost in the sea, it becomes what we call ghost fishing: it will fish, nobody will collect, and it will keep swimming on the ocean. That's why it is illegal. So, the county provides the legal gillnets, that degrade faster and the holes have 2 inches. We don't provide them every time. We provide a piece hoping they will buy the same type next time. (KI_16_government_county_Kwale)
Fa97	We need to ban completely some of these gears, the same we did with plastic bags. If they are found, then they are illegal. For example, the hook and line. Why do they have to insist in plastic ones when there are other materials? They say the fish cannot see it, that is invisible in the water, and it is the same thing with the gillnet. They are appropriate, they work the same way as plastic gears. The monofilament gears are already illegal, but the hook and line are legal regardless the material. (KI_16_government_county_Kwale)
Fa99	The quality is very bad, they *(fishing nets)* break more. More money would help. (BMU)
Fa99	The bad quality can also be related to the type of plastic used to fabricate that gear. There are all kinds of materials, and some are cheaper. Maybe the fisher doesn't want to buy a particular kind of gear, but it is a matter of price. (KI_16_government_county_Kwale)
Fa100	Sometimes, when a gear is lost, we talk to fishers from another BMU and they can be found. The ones recovered are burned or we take home to use for other stuff. The county collects some too. (KI_24_BMU 3_Kwale)
Fb101	We also have lots of plastic bottles. Fishers use a lot. For instance, when they use basket traps, they need to locate them. And for that they need a buoy. They use plastic bottles for that, because it is the locally available material. After using them, they are just going to dump them anywhere, and this means they are generating direct waste into the ocean. (KI_16_government_county_Kwale)

Fb101	We use bottles as buoys, but we do not leave them in the sea, we always try to remove. Unfortunately, some we can't. From every 10 bottles, maybe 2 or 3 are lost in the sea *(per week*). Each bottle is used by two persons. (KI_23_BMU 1_Kwale)
Fc103	The County Fisheries Office is the umbrella organization for the BMUs. There are 33 in Kwale County. They are not evenly distributed. The country has counties, that have sub-counties, that have wards. One ward close to the border of Tanzania, for instance, has 2 BMUs. The next ward has 7 BMUs. The next, 6 BMUs. The next, 3. Diani has no BMUs. The next one has 1 BMU. The distribution of BMUs is based on the demand for services, number of fishers and number of fisher boats. If there is not enough boats or land in a certain location, there is also no need to establish a BMU *(case of Diani)*. A BMU is an umbrella for fishers, boat owners, traders and a category called "others", from which food vendors are part, or sellers of swimming suits. Sometimes there is a landing site, but the headquarters are somewhere else – it is the case of Diani. It is a landing site, but the BMU headquarter is in another location. (KI_16_government_county_Kwale)
Fc103	Some *(fishers)* are aware *(about entanglement and ingestion of plastic by marine wildlife)* . But some of them have to see a fish that is entangled in plastic to realize that this is possible. If you explain bioaccumulation, they won't understand. But if you sensitize about this *(entanglement of marine wildlife)*, that will be of help. (KI_16_government_county_Kwale)
Fc103	*(about what fishers' communities need)* Subsidies and a lot of sensitization. They might not see a problem on buying a gear that is cheap. So, sensitization would teach them that it is not only about the money you are spending. It has also an implication to our ecosystem. (KI_16_government_county_Kwale)
Fc104	They *(fishers)* need places to collect this waste, for recycling. Waste is going to be generated and accumulated, so we need garbage bins where they can separate waste – plastics, biodegradable. (KI_16_government_county_Kwale)
Fc104	We *(fishers)* need a proper landing site, a place where we can store the material, and change clothes, have a freezer for fishes, a place to cook. (KI_25_BMU 3_Kwale)
Fc105	*(about the implementation of a return fee for broken fishing nets)* I think they would come with more broken gears than there are. I've seen it before, in beach clean-ups, they are supposed to collect all waste that is not biodegradable, and they sell it. I've seen them bringing waste from inland to have more. So, this is the real situation, but it is also a good approach. (KI_16_government_county_Kwale)
Pa116	Awareness is very much needed for the system to work. It should be introduced to schools, formal and informal education. NEMA's role is to give direction for that. (KI_26_government_county_Kwale) – ROW 1 TABLE 5
Pa118	So, even in the stations in which we have the segregation bins, not all the stations are always well managed. Some of them are mixed. These are some of the challenges that we face on the ground. But it is a good thing. Because if you mix it today, and tomorrow you come and find it sorted, it is a new learning. (KI_9_Kwale Recycling Center_Kwale) – ROW 1 TABLE 5 / ROW 1 TABLE 5
Pa121 Ph164	The county has a partnership with the private sector, with *(mentions the company)* to develop education/awareness projects in schools, and they have been seeing a positive change on disposal of waste, recycling. So, in this sense, formal education helps to address waste management issues, specially related to learning that single-use plastic has value and can be recycled. (KI_15_government_county_Kwale) – ROW 1 TABLE 5
Pa122	We also have schools programs. There are 18 primary schools, 12 secondary schools, 5 higher learning institutions and 5 special schools. The program is about environmental

	conversation, especially tree planting and solid waste management. (KI_12_NGO_Kwale) – ROW 1 TABLE 5
Pa122	Bringing the right people together is important. Authority is also important. If the village's chairperson says, "No more waste thrown close to your house", and you still do it, you will be in trouble. The chairpersons really embrace the idea. (KI_12_NGO_Kwale)
Pa123	We work with tree planting and garbage collection, efficient awareness and child education. Those are the activities we are developing. (KI_8_CBO_Kwale) – ROW 1 TABLE 5
Pb127 Ph162	The good thing is the community is collecting, reducing the amount of waste, and putting a value on it. Some communities take a boat, go to the ocean and collect plastics from the sea. They need some money. (KI_12_NGO_Kwale) – ROW 9 TABLE 5
Pb129	What we have seen mostly about street clean-ups, like the ones our organization organizes, is more an event than it is continuous. (KI_7_NGO_Kwale) - ROW 1 TABLE 5
Pb129 Pb133	*(about street clean-ups)* In the beginning of the project, we had 200 to 300 people, but since COVID we had to reorganize into different areas. Now, people clean the areas close to their residence, in groups of 10 and 20. But initially we use to carry the process as a whole, everybody together. The amount has been progressively reduced, because as we do it, we also have a great improvement on the cleanance of the town. So, the amount we collect is reducing. We are doing good, we also do awareness with the community to ensure the town is clean. At the moment, we have even more people coming in, due to the way we organize it. We have some representation from the hotel industry, we have the community, we have some organizations. So, the more representation we have, the more people we have. What we are doing is including more people and organization to team-up. As we increase representation, we also increase participation. (KI_31_government_sub-county_Kilifi) – ROW 10, TABLE 5
Pb130	We participate on beach clean-ups. You see, the communities we are trying to target are along the Coast, so we are really participating a lot on beach clean-ups, that's one. (KI_9_Kwale Recycling Center_Kwale) – ROW 8 TABLE 5
Pb132 Pb134	We organize beach clean-ups every 2 months, volunteer work. To raise community awareness and lead by showing. Since it is a volunteer work, it should not be 'too much' (KI_7_NGO_Kwale) - ROW 8 TABLE 5
Pb134	I don't think there is a group to clean the streets. Most likely because you are not going to clean streets if you don't have food. The fact that there is no way for it to be monetized is a challenge. (KI_7_NGO_Kwale)
Pb135	We *(fishers)* want the government bringing more people to collect the plastic material from the sea. (KI_23_BMU 1_Kwale) – ROW 9 TABLE 5
Pc136	We've been living here for 10 years and we do regular beach cleanings, which depend a bit of on our time, but normally it was every Wednesday, and we would do mostly the beach front. We definitely see a difference since plastic bags were prohibited, it had a great impact. (KI_10_NGO_Kwale) – ROW 8 TABLE 5
Pc137	*(The solution for the PET bottles is)* Ban them! There are glass bottles. You see, people need to be innovative. When we were banning the plastic bags, nobody ever imagined what we should do. Bring water from home, put water in glass bottles, non-disposable ones. It's for the industry to be creative. Sometimes you just need to let the system go, for let's say, 6 months. If you use a calculator, if you look at the Kenyan economy, what we are gaining form the sales of these bottles, vis a vis the environmental degradation and the cost of remediation, it is ten fold. And that is, sometimes, what the policy makers cannot see. I am aware the industry plays a role in the producer responsibility, and we really want

	to ban the plastic bottles. Or at least a temporarily ban, so the residents of the country can appreciate what they have. So they can be responsible. (KI_6_government_county_Mombasa)
Pc138	When we banned plastic bags, we literally didn't know how to substitute them. We were 250, 300 technical officers trying to enforce this plastic ban in a population of 47 million people. It was actually the people who made our work quite easy. Because if they continued to use plastics bags, they would probably still be in the environment. Even with other organs to assist, like police and county government, it was the public that decided. So, attitude really helps and is also the biggest challenge. They really assisted us on carrying on the plastic bags. (KI_6_government_county_Mombasa)
Pc139	There is a black market of bags. It's like banning drugs, there are dealers. (KI_26_government_county_Kwale)
Pd141	The organization *(Clean Green Mswambeni)* set up a green station where people can take their own waste. This happened two weeks ago *(end of March)*, so not enough data to make an assessment. (KI_7_NGO_Kwale) – ROW 2 TABLE 5
Pd142	With PETCO *(Kenya PET Recycling Company)* we put some bottle bank containers, which we put in Marine Parks (Watamu and Mombasa), some town centres. That's what we call a green station, a public plastic waste container where people can drop their plastic. So this is a small project, but it's the first time we have that kind of engagement with the industry. It is a beginning. (KI_32_EcoWorld Watamu_Kilifi) – ROW 2 TABLE 5
Pd143	Before the stations being around, Diani started to become dirty. There was littering around the road, but due to the installation of the centres it is becoming cleaner. (KI_9_Kwale Recycling Center_Kwale)
Pe145	We have a partnership with the government also, because we are trying to come up with this model of waste management for the entire county. But again, we are trying to encourage the community because we can't fund all the bins *(green stations)* that we want to be around. The ones that we have in Mswambeni have been sponsored by the team in Mswambeni – some community groups and hotels that are conscious enough to support the instalment. Once that happens, we can partner with them, provide the bags, the collection system, so we can incorporate them to the system we already have. So, it is basically us, the community and the county as well. Basically everyone. (KI_9_Kwale Recycling Center_Kwale) – ROW 2 TABLE 5
Pe145	Up to now I think we can say that we mostly sustain ourselves by depending on doners. So the guys that are conscious about the environment, waste management and conservation are the guys that are funding us. (KI_9_Kwale Recycling Center_Kwale) – ROW 5 TABLE 5
Pf147 Pf149	*(about the dumping site having its capacity exhausted in the future)* The county will develop a waste recovery project, so recyclable waste can be separated and recycled. Also planning a project to recover the organic waste, producing proteins. The goal is having only 10% from the current amount of waste taken to the dumping site. (KI_15_government_county_Kwale)
Pf150 L176 L177	There is an ongoing project to estimate the amount accumulated on dumping sites by using drones. However, the protocol is not yet ready and is rather complex, because it is an urban area with planes, etc. (KI_7_NGO_Kwale) – ROW 11 TABLE 5
Pf151 Pf148 Pf149 Pf151	A key issue is that plastics are voluminous, and you have to carry large amounts, so it is not cost-effective. So, the county is looking to have some recyclers and machinery within that area: plastic shredders, compressing machines, so they become less voluminous.

	What we really want is that organizations such as Kwale Recycling Center collects plastics from facilities/transfer stations instead of *(the government taking to)* the dumping site. (KI_15_government_county_Kwale)
Pg153 Pg155	We *(5 star-resort)* don't have plastics. Not at the restaurant, not at the bedrooms. If guests bring PET bottles with them, they are asked to dispose them in a garbage bin. The owners respect sea creatures. I believe 70% of the hotels and resorts in the coast do that. In the last years, you see much less *(PET)* bottles on the beach. (KI_19_4-star resort_Kwale) – ROW 3 TABLE 5
Pg153 Pg154 Pg155	Hotels do realize their business rely on a clean environment, so even in terms of regulation, licensing, making sure that waste is collected. Many hotels have their own garbage collection centres. For the last 2 years, we have banned plastics in hotels in the coast, they use glass bottles. I would say 50% of the hotels do not use plastics. The mainstream ones, the big ones, do not use plastics. The smaller ones still do. Specifically at the beaches, at the shoreline this percentage is around 80%. That's why I am saying 50, because there are the ones that are not on the beaches. (KI_6_government_county_Mombasa) - ROW 3 TABLE 5
Pg154	The hotel staff cleans the beach in front of the hotel frequently. The hotel policy is to keep the private beach tidy. (KI_19_4-star resort_Kwale) – ROW 8 TABLE 5
Pg155 Pg54	NEMA has a role in the sustainable practices of hotels: the green labels, that mean sustainable facility. Waste collection is one of the main pillars of the annual license, so they have to come up with models. Private sector is responsible for 80 % of the collection from hotels and resorts. (KI_26_government_county_Kwale)
Pg156	The hotels separate because we have trained the staff to separate into plastics, metal, glass. We just drive in, load and take it away. (KI_32_EcoWorld Watamu_Kilifi) – ROW 12 TABLE 5
Pg157	The plastic bottles are collected from the restaurant, bar, bedrooms and garbage bins and taken here *(shows a storage located inside the property)*. From there, it is picked by the staff, and they sell the bottles to recycling companies. They do not get much money with them, but is an extra, and it is a good for the hotel. (KI_22_3-star resort_Kwale) - ROW 12 TABLE 5
Pg158	One tourist consumes one bottle of 1.5l of water per day or 3 of 500 ml. There also the ones that buy a 10l bottle that is used for a week. Majority of guests consumes the small ones. (KI_22_3-star resort_Kwale)
Pg159	The hotel does not use glass bottle water yet because of the price. But we consider sparkling water a high-end product, and it is already in glass, because people who pay for sparkling water are willing to pay more. (KI_22_3-star resort_Kwale)
Ph162	We currently have a ban on the use of plastics in Kenya, drove by NEMA, but it mainly focused on plastics packaging. But for other types of plastics, like PET bottles, we usually have clean-ups, when we encourage community groups to collect them and take them to some storages. This way we add value for the recycling process. (KI_31_government_sub-county_Kilifi) – ROW 6 TABLE 5
Ph164	A lot of them *(hotels)* do not recycle, a lot of them do not separate, but is happening more and more now. Especially now that they realize that plastics, metals, have a value. (KI_32_EcoWorld Watamu_Kilifi) – ROW 7 TABLE 5
Ph165	We need to encourage industry symbiosis: material integrity, jobs created, recycling with profit. (KI_26_government_county_Kwale)
Pa119 Ph167	*(about plans to recycle plastic locally, at the facility)* Right now we are trying to come up with a system first. So if you have a lot of plastics, you want to start recycling and you have

	a machine that does 10 tones everyday, and you have 100 tones. This means that after 10 days you are going to run out of the material you have to supply to the machinery. So right now what we are doing by collecting is establishing the awareness to establish a system, so that we can have a regular flow. So as the community is aware about sustainable waste management, and we have enough green stations in the community, we can take more plastics and more waste. This can become every day, so once we have that channel, once we have this regular system, that's when we can start operating the machinery. (KI_9_Kwale Recycling Center_Kwale)
Ph167	*(about Kwale Recycling Center having to achieve a regular flow to start recycling)* I don't see it as a problem. The problem is that we also sell to Mombasa. Imagine Mombasa not buying and we sending all this plastic to Kwale Recycling Center. Also, Mombasa is drowning in plastics, they don't need to buy from Kwale. (KI_14_government_municipality_Kwale)
Ph168	People try to reuse it for seedbeds, flowerpots and stuff like that, but it is not that sustainable, because a part of them, if you are using for seedbeds, when you transplant what was inside, you have to cut it open. The challenge is, after you cut it open, now it has no use and it will be dumped. So, people try to reuse them, but it is not really sustainable. (KI_9_Kwale Recycling Center_Kwale) – ROW 13 TABLE 5
Ph169	Most of the process is linear: *(waste)* produced, collected, dumped. But the system has also aspects of circularity: recycled or reused. (KI_26_government_county_Kwale)
Pi170 Pi171 Pi172 Pi173	*(about EPR – Extended Producer Responsibility)* It's there on paper, but the reality in the ground is not implemented.We are hopeful about the EPR regulations, that they will be implemented, that the industry will be complied. Because it is good for the industry too, it is good to show that you are part of the solution. It is a good opportunity for responsible business, for CSR *(Corporate Social Responsibility)*, it is a good opportunity to invest in recycling. I think we are going to see some progress more than ever before this year. We should start seeing the industry being more supportive of circular economy for plastics, wanting to come down to the ground, working with organizations like us. And we have the Producer Responsibility Organizations, such as KEPRO *(Kenya Extended Producer Responsibility Organisation)* and PETCO *(Kenya PET Recycling Company)*. Both represent the industry and we've worked with them. We have been also talking to Coca-Cola, which is interested in our work, and we will be submitting a proposal to Coca-Cola Foundation. It's early days, but is the beginning of partnerships. But what we really need to see is the EPR regulation really driven by NEMA and accepted, adopted by the industry, and being totally complied. (KI_32_EcoWorld Watamu_Kilifi) – ROW 4 TABLE 5
Pi170 Pi173	Also, although we have not started yet, there is a department for EPR, which is going to touch all recyclable materials: glass, metals, plastics, etc. The main focus, however, is plastics.The guys that are producing PET bottles, for example: what are their responsibilities? So, this has made a lot of pressure for the companies and they are coming up with a separate entity, they are investing in the company to create a process that makes the plastics go from the consumers back to the company. (KI_6_government_county_Mombasa) - ROW 4 TABLE 5
Pi171	*(about EPR)* It's a good thing that Kenya is leading in that. But again, I think we need to have more enforcement because companies are taking the EPR agreements, they are paying some money to the government, but they are not really doing much on the ground. So, there is a policy, there is a governance on that, but they are not really doing anything on the ground. We still see the waste being generated by these big companies, they do nothing. They are not focused on cleaning the environment, they just want to portray a

	better image outside there. They want to sell like “look, we are conscious about the environment, we are paying this”, but they are not really doing it. I think they need to empower these groups we are working with so that we have more communitY groups that are assisting them. (KI_9_Kwale Recycling Center_Kwale) - **ROW 4 TABLE 5**
X174	Estimating per capita waste production has not been done in Kenya and is an important gap that could be fulfilled. (KI_7_NGO_Kwale)
X174 X177	This *(estimate of household PW production)* could be estimated, but we would need more areas, different types of houses, more people. This would need more resources and people, so very difficult. (KI_7_NGO_Kwale)
X174 X177	Definitely it is not possible to calculate how much is coming from each place – all waste come from all places, is mixed and taken to a unique place *(the public dumping site)*. (KI_15_government_county_Kwale)
X174	But in terms of total plastic waste generated, it is very little and difficult to estimate a percentage. The only way to do that is by making a survey with households and community to get an understanding. (KI_32_EcoWorld Watamu_Kilifi)
X175	There hasn’t been consistent efforts on looking at dumping, and we need that. This is something we want to do, GIS projects to create maps of Kilifi county so we can look at those hotspots and illegal dumping mapping as well. (KI_32_EcoWorld Watamu_Kilifi)
X178	I think another thing you should be able to do is just establish what the average citizen thinks about plastic. I’ve met people with whom you cannot talk about climate change, you cannot talk about plastic. These aren’t issues. In this end, for the lack of a better word, it really is an ignorance problem. In this other end, people are extremely aware, and the majority of people are neither in one nor in the other side. This should be an area for us to look at. (KI_7_NGO_Kwale)
X179	Mombasa has a population of 1.2 million, Mombasa has to be the target *(for collection of PW for recycling)*. Statistics show that 2 thousand tons of plastic a month. We don’t know what those fractions are: how much is PET, how much is PP, how much is LDP? We don’t know. So much is unknown. But Mombasa has to be the target. Personally I believe that Kilifi is not producing the amount of rigid plastic waste we would like in terms of recycling. Knowing this kind of data is important. We need to break it down into fractions because that is important information for the plastic circular economy. Because then we can start putting a value. When we know the value – for instance, X tons are produced every month, then we know if it’s going to be challenging to recycle because of the value, or if it is going to be worth recycling because of the value. (KI_32_EcoWorld Watamu_Kilifi)
X180	Right now, I think one of the main gaps we have on recycling is how we manage diapers, which is a type of plastic that’s very hard to recycle. (KI_9_Kwale Recycling Center_Kwale)

ANNEX 5: Cause and effect matrix of challenges (codes with frequency 1 and 2)

		Flows affected											*Stakeholders affected*							*Prevention affected*						
ID(s)	*Challenges and frequency of mentions*	Collection	Littering	Burning	Illegal dumping	Burying	Disposal in a pit	Fishing material	Natural transportation	PW directly entering the sea	Dumping site capacity	PW in sensitive areas	Local community	Government	Social enterprises	CBOs	NGOs	Fishers	Informal collectors	Hotels	Plastic bags ban	Clean-ups	Green stations	Recycling	Circular economy	Zero-plastic environment
G11, G12, Ib91, Ib92	Informal settlements and marketplaces are hotspots of mismanaged waste (2)		■	■	■				■				■	■												
Lc80	Khat and chewing gum packaging are left at the beach (2)		■										■									■				
Fa99	Bad quality of fishing nets (2)									■								■								
Ra113	Burying is widely practiced in rural areas (2)												■													
Bb107	Burning is the most common mode of disposal (2)			■									■													
Cd53, Pd53	Metal green stations are stolen (1)		■												■								■	■		
Ce58	Private companies take collected waste to the dumping site (1)										■			■												
Lb73	PW is thrown from tuk-tuks (1)		■						■			■	■										■				
Lc81	Beaches have hotspots of littered PW (1)		■																				■				
Lc82, Pb82	Littering is a daily occurrence (1)		■																				■				
Ib90	Illegal dumping is widely practiced (1)			■					■			■	■	■												
Bc108	PW is burned in the dumping site (1)																									

Fa100, Bc100	Some fishing nets are burned (1)																									
Fc105	Return fee would not work with fishers (1)																									
Pc139	There is an illegal market of plastic bags (1)																									
Ph168	Reuse is not sustainable (1)																									
Ph169	The system is linear (1)																									
Pi171	EPR is only 'on paper' (1)																									
Pb135	More people are needed in ocean clean-ups (1)																									
Bb84	Illegal dumping increases burning (1)																									

Annex 6: Table of quantitative information

The following table presents the quantitative data for flows collected through (i) interviews; (ii) gray literature; (iii) literature review. The numbers in column 4, however, are not always precise. The objectives of the table are (i) registering the data that seems to be as close to reality as possible, among the quantitative data collected during this research, and/or (ii) provide clues for future quantification. Furthermore, the table does not assure the validity of the data, since numbers provided by key informants are usually an estimate. The last column shows comments about the data. The judgement about the degree of complexity to obtain the data is merely a suggestion, based on the author's perception at the end of the research.

LEGEND:

KI = KEY INFORMANT Unit = UNIT SUGGESTED FOR THE DATA

Source = information was provided by a key informant
Reference = information was obtained from scientific or gray literature

PRO = FLOW RELATED TO THE PRODUCTION OF PLASTIC WASTE
COL = FLOW RELATED TO COLLECTION OF PLASTIC WASTE
MD = FLOW RELATED TO OTHER MODES OF DISPOSAL (EXCEPT COLLECTION)
CU = FLOW RELATED TO CLEAN-UPS
R = FLOW RELATED TO RECYCLING
S = STOCK

BMU = Beach Management Unit
CBO = community-based organization

	Flow	Unit	Closest information among the data collected	Comments
PRO	PW produced by households in urban areas	kg or tons	Mombasa: 700-800 tons of solid waste are generated per day. *Reference*: Haregu et al. (2017) A non-published document called 'Proposal for Control of Waste Disposal and Litter In Kilifi County, Kenya, written by Adedotun Anjorin, Austin Allan Okoth and Mbindyo Didz Muteti, estimates a per capita production of solid waste of 0.75 kg/day. *Source*: KI 29 (the referred document could not be shared, but was consulted by the KI). Estimate for Malindi sub-county: 70% of the solid waste comes from households - *Source*: KI 31 "Looking at the African continent, the daily plastics consumption generally ranges between 0 to 0.2 kg per person; with South Africa being the only exemption. Kenya's daily plastics consumption is estimated to be 0.03 kg per person, which is at the lower end of the spectrum and roughly represents a tenth of the total municipal solid waste volume [Jambeck et al., 2015]." *Reference*: KAM (2019), p. 11 "According to the World Bank [2018], every Kenyan generates 0.39 kg of waste per day. The portion of plastic has not been evaluated for the whole country. For Nairobi, the percentage ranges from 9 % for low income over 12 % for middle income to 15% for high income households; 11.8 % for the whole of Nairobi [UN Habitat 2019]. Data obtained by JICA [2010] assumes the portion of plastic at the lower end of this, with 9.5 % of the total municipal solid waste volume." *Reference:* KAM (2019), p. 31	There is no available data about plastic waste production in urban households in Coastal Kenya. This is priority data gap to be filled, since it is important for collection planning. Furthermore, the classification of households into high, middle and low income households is recommended due to the significant differences on the consumption profile depending on the income. This data is also important for identifying priority areas (ie. where public containers should be placed).

PRO	PW produced by households in rural areas	kg or tons	no available data	Same as above.
PRO	PW produced by fishers	kg or tons	Monofilament gears are bought by BMU 1 one to 2 times a year, 4 to 6 pieces in each purchase. Fishers estimate that 5 to 10% are lost in the sea and cannot be recovered. Five plastic lines (for the hook and line) are bought by fisher per year, however not all fishers use them. *Source*: KI 23 Monofilament gears are used by approximately half of the fishers in BMU 3. Every fisher buys around 10 pieces per year, because 'they are weak and break easily'. Moreover, every fisher buys an average of 5 plastic lines (for hook and line) per year. *Source*: KI 25 "A rapid assessment based on Kenya Fisheries Service (KeFS) data and interviews indicated that potentially 900 fishing nets are lost annually in Kenya's coastal zone". *Reference:* Envasses Environmental Consultants Limited (2019, p.1)	Material must be weighted to be in accordance with the units.
PRO	Number of fishers	persons	In Kwale: approximately 4.000 - *Source*: KI 16	Low level of complexity, BMUs and county government can provide the data.

PRO	PW produced by hotels	kg or tons	One tourist consumes in average one bottle of 1.5 litter of water per day or 3 of 500 ml. Some buy a 10 litter bottle that is used for a week. However, majority of guests consume the small ones. *Source*: KI 22 An estimate 70 to 80% of hotels adopt a zero-plastic environment policy in Coastal Kenya– *Source*: KIs 6, 15, 19, 29 and 31 “Not surprisingly, Pirani & Arafat (2014: 322) comment that “there is much variation between hotels when it comes to how much waste per room they are generating on a daily basis. This is because the waste generation rate depends on many variables such as the hotel type, guest attributes, guest and employee activities, and occupancy rate.” This ‘forces’ research into the amount, or percentage of municipal waste generated by tourism into locally specific estimations rather than calculating with the 1 kg per day per tourist. Both Fortuny et al. (2008) and Mateu-Sbert et al. (2013) suggest a method that takes the seasonal fluctuation of tourism into account. Fortuny et al. (2008) explain differences in total amounts between calendar months in a tourist destination by the monthly differences in its total population due to number of tourist-days divided by the number of days in that month.” *Reference:* Romein and Louw (2016), p. 35	The first information in the left was provided by a 3-star hotel's manager. The number of tourists per week must be multiplied by the number of bottles. The result must be converted to weight. Medium complexity, since it can be obtained with hotels, but they are many.

COL	PW collected by the government from households (from public containers)	kg or tons	Kwale county: - 3.650 tons of solid waste collected per month, in average, in 2021 (120 tons/day). *Source*: KI 15 - 77 tons of solid waste collected per month. *Source*: KI 27. - In Diani municipality: 70 to 80 tons per day. *Source:* KI 14 Kilifi County: an estimate 60% of the solid waste is collected from households by the government. *Source*: KI 31 Malindi sub-county: - estimate 80 tons per day. *Source:* KI 31 Mombasa: 700-800 tons of solid waste are generated per day. 68% of the solid waste is collected by the government. *Reference:* Haregu et al. (2017) All Coast: - estimate 630 tons per month *Reference*: Envasses (2019)	Having a number about plastic waste collection is very difficult, since there is no separation during collection. Therefore, it is also necessary to estimate a percentage for plastic waste within the solid waste streams, which can vary significantly depending on the area (urban/rural).
COL	Equipment available for collection by the government	lorries (trucks)	Kwale County: 3 lorries, but 1 was broken for more than 1 year at the time of the interview (April 2022). A compression truck was commissioned but hadn't arrived at the time of the interview. - *Source*: KI 27 Kwale County: Each truck has a 6 tons capacity. - *Source:* KI 15 Kilifi county: 4 trucks, no data about capacity. - *Source*: KI 29	Low complexity, since the government should be able to provide the information. However, it is important to determine the capacity of the truck in order to calculate how many are necessary to cover a certain area.

COL	Capacity and number of public containers	kg or tons	In Malindi sub-county: 15 waste bins of 6 m2 + 10 permanent structures (transfer stations) of 10.000 m3. – *Source*: KI 31 In Kwale county: 32 containers, no data about capacity. *Source*: KI 27. The number of containers is 42 according to Envasses (2021) In Diani (Kwale): 35 containers, capacity 10 tons each. *Source*: KI 14. However, this number was considered too high by KI 26. In Mswambeni (Kwale): 3 containers. *Source:* KI 10	For the first information, the height of waste bins must be measured in order to calculate the volume. Medium complexity because all streams of waste are deposited in the waste bins, thus PW must be separated and weighted. In the case of green stations, complexity is low because plastic is already separated.
COL	Capacity of dumping sites	hectares	Malindi dumping site: approximately 20 hectares. – *Source:* KI 29 Kinondo dumping site (Kwale): approximately 4.5 hectares *Reference:* Envasses (2021)	The information about Malindi's dumping site seems too high and must be confirmed. Dumping sites' capacity is not part of the model because all waste streams are mixed. Non-recyclable material is the most voluminous type.
COL	PW collected by CBOs from households	kg or tons	Kwale: one CBO collects an average of 260 kg of recyclable material (plastics, glass, metal and paper) from one green station per week – *Source:* KI 11 NEMA estimates that CBOs are responsible for collecting 2% of the total solid waste in Kwale County. *Source*: KI 26 One CBO in Kwale collects recyclable waste from 200 households. They pay 100 Ksh per month each. *Source*: KI 8 One CBO in Mombasa considers that 'in a good month', 20 tons of plastic waste are collected. The shredding machine has capacity to process 5 tons per day. *Source*: KI 13	The amount collected highly depends on the characteristics of the CBO (area of operation, number of people working, equipment, capacity of storage, etc). The complexity is medium, since many CBOs are informal. Local leaders usually know the directors of these CBOs, so they might help on the data collection.

			Kilifi County has approximately 40 CBOs. *Source*: KI 29 Mombasa has approximately 20 CBOs. *Source*: KI 6 In *Diani (Kwale County),* there are 11 CBOs (2 in Kombani, 2 in Tiwi, 5 in Ukunda and 2 in Gombato/Gombwe) - *Source*: KI 14	
COL	PW collected by private companies	kg or tons	Kilifi County: an estimate 10% of all solid waste is collected from households by private companies. - *Source*: KI 31 Malindi sub-county: an estimate 20 tons are collected by private companies per day. – *Source:* KI 31	Many private collectors operate without official registration or for undefined periods (seasonally), which makes the complexity high.
COL	Number of households paying a fee to private collectors	households	No available data	The private companies that charge a monthly fee are likely the licensed ones. The complexity is low.
COL	PW collected by social enterprises from households	kg or tons	EcoWorld (Watamu, Kilifi): 40 households – *Source:* KI 32 Kwale Recycling Center: 10 to 15 tones per week, including all waste streams. Plastic is an estimate 15% of the total amount. - *Source*: KI 9 'In 2020 EcoWorld received 47 tons of marine litter and recycled 15 tons of plastic waste.' *Reference:* NEMA (2022), p. 18	Data can be provided (at least an estimate) by the social enterprises, although not available in this study. Low complexity.

COL	PW collected by social enterprises from hotels	kg or tons	EcoWorld (Watamu, Kilifi): 6 hotels, no data about weight. – *Source*: KI 32	Same as above.
COL	PW collected by staff in hotels	kg or tons	No available data	To collect this data, all hotels that use this strategy must be identified. Medium to high complexity.
COL	PW collected by informal collectors	kg or tons	No available data	Complexity is very high, since informal collectors are not monitored whatsoever. No data about how many, where or when the operate.
COL	Number of informal collectors	persons	No available data	Same as above.
MD	PW illegally dumped by private collectors	kg or tons	No available data	Very high complexity, since it is unlikely that private collectors would provide the information. Furthermore, it is difficult to map all areas of illegal dump to make an estimate and impossible to know who deposited the material.
MD	PW taken by private collectors to the dumping site	kg or tons	No available data.	Low to medium complexity. Although it is unlikely that private collectors would provide the information, they are probably able to calculate it (by capacity of vehicles and number of trips to the dumping site)
MD	PW burned	kg or tons	In Mombasa: 32% is burned, littered or illegally dumped. Furthermore, 47.1% of households routinely burn some solid waste. *Reference*: Haregu et al. (2017)	High to very high complexity. A survey with the community or stratified sampling might be options.

			The 2019 Population and Housing Census contains information about the number oh households that mainly burn their waste. No data about volume.	
MD	PW burned in the dumping site	kg or tons	No available data	Can be obtained through measurements/observations in situ.
MD	PW burried	kg or tons	No available data	High complexity. A survey
MD	PW disposed in pits per month	kg or tons	The 2019 Population and Housing Census contains information about the number oh households that mainly put their solid waste in a pit. No data about volume.	High to very high complexity. A survey with the community or stratified sampling might be options.
MD	PW illegally dumped by local community	kg or tons	In Mombasa: 32% is burned, littered or illegally dumped. *Reference:* Haregu et al. (2017) Kilifi County: an estimate 30% of all solid waste is illegally dumped. *Source*: KI 31	High to very high complexity, since the community is probably not willing to provide the information. The second information in the left seems too high and ignores the percentage that is burned.
MD	PW put in pits by hotels	kg or tons	No available data	Low to middle complexity. A survey with hotels might be an option. However, majority of hotels that are close to the beach do not generate plastic waste.
MD	Fishing material (plastic) burned by fishers	kg or tons	No available data	Low to medium complexity. BMUs and fishermen can provide the data.

MD	Fishing material (plastic) lost in the sea	kg or tons	Fishers estimate that 5 to 10% of the illegal fishing nets cannot be recovered from the sea. Furthermore, every 10 PET bottles used as buoys, 2 or 3 are lost in the sea per week. *Source:* KI 23 In another BMU, fishers declared that from every 10 PET bottles used as buoys, only 2 or 3 can be recover. *Source*: KI 25	The data obtained suggests low complexity. Fishermen can provide the data. However, since the plastic fishing nets are illegal, the person asking the questions should not be connected with government agencies.
MD	Fishing material (plastic) abandoned by fishers on beaches	kg or tons	No available data 'Around 14 tonnes of abandoned, lost or otherwise discarded fishing gears leak into the Kenyan marine environment annually'. Reference: NEMA (2022), p. 17	A survey collection on beaches can reveal this data. Beaches can be sampled according to the number of fishers per BMU.
MD	PW thrown on streets	kg or tons	No available data In Mombasa: 32% is burned, littered or illegally dumped. *Reference:* Haregu et al. (2017)	Medium complexity. As estimate can be calculated through collection of plastic from streets.
MD	PW thrown on beaches	kg or tons	Data is partially available in Okuku et al. (2021) 'Beaches in Kenya have up tp 5 macro-litter items per square meter, mostly dominated by plastic, foam and rubber at 58%, 15% ans 11% respectively. Urban beaches have more litter compared to remote beaches while recreational beaches accumulate up to 24 litter items per square meter of beach daily, translating into 12864000 items/day for the entire Kenyan coast'. *Reference:* NEMA (2022), p. 8	The referred study collected, quantified and characterized litter found in six beaches of Kwale, Kilifi and Mombasa.
MD	PW disposed in green stations and collected by	kg or tons	No available data	Very low complexity, since social enterprises know both the capacity of green stations and the number of times plastic waste is removed from them. Must be weighted.

	social enterprises			
CU	PW collected by NGOs during clean-ups	kg or tons	'308.653 litter items weighting 24.156.54 kg were collected in 2019 during the annual international coastal clean-up compared to 197.137 items weighting 59.846 kg collected in 2020'. *Reference:* NEMA (2022), p. 8 / ICC 2019, 2020)	NGOs that sell plastics know the weight of the collected material. NGOs that organize clean-ups can weight the collection before selling. Low complexity.
CU	PW collected during ocean clean-ups	kg or tons	Although not in this research, data is probably available.	Same as above.
CU	PW collected during street clean-ups	kg or tons	Malindi: ranges from 500 - 800 kg per clean-up. *Source*: KI 31 One clean-up carried out by 25 persons in a small area of Ukunda collected 0.5 tons of plastic waste. *Source*: KI 7	The range has high variation, depending on how many people participate in the clean-up. Furthermore, clean-ups are eventual, so there is a high variation depending on the month too. According to the KI, the clean-ups are carried out in the areas with high population density and cover approximately 10% of Malindi sub-county area. Low complexity, since the collected PW can be weighted.
CU	PW collected during beach clean-ups	kg or tons	"The annual International Coastal Clean-up (ICC) in Kenya yielded 24 Tonnes of marine litter from selected beaches along the coast including Diani, Mombasa, Kilifi, Watamu, Malindi and Lamu. A conservative	NGOs that organize clean-ups are able to weight the material collected. Although the number is not available in this study, can be

			estimate of 20% plastic wastes composition in marine litter (https://oceanconservancy.org/) means that 5 tonnes of plastics could have been realized during the one day clean up event. A consistent 12km beach cleanup project at Shela Beach in Lamu County collects an average of 0.5 tonnes of plastics per month. This indicates that Kenya's 600Km coastline holds enormous potential as a source of plastics to support recycling initiatives which translate to environmental benefits for the blue economy sector." *Reference:* Envasses Environmental Consultants Limited (2019), p. 1	provided by beach clean-us organizers. Low complexity.
MD	PW illegally dumped that is transported to drainage systems	kg or tons	No available data	Plastics can be collected from drainage systems so an estimate can be made. Medium complexity.
MD	PW transported from drainage systems to rivers	kg or tons	No available data	Once the data above is obtained, this data might be modeled with spatial data.
MD	PW illegally dumped that is transported to the streets	kg or tons	No available data	High complexity, since it is difficult to determine the origin of plastic waste on streets. Simulations might be made with base on terrain, wind, surface runoff and rainfall data.
MD	PW illegally dumped that is	kg or tons	No available data	Data about amount in mangroves can be obtained in situ. Assumptions about the origin (illegally dumped) can be made through geo-spatial analysis and observations of the area.

	transported to mangroves			
MD	PW transported from streets to drainage systems	kg or tons	No available data	Might be modeled with geo-spatial data.
MD	PW transported from streets to mangroves	kg or tons	No available data	Same as above.
MD	PW transported from streets to beaches	kg or tons	No available data	Simulations might be executed with base on terrain, wind, surface runoff and rainfall data.
MD	PW transported from streets to rivers	kg or tons	No available data	Same as above.
MD	PW transported by rivers to the ocean	kg or tons	Lebreton et al. (2017) has developed a model to quantify the plastic inputs from rivers into oceans. 'The riverine survey estimated that litter is discharged at a rate of 0.035 items m-3 s-1 translating to an estimated annual litter flux between 6.622.560 and 614.952.000. The standing stock survey in the estuary revealed that plastics contributed 90.8% (0.046 items m-2 wheighting	The model is global, so must be adapted, if possible.

			0.0007 grams m-2) of the total branded litter'. *Reference:* NEMA (2022), p. 12	
MD	PW from beaches entering the ocean	kg or tons	No available data	
R	PW sold by CBOs to recyclers	kg or tons	No available data	Can be obtained with CBOs. The number of informal CBOs increases the complexity level.
R	PW sold by private collectors to recyclers	kg or tons	No available data	Same as above
R	PW sold by social enterprises to recyclers	kg or tons	No available data	Can be obtained with social enterprises. Material must be weighted.
R	PW collected in clean-ups and sold to recyclers	kg or tons	No available data	Can be obtained with NGOs and clean-up organizers.
R	PW recycled	kg or tons	There are 7 recycling companies licensed by NEMA, all in Mombasa (no one in Kwale or Kilifi). *Source*: KI 6 "Among these 7 companies, 'four were visited during the site visits. These are Jilplastics Limited, Modern Soap Factory Limited, Rubi Plastics	Data is not available in this study, by the licensed recyclers would likely be able to provide it. Low complexity, since the recyclers probably have information about weight.

			Industries Limited and Mombasa Polythene Bags Limited aged between 4 and 28 years. The companies obtain their plastics from the collection points, transfer stations and dumpsites mainly in Mombasa, Kwale and Kilifi as well as rejected industrial packaging. The four companies recycle over 500 Tonnes of plastics per month which is comprised of HPDE (31%), LPDE (45%), LLPDE (3%) and others (21%) (Figure 4). Mombasa and Kilifi Counties have the highest volumes of high value HPDE polymers compared to Kwale and Lamu 4 of them recycle 500 tons of plastic per month." *Reference:* Envasses (2019) Kwale Recycling Center wants to start recycling in the facility. The machine has capacity to process 10 tons per day. *Source:* KI 9 'In 2017, of the 42.970 MT of plastic waste forwarded to recyclers, 36.193 MT were recycled, 23.006 MT being plastic material (in Kenya). Reference: NEMA (2022), p. 16	
R	Price of plastics when sold for recyclers	Ksh (Kenyan shillings)	Ranges from 10 to 15 Ksh - *Source*: KI 8 PET bottles (when sold by informal collectors): 10 Ksh - *Source*: KI 32 PET bottles: 16 Ksh per kg. Started on 10 and was negotiated with buyer over time. *Source*: KI 12 "The main plastic polymers targeted for collection are PET (36%), HDPE (28%), LDPE (29%) and others (7%). HDPE is a high value plastic that retails at US$ 0.18 at collection points while the least price recorded was for LDPE at US$0.04"	Available.

			Reference: Envasses, 2019	
S	PW on the ocean	Kg or tons	'Up to 347.337 litter items are floating in a square kilometer in Kenyan nearshore coastal waters'. *Reference*: NEMA (2022), p. 10	
S	PW from overseas	Kg or tons	'Marine litter collected on the Kenyan beaches were mainly of Kenyan origin constituting 88% of the total litter on beaches whereas 12% originated from foreign countries i.e, Tanzania (4.7%), India (1.8%), South Africa (0.9%), Cinha (0.7%), Thailand (0.7%), UK (0.4%), Uganda (0.3%) and Egypt (0.2%)'. *Reference:* NEMA (2022), p. 9	

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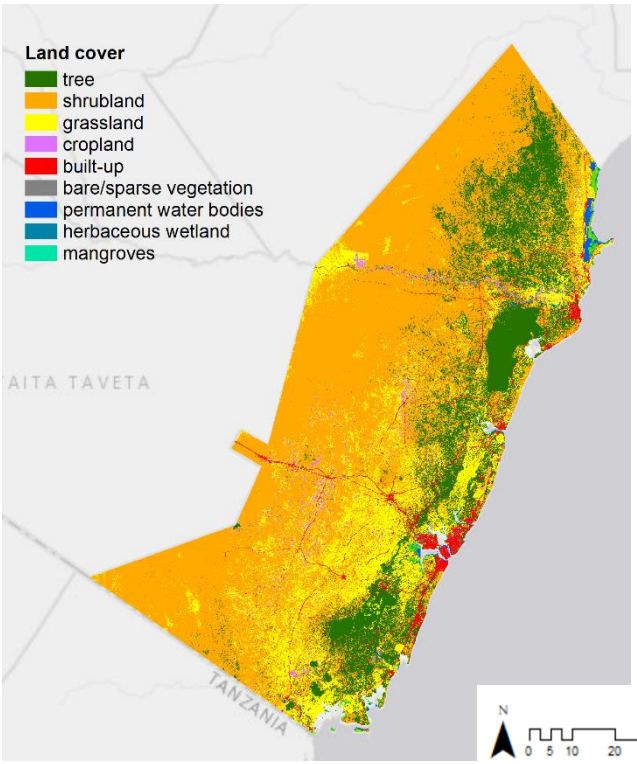
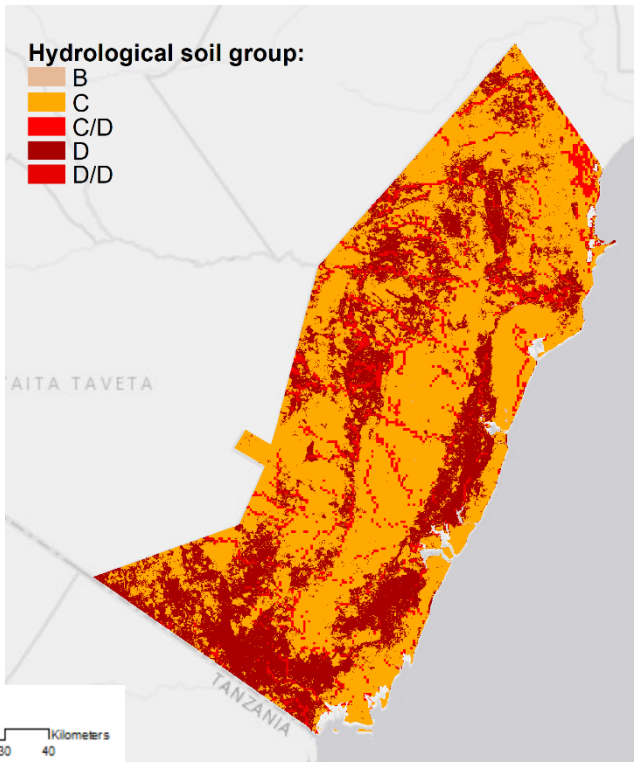
Annex 7 . Runoff potential

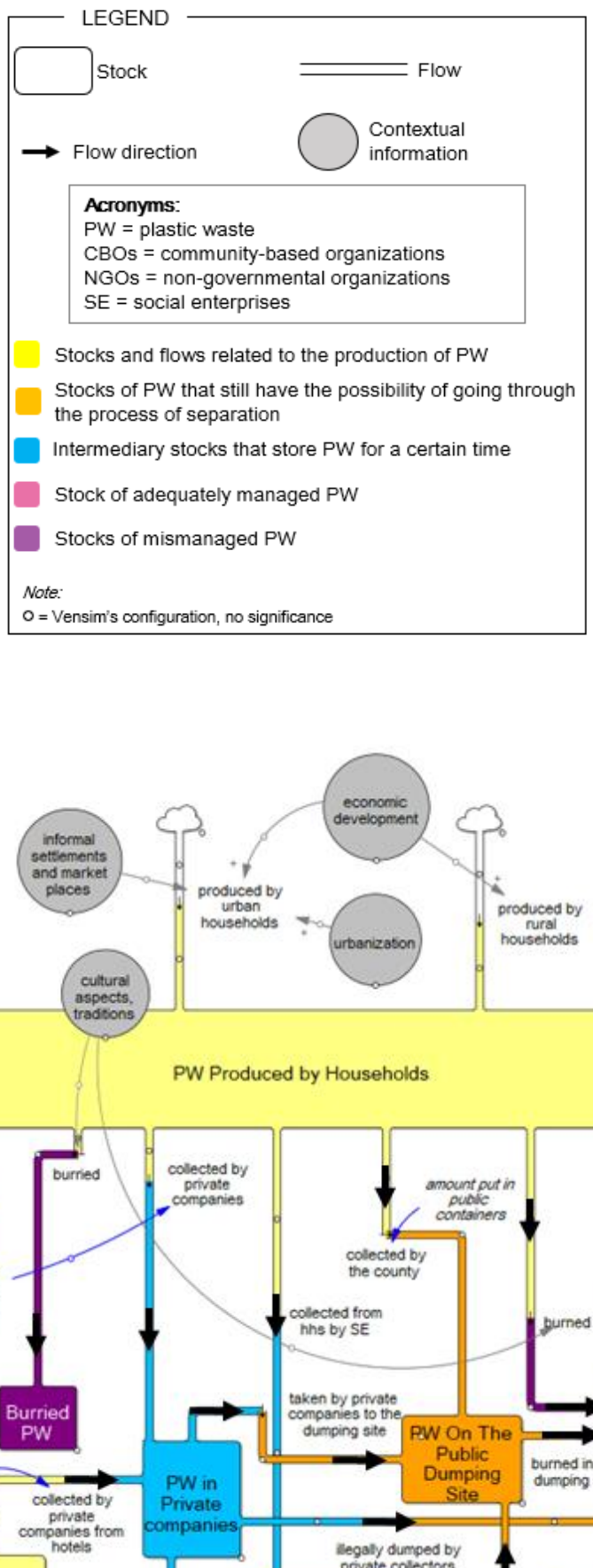
The figures below were created during the calculation of the curve number (Section 3.7). Together, the land cover map and the soil group type can be related to a CN, as shown in the table.



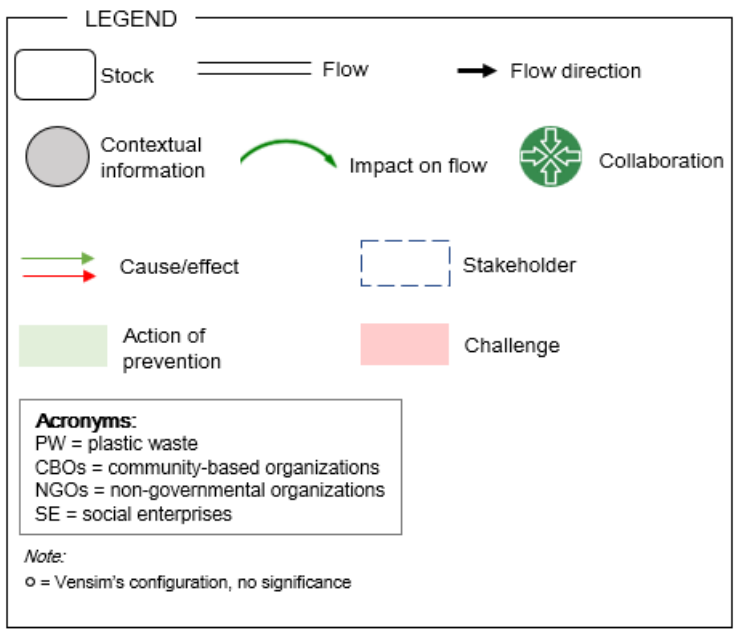


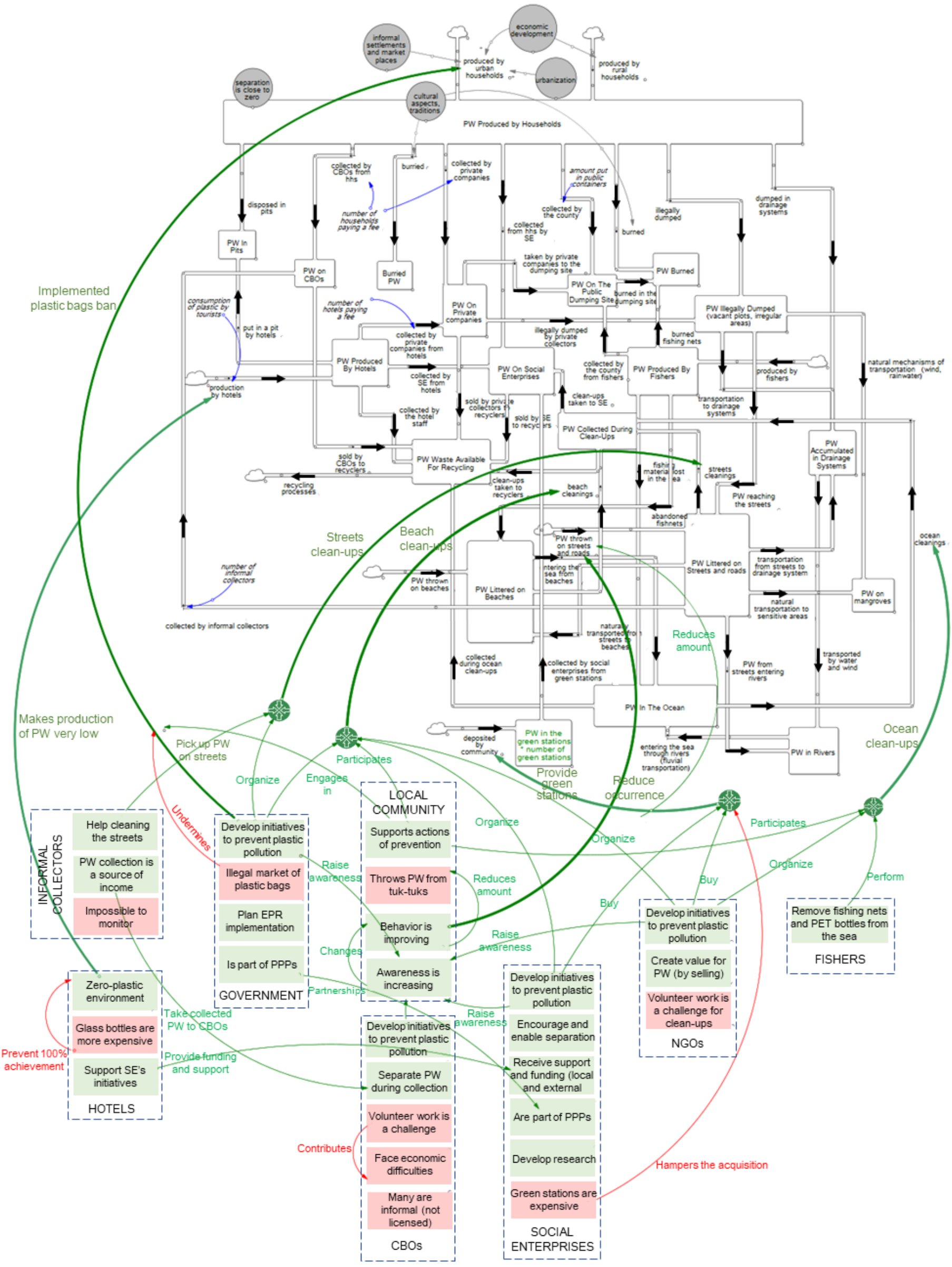
			Curve number according to HSG		
Code and land cover according to ORNL DAAC		Classification according to SCS	B	C	D
1	Tree	Woods (fair hydrological condition)	60	73	79
6	Shrubland	Brush – brush-weed mixture (fair hydrological condition)	56	70	77
7	Grassland	Herbaceous (fair hydrological condition)	71	81	89
8	Cropland	Row crops (not contoured, poor hydrological condition)	80 81	87 88	90 91
9	Built-up	Urban areas – commercial and business	92	94	95
10	Bare/sparse vegetation	Fallow – Bare soil	86	91	94
12	Permanent water bodies	Water (not considered for curve number calculation)			
16	Herbaceous wetland				
17	Mangroves				

Annex 8. Structure of the stocks and flows model (system dynamics model). A3 size.

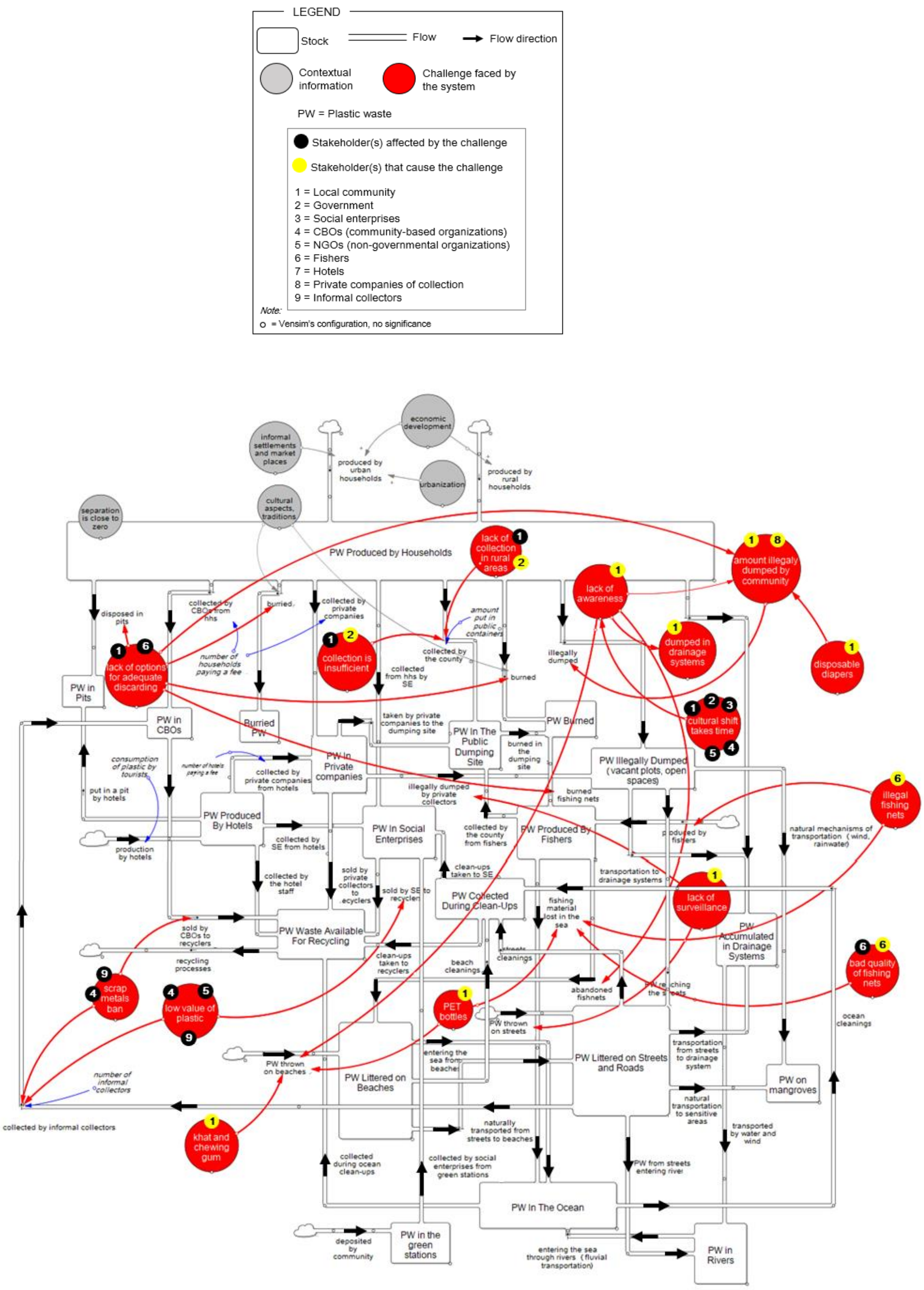


Annex 9. Conceptual System Model showing stakeholders and their properties, the effect of the properties on flows and the effect of challenges on properties. A3 size.





Annex 10. Conceptual System Model showing the challenges faced by the system (red circles), their impact on flows, and the stakelholder(s) that create and/or are affected by the challenge (s). A3 size.



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