Characterisation of plastic waste in the city of Yaoundé and impacts on a number of environmental components Plastic pollution in the city of Yaoundé

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The aim of this report is to present the methodological approach and the main results of the work carried out as part of the CMR001 project entitled **Characterisation of plastic waste in the city of Yaoundé and impacts on a number of environmental components Plastic pollution in the city of Yaoundé**

The aim of the project, which ran from November 2021 to December 2022 in the city of Yaoundé, was to identify, understand and analyse the impact of the high level of plastic pollution in the city on **a number of environmental components**, including water, air and soil.

Summary

This study, conducted from November 2021 to December 2022, is a contribution to improving plastic waste management in the city of Yaoundé, Cameroon. Its objectives were to: (i) draw up an inventory of plastic waste management in the city; (ii) characterise plastic waste in agricultural soils (urban market gardening areas) and the city's water bodies; (iii) analyse the impact of plastic waste on these ecosystems and propose possible solutions that could make a significant contribution to improving the situation. Photographs, visual observations and a map of sites polluted by plastic waste were taken. The data collection tools, in particular the survey sheets and interview guides, were developed on the basis of a literature review, which also enabled the types of plastic to be identified and classified. A total of 411 households were surveyed in the city's 7 arrondissement communes, and semi-structured interviews were conducted with a number of state actors (technical departments of ministries and arrondissement communes) and non-state actors (NGOs and associations). Plastic waste was characterised using the MODECOM method in 440 households and 5 watercourses with a high accumulation rate in 5 Communes. Finally, the impact of plastic pollution on the ecology of the city of Yaoundé was analysed on the basis of direct measurements carried out in the field, particularly on surface water in 5 boroughs. A floristic inventory and laboratory work (physicochemical analysis of surface water) were carried out, together with information from the literature. Most of the interviews (60%) were conducted with women in the households. A lack of waste sorting was observed in households, where plastic is mixed with other waste in pre-collection bags/bins, reused (28%), burnt (13%) or thrown away in nature (12%). Pre-collected waste is then placed in collection bins intended for household waste, and transported by HYSACAM for disposal. Several organisations in the city collect and recycle plastics, particularly PET. Observations and analyses show that agricultural soils and surface waters are polluted by plastic waste and the elements produced by its degradation. The air at sites with a high accumulation rate generally showed high levels of greenhouse gases (CO_2 and VOCs), with higher concentrations of 650 ppm (CO_2) and 0.078 mg/m³ (VOCs) in the microclimate of the drain in the Yaoundé 3 district municipality. These values are higher than the thresholds set by the European Union, of 350-400 ppm (CO_2) and 0.02 mg/m³ (VOCs) respectively. The surface water in the study area, particularly at the accumulation sites (5 rivers), is relatively more polluted (physicochemically) than the water at the control sites; this seems to have an impact on zooplankton and phytoplankton, which have a lower diversity at the accumulation sites than at the control sites. Overall, plastic waste is present in all components of the environment and is having a negative impact on the ecology of the city of Yaoundé, while also contributing to the already worrying phenomenon of global warming. There is therefore an urgent need for preventive and curative measures to be taken in order to better structure the plastic waste sector in the city of Yaoundé and thus minimise the health and environmental risks.

Key words: Plastic waste; management; impacts; ecosystems; Yaoundé.

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I. INTRODUCTION

Plastics have become the most versatile polymeric material that is successfully integrated into our daily lives (Rahimi, 2017). Due to the different properties and qualities conferred to plastics, they are used in many fields such as: packaging, construction, transport, electricity, electronics, sports and even the medical sector, etc. Once these plastics have served their purpose, most of them are disposed of, becoming post-consumer waste, thus introducing the notion of plastic waste (Ragaert, 2017). Globally, the recycling rate of plastics is low, with 14% of plastic packaging collected for recycling and only 5% successfully recycled into a new plastic product (Douvergne, 2018). This means that around 86% of the world's plastic waste is disposed of in the environment. Plastics are ubiquitous in the global environment and have been used for over a century (Seisini, 2011). Its main characteristics, such as light weight, durability, resistance to light and chemicals, ease of processing and relatively low production cost, make plastics a material of choice (Raynaud, 2014; Seisini, 2011; Andrady and Neal, 2009).

A large proportion of plastics are easily found in open spaces in the form of rubbish, municipal waste, landfill sites and in the oceans, while few are recycled (Ncube et *al.,* 2021). This reality is even more marked in poor countries. Plastic waste accounts for around 8% of the total weight of waste collected in cities in developing countries (Doublier, 2008; Mathieu, 2015). Its abundance in the environment is partly the result of human behaviour, particularly uncontrolled dumping (McDermott, 2016). Once plastic enters the environment, it is capable of lasting hundreds and thousands of years (Anonymous, 2018), due to its very slow degradation process. Their ability to last a long time gives them the power to sustainably degrade our environment and, consequently, our living conditions.

Plastic causes a wide range of problems when it is present in nature. It also contributes to global warming. When plastics are disposed of in landfills, methane is created, a greenhouse gas that exceeds carbon dioxide by more than 2,000% (Singh, 2019). They can also clog sewers, suffocate and/or entangle animals, and toxic materials can escape and end up in the human food chain (Ncube et *al.,* 2021).

In Cameroon, the Ministry of the Environment, Nature Protection and Sustainable Development (MINEPDED) estimates that plastic waste accounts for 10% of all household waste, or 600,000 tonnes/year. Similarly, a study carried out by the Ecole Nationale Supérieure de Polytechnique (ENSP) in 1995 on the waste situation in the city of Yaoundé reported a plastic waste deposit of 10,000 tonnes/year, or 25 tonnes/day. Cameroon's major cities, particularly Yaoundé, are increasingly faced with the problem of managing plastic waste.

In 2007, Cameroon's household waste collection company (HYSACAM) revealed that of the 700 tonnes of rubbish it collects every day in Yaoundé, 14 tonnes is non-biodegradable waste and 05 tonnes is empty plastic bottles. In the absence of a specific management plan for this waste, from production to final disposal, it gradually accumulates in the natural environment (watercourses, shallows, gullies, uncontrolled heaps, etc.) and poses serious threats to the environment and human health, hence this study, the general aim of which is to assess the management of plastic waste in the city of Yaoundé and its impact on environmental components, in particular surface water, air and agricultural soil. Specifically, the aim was to **(i)** take stock of plastic waste management in the city of Yaoundé; **(ii)** characterise the plastic waste present in households and in nature in Yaoundé; **(iii)** analyse the impact of plastic pollution on natural environments and their biodiversity. Finally, **(iv) to** propose possible solutions that could significantly improve the management of plastic waste in the city of Yaoundé. The study was designed around the following central question: What are the impacts of plastic pollution on the ecology of the city of Yaoundé? This question gave rise to the following secondary questions: How is plastic waste currently managed in Yaoundé? What are the types and proportions of plastic waste found in nature in Yaoundé? How does this plastic waste affect the natural environment and the animal and plant life living there? These various questions will form the backbone of this report, which will successively present a literature review on plastic waste and its management, a methodology that will explain the scientific approach used to achieve the objectives set, the results obtained and the measures proposed for better management of plastic waste in the city of Yaoundé.

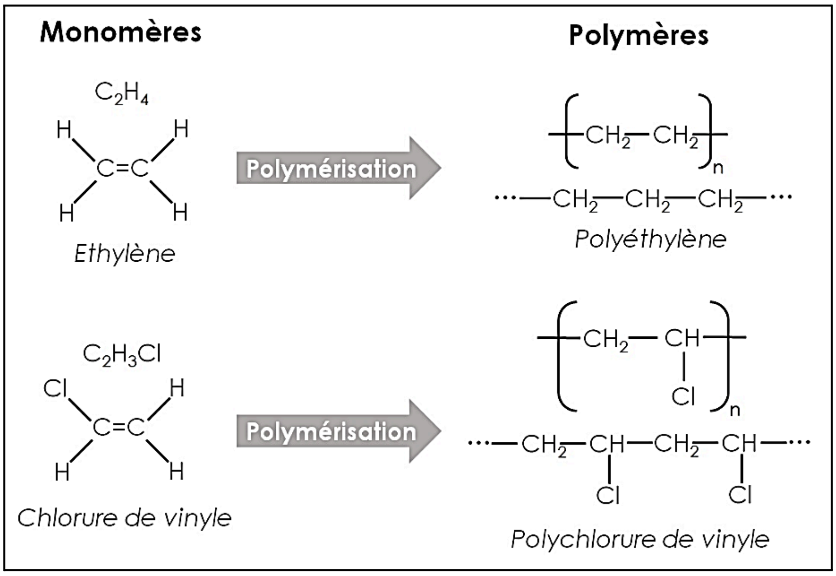
II. LITERATURE REVIEW

This section is devoted on the one hand to a presentation of general knowledge about plastics and plastic waste management, and on the other hand to a review of the main legal texts governing plastic waste management in Cameroon.

II.1- General information on plastics

II.1.1- Definition of some concepts

Polymers: are synthetic macromolecules obtained by polymerisation or polycondensation of small molecules, the monomers. The polymerisation reaction gives rise to carbon chains whose structure (linear, branched, cross-linked), length (number n of combined carbon atoms of the simplified chemical formula CH3-(CH2)n-CH3) and assembly form topologies that determine their physical and chemical properties. (Parliamentary report, 2020)



Plastic = polymer + filler + plasticisers + other additives

Plastics: Plastics are organic or semi-organic materials. They are made up of one or more polymers and a number of additives (auxiliaries, stabilisers, colourants and pigments, plasticisers, flame retardants and fillers and reinforcing materials) (PFERD Tools, 2012).

Plastics are defined as man-made, non-metallic polymers with a high molecular weight, made up of repeating macromolecules obtained by polymerising monomers extracted from oil or gas. To give them the characteristics that meet everyday needs, elements (chlorine, nitrogen, etc.) are added in the form of additives or adjuvants. (Bowmer and Kershaw, 2010)

Microplastics: PM can be defined as primary or secondary depending on its origin (Crawford and Quinn, 2016). Primary PM is intentionally manufactured as small particles for industrial purposes including pre-production pellets, microbeads for abrasives or cosmetics, toothpaste and sandblasting (Crawford and Quinn, 2016). Secondary PM is the degraded fragments of large plastic debris. The formation of secondary PM from plastic debris depends on the action of certain environmental factors such as ultraviolet exposure, oxygen concentration, temperature, mechanical forces, biological fouling and the size and shape of the debris (Ter Halle et *al*., 2016).

Polymer: These are large molecules made up of basic units called "monomers" which are linked by covalent bonds (P. WEISS, 2009-2010). They resemble a string of pearls. Polymerisation, the process of linking the monomers that form the polymer, is used to obtain solid everyday objects, for example ethylene, which is transformed into polyethylene, a common plastic (Christopher and Crawford, 2017).

II.1.2- Genesis and development of plastics

The creation of new synthetic chemicals combined with the engineering capabilities of mass production has made plastics one of the most popular materials of modern times. The term "plastic" first appeared in the early 17th century, when it was used to describe a substance that could be moulded or shaped. The term derives from the ancient Greek "*plastikos*", which refers to something suitable for moulding, and the Latin "*plasticus*", which refers to moulding or shaping. The modern use of "plastic" was revived by the American chemist L. Baekeland who, in 1910, developed the first industrial process for producing a synthetic polymer, which he named "bakelite" (Fontanille and Gnanou, 2002). The many discoveries that followed in this field were rewarded with several Nobel Prizes and marked the start of the mass production of synthetic polymers, which dominate the plastics market (Fontanille and Gnanou, 2002). Their low density, durability, impermeability, shape flexibility and low cost make plastics ideal materials for a wide range of industrial and domestic applications.

Table I: Brief profile of plastic development according to Lambert (Lambert et al., 2017)

Years	Types of polymers	Inventor
1839	natural rubber latex	Charles Goodyear
1839	Polystyrene	Edouard Simon
1862	Parkesin	Alexandre Parkes
1865	cellulose acetate	Paul Schützenberger
1869	Celluloid	John Wesley Hyatt
1872	polyvinyl chloride	Eugen Baumann
1894	rayon viscose	Charles Fréderic Croix
1909	Bakelite	Leo Hendricks Baekeland
1926	Plastic-coated PVC	Walter Semon
1933	polyvinylidene chloride	Ralph Wiley
1935	low density polyethylene	Reginald Gibson and Eric Fawett
1937	Polyurethane	Otto Bayer
1938	Polystyrene	as a variable commercial polymer
1938	polyethylene terephthalate	John Whinfield and James Dickson

1942	unsaturated polyester	John Whinfield and James Dickson
1951	high-density polyethylene	Paul Hogan and Robert Banks
1951	Polypropylene	Paul Hogan and Robert Banks
1953	Polycarbonate	Hermann Schnell
1954	Polystyrene	Ray Mc Intire
1960	Polylactic acid	Patrick Gruber
1978	linear density polyethylene	Du Pont

II.1.3. Types of plastics

There are three main families of plastics.

II.1.3.1. Thermoplastics

Thermoplastics are polymers whose mechanical properties vary with temperature. Under the effect of heat, the chains of these polymers slide in relation to each other. This makes it possible to soften them a large number of times, without which it would not be possible to recycle these materials (Carrega et *al.*, 2012). After cooling, the shape that has been given to them is fixed, but the operation is reversible. When heated again, thermoplastics become malleable and can be reshaped. This exclusive characteristic of thermoplastics means that they can be mechanically recycled.

Thermoplastics include the following polymers:

- **polyolefins such as polyethylene (PE) and polypropylene (PP).** There are two types of polyethylene: low-density polyethylene (LDPE), used for bottles, toys, plastic bags, bin liners, packaging and gas and water pipes, and high-density polyethylene (HDPE), used for household and kitchen items, electrical insulation and food packaging. Polypropylene is used mainly for food films and in the automotive industry (filters, bumpers);

- **linear polyesters, the best known of which is polyethylene terephthalate (PET),** which is used in ribbons, electronic components and drinks bottles;

- **styrenics such as polystyrene (PS),** used as food packaging (yoghurt pots and trays) and for their insulating properties (refrigerator and freezer doors). The styrenics family also includes expanded polystyrene (EPS) used as insulation, food trays or insulated fish boxes;

- **Vinyls such as polyvinyl chloride (PVC).** Flexible, PVC is used to manufacture coated fabrics for clothing and leather goods, insulation sheaths, adhesive tapes or tarpaulins, blood bags and medical gloves. Rigid PVC is used to make pipes for sanitary installations, windows, shutters, gutters and food packaging;

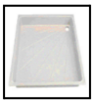
- **Polyamides (PA), such as nylon**: these are mainly used to make textile fibres and fishing nets, but are also used to produce switches, electrical sockets, gears, screws, household appliances, syringes and car parts;

- **Polyacrylics and polymethacrylics: polymethyl methacrylate (PMMA)** is used to produce synthetic fibres, spectacle lenses, glazing, squares, rulers, lenses and various hairdressing items. Polyacrylonitrile (PAN) is used as a synthetic fibre in the textile industry;

- **Polycarbonates (PC)**: technical materials that are very rigid and not very combustible. They are used in the manufacture of compact discs, motorbike helmets and safety glass. *Thermoplastics account for 80% of the world's plastics consumption* (Parliamentary report, 2020).

Table II: Different types of thermoplastics and their recovery symbols (Gervais, 2010 and Kumar, 2016)

Polymer Abbreviation	**Recycling number identification**	**Illustration**	**Examples of materials**
PET	1 PET		Lemonade bottles, rags, carpet and brushes
HDPE	2 HDPE		Bottles, bin liners, packaging bags, playground equipment, acid cans
PVC	3 PVC		Used for the construction of pipes and grids, non-food bottle
LDPE	4 LDPE		Plastic bags and film
PP	5 PP		Automotive parts, carpets, geotextile or industrial fibres

PS	6 PS		Toys, video cassette, insulation board
Other plastics	7 OTHER		Various products: packaging, mechanical parts and miscellaneous items

II.1.3.2. Thermosets

They are made up of cross-linked or networked polymers. Unlike thermoplastics, they are rigid and fragile. The addition of heat only serves to freeze or even degrade the material (Carrega et *al.,* 2012). Unlike thermoplastics, thermoset plastics cannot be melted down for reuse.

This category includes the following polymers:

- **Polyurethanes (PUR):** these are used in the manufacture of a large number of products (foams, paints, preservatives, varnishes, glues and other miscellaneous solutions). In their thermoplastic elastomer form, they also enable the textile industry to produce Lycra;
- **phenoplasts**: used in the composition of certain printing inks, foams, abrasives, brake and clutch linings and various paints;
- **polyepoxides**: these are used to manufacture coatings, adhesives and various paints;

II.1.3.3. Elastomers (rubbers)

They are characterised by their high deformability, such as natural rubber, neoprene and silicones. However, they are not strictly plastics. They are not recyclable and will not be the subject of this study.

Table III: Main polymers used in the manufacture of plastics

Main plastic polymers	Abbreviation	Examples of use
High-density polyethylene	HDPE	Flasks, bottles, rigid cans
Low-density polyethylene	LDPE	Plastic films, flexible containers
Polypropylene	PP	Moulded parts for the automotive industry, food packaging, electrical sheaths and wires
Polystyrene	PS	Packaging and insulation
Polyethylene terephthalate	PET	Soda and mineral water bottles

Polyamide	PA	Nylons, fishing nets, industrial hoses, textiles
Polyurethane	PU	Foam insulation
Polylactic acid	PLA	Biodegradable plastic bags
Polycarbonates	PC	Motorbike helmets
Polytetrafluoroethylene (Teflon)	PTFE	Tapes in pipe joints
Polycaprolactone	PCL	Biomedical
Polyvinyl chloride	PVC	Hoses

II.1.4- Classification of plastics according to size

Plastic waste can be classified according to its size. In ascending order, these are nanoplastics, microplastics and macroplastics (Figure 1).

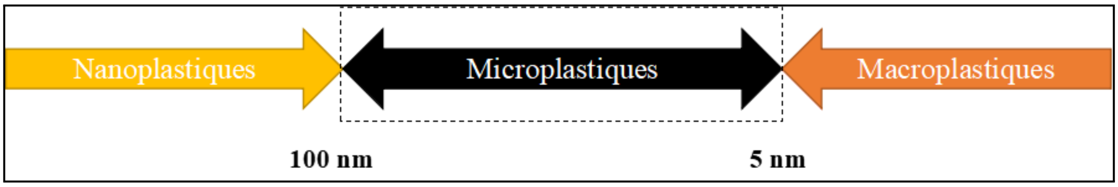


Figure 1: Diagram of plastic particle size categories (source: Thibaut Saur, 2018)

The figure below shows in more detail the size ranges of nano, micro, meso and macroplastics and the authors who have highlighted them.

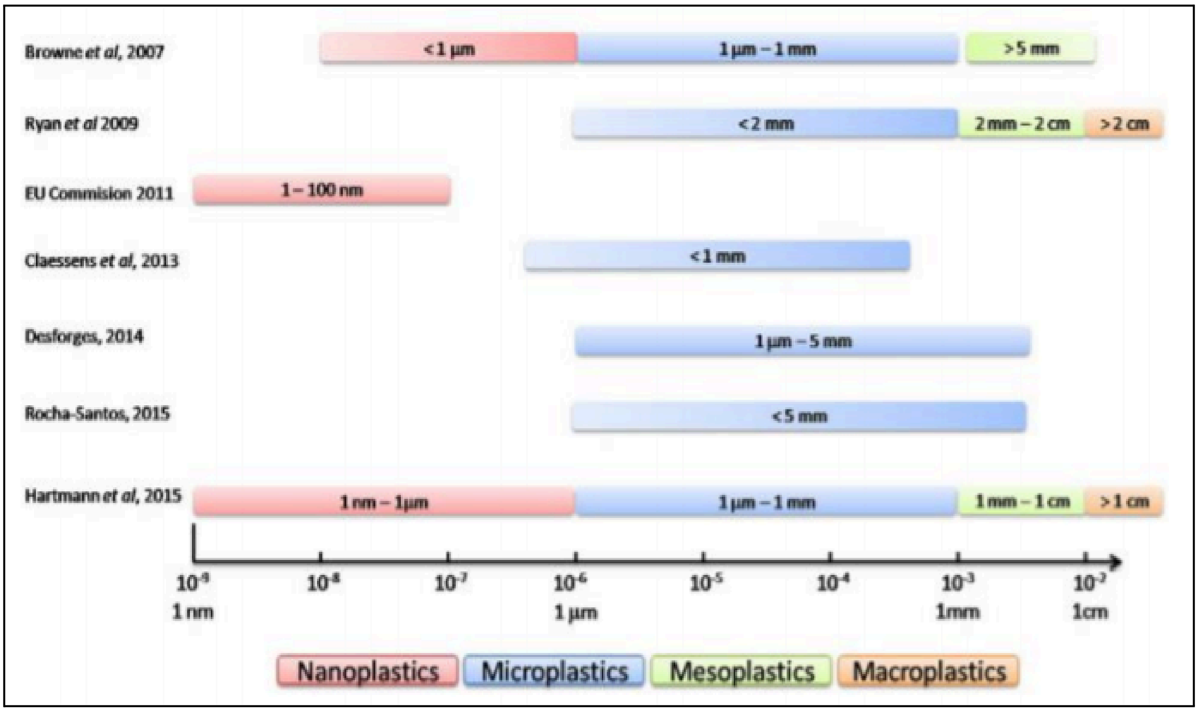


Figure 2: Representation of plastic sizes according to different authors (source: Da Costa, J et al., 2016)

II.1.5- Sources and origins of macro- and microplastics in the environment

The terrestrial sources of macroplastics in the environment are packaging, construction materials, household goods and items related to coastal tourism (UNEP, 2016). Microplastics are therefore produced by the wear and tear of larger plastic objects, either intentionally (primary microplastics) or unintentionally (secondary microplastics). In other words, there is no natural source of microplastics.

- **Secondary microplastics**

Wear and tear can occur at the end of a product's life, in the environment, particularly as a result of erosion. The microplastics produced in this way are known as secondary microplastics, and all plastic waste (plastic bags, packaging and various objects, etc.) that is not properly disposed of is a potential unintentional source of microplastics. This phenomenon of wear and tear was first highlighted in the marine environment, then systematically observed in all surface waters, organic fertilisers or compost and waste sludge from sewage treatment plants. A number of studies have reported the contamination of water bodies considered to be 'pristine', in regions with very little urbanisation and no industry, correlated with erosion and the airborne transport of debris, in the absence of a waste management policy (Free et *al.*, 2014).

- **Primary or intentional use microplastics**

Wear can also occur during the use phase of products with plastic parts. The sources most often cited are synthetic textiles (the largest source in this category, with 6 million fibres for a 5kg load of laundry) (De Falco et *al.*, 2018), fishing nets, and certain paints used on ships or in road markings. To this inventory, it is possible to add microparticles from tyre wear if elastomers are included in the definition of plastics. In terms of tonnage, they constitute a source of emissions of an order of magnitude equivalent to that of textile fibres (IUCN, 2017).

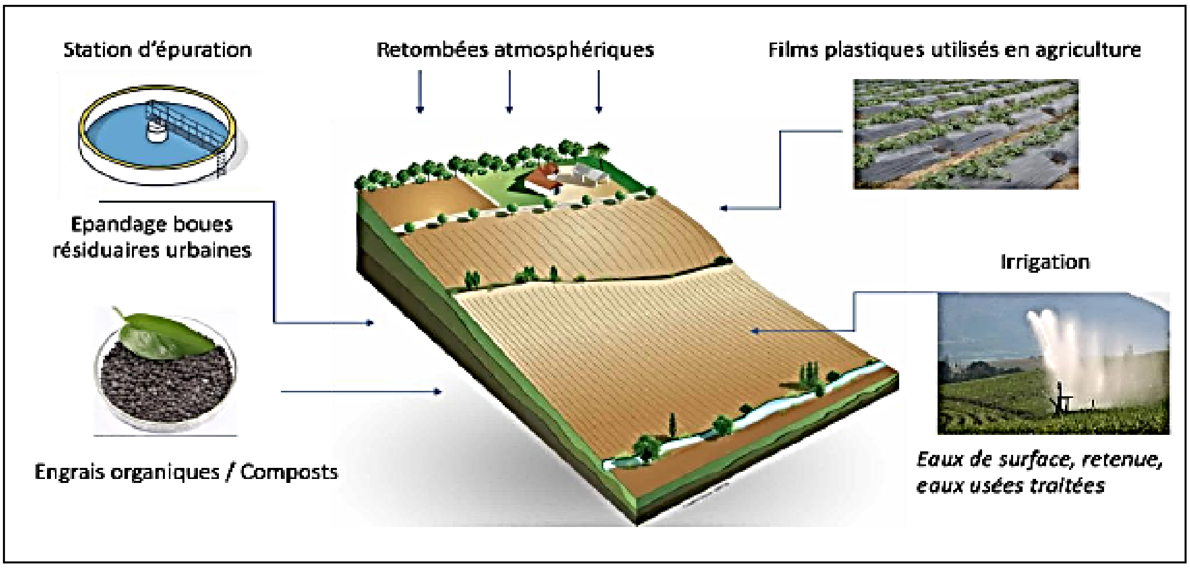


Figure 3: Main sources of microplastics in nature

Some authors have been able to estimate microplastic flows in certain countries according to their sources, as shown in Table IV below:

Table IV: Summary of sources of microplastics in the environment

Sources of microplastics	Estimated flows	Authors	Country
Atmospheric fallout	13 to 110 particles/m²/d 27 µg/kg soil/year	Dris *et al,* 2016	France
Plastic films	0.03 to 10.82 kg/ha/year	Huang, 2020	China
Irrigation	3,900 to 17,000 p/m3	Zhou, 2020	China
Organic fertilisers and composts	0.08 to 6.3 kg/ha/year	Blasing, 2018	Slovenia
Spreading sludge from wastewater treatment plants	0.2 to 8 mg/ha/year/capita	Nizetto, 2016	Europe
	1.68 to 40.8 x 106 p/ha/year	Blasing, 2018	United States
	106 to 109 p/ha/year	Qi, 2020	China

Five main sources of microplastics have been identified: atmospheric precipitation; sewage sludge from wastewater treatment plants; plastic films used in agriculture; fertilisers and composts; and irrigation. Given the heterogeneity of the units of measurement associated with each source, it is difficult to make solid comparisons and rank the contributions. Apart from quantifying microplastic inputs, there are few analyses of the exposure of soil organisms to plastic pollution. Experiments are conducted over a short period of time. If we are to understand the impact of plastic pollution in the soil on ecosystems, we need to develop biomonitoring systems to monitor the soil. Metals such as zinc, lead, arsenic or chromium and molecules derived from the degradation of plant protection products can adsorb to microplastics in toxic forms that accumulate in the soil.

II.1.6- Plastic decomposition

The decomposition of plastic generally takes a few years to several decades. In the environment, plastic degradation is slow and can be affected by multiple factors (Andrady, 2015; Gewert et *al*., 2015). Plastics that are exposed to sunlight, oxidants and mechanical stress over time erode and degrade, but the extent of their degradation depends on both the environment and its chemical composition (Eubeler et *al*., 2010). Due to their chemical structure, common synthetic polymers are durable and can resist degradation. However, multiple processes can induce their degradation, including photodegradation by solar UV radiation, thermo-oxidation, hydrolysis and biodegradation (i.e. degradation by micro-organisms). The most common polymers in the environment, such as PE, PP, PS and PVC, have a carbon skeleton that is resistant to biodegradation.

Therefore, for their biodegradation to occur, an abiotic degradation step is required to break them down into smaller, lower molecular weight fragments (Gewert et *al*., 2015; Ng et *al*., 2018). Since plastic degradation occurs primarily through exposure to sunlight, degradation is most intense in environments such as the sea surface and beaches (Andrady, 2015). The first visible effects of polymer degradation are colour change and surface cracking (Gewert et *al.*, 2015). Surface cracking exposes the plastic material from the inside, and in so doing, makes it available for degradation. Plastic eventually becomes brittle and physically degrades when exposed to abrasive or mechanical forces such as wind, waves and physical impact (Gewert et *al*., 2015; Ng et *al.,* 2018, SAPEA, 2019). Over time, fragmentation can result in plastics no longer being visible in the environment (Selke et *al*., 2015). It is important to note that several degradation pathways can occur simultaneously, as various factors trigger degradation. For this reason, the products of degradation can be more varied than the products that might be expected from a particular pathway. In the marine environment, the degradation of most plastics occurs first at the surface of the polymer, which is exposed and therefore susceptible to chemical or enzymatic attack. Microplastics have higher surface-to-volume ratios than macroplastics and therefore degrade faster, yet the process remains slow (Andrady 2015). There are many gaps in research into plastic degradation. To estimate biodegradation, factors such as mass reduction, reduction in tensile strength, disappearance (out of sight) or proliferation of various microorganisms have been the subject of numerous studies (Zumstein et *al*., 2019). Plastics often contain additives which, once released, can degrade and form other chemicals. In addition, additives such as stabilising agents can increase resistance to degradation. Selke et *al* (2015) evaluated the effect of biodegradation-promoting additives on the biodegradation of PE and PET present in compost, landfill and soil. They found that none of the additives significantly increased biodegradation under any conditions, and that there was no evidence that these additives promoted or enhanced the biodegradation of PE or PET polymers (Selke et *al.*, 2015).

II.1.7- Analysis and trends in global plastics production

Plastic has become the third most manufactured material in the world after cement and steel. 359 million tonnes were produced in 2018, a figure that rises to 438 million tonnes when plastics in textiles and synthetic rubbers are taken into account. At the current rate, this production is set to double by 2050 (Parliamentary Report, 2020).

Its production has soared from two million tonnes in the early 1950s to 438 million tonnes in 2018. It has overtaken glass, wood, cardboard, paper and other metals because of its low production costs and properties. Plastics production has literally exploded over the last fifteen years. It is estimated that of the 7.8 billion tonnes produced between 1950 and 2015, 3.9 billion tonnes, or more than half, have been produced since 2002. The growth in plastic production is set to accelerate even further, with projections suggesting that over 600 million tonnes of plastic could be produced by 2025 (Parliamentary Report, 2020).

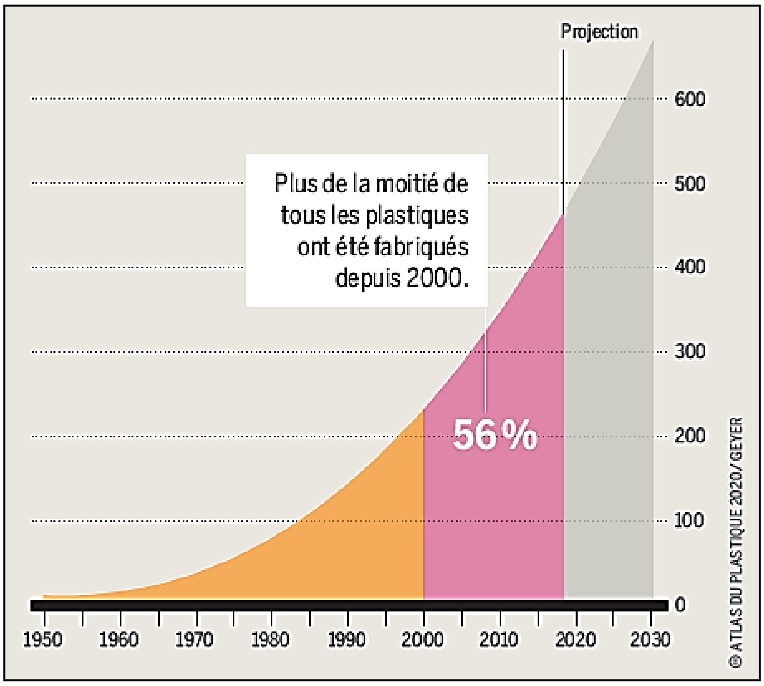


Figure 4: Trends in global plastics production (in millions of tonnes)

Global plastics production continued to grow in 2017. At 348 Mt, global plastics production increased by 3.9%. For the third year, production increased in all customer sectors, particularly in two major plastics-consuming sectors: automotive, where growth has almost doubled since 2015 (6.2% compared with 3.5%), and electrical and electronic equipment (6.4% compared with 3.1%). Other sectors whose growth is still up on that of the previous 2 years: food and beverages. Thermoplastics are by far the most widely used, accounting for 80% of demand from plastics converters. Of this, 248 Mt comes from standard plastics (90% of thermoplastics), to which must be added 27 Mt for engineering plastics. (Plastics Europe, 2017).

In 10 years, global plastics production has increased by 103 Mt, or by a third (245 Mt in 2006 compared with 348 Mt in 2017). But we are witnessing a clear reshuffling of the cards: in 2006, Europe was in the lead (25%) ahead of North America (23%) and China was in 4th place with 15%. In 2017, China was in the lead with 29%. If we add together China, Japan and the rest of Asia, 51% of plastics are produced in this region of the world (Figure 3). Europe, with -7%, and North America, with -6%, did not benefit from this growth. European production volumes have remained virtually stable over the last ten years. The Middle East, Latin America and Russia remained at the same level over the same period.

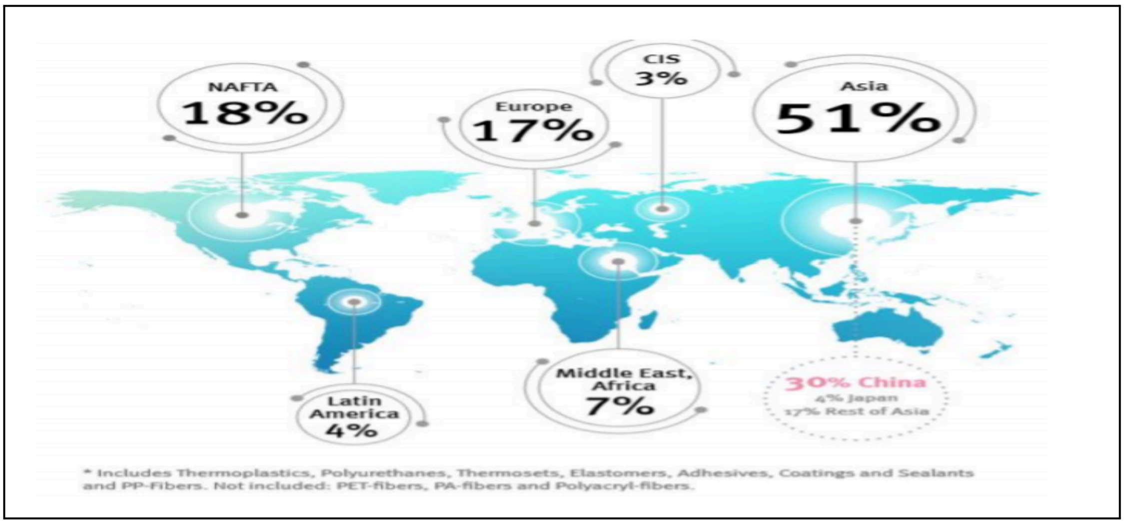


Figure 5: Breakdown of global plastics production in 2018 (Plastics Europe, 2019)

The significant drop in the quantities of plastics produced by Europe and North America over the last 10 years is essentially due to the political will to direct efforts towards reduction at source, reuse and recycling (4Rs) in line with the ideals of sustainable development. This is proof that the trend towards high levels of plastic pollution observed in developing countries in recent years can be reversed if a coordinated plastic waste management plan is put in place: reduction at source - collection - recovery - rational disposal of final waste.

II.1.8- Plastic pollution and water resources

Water is an important natural resource that forms the core of the ecological system (Selvam et *al*., 2013). It plays an extremely important role for living beings, particularly in socio-economic development and ecosystems (An et *al.,* 2014; Ma et *al.,* 2014; Eshtawi et *al*., 2016).

A particular societal and scientific concern has developed around the quantity of plastic entering the marine environment and its potential effects on the animals living there (Gregory, 2009). The visible part of plastic pollution in the oceans, which includes large pieces of plastic known as 'macroplastics', has attracted the attention of the media, the general public and scientists since the 1980s. As a result of this media coverage, when we think of plastic pollution, we all think of shorelines full of rubbish, turtles trapped in packaging and 'continents' of bags floating on the surface of the oceans.

Although the societal benefits of plastics are considerable (Andrady and Neal, 2009), this material is the subject of growing environmental concern (Derraik, 2002; Thompson et *al.*, 2009). Indeed, the durability of plastic, which makes it an attractive material, also makes it highly resistant to degradation, making the disposal of plastic waste problematic (Barnes et *al.*, 2009). Exacerbated by the widespread use of disposable and non-reusable plastics, plastics account for 10% of the waste generated worldwide (Barnes et *al.*, 2009). While some plastic waste can be recycled, most ends up in landfill sites or directly in the environment, where it can take centuries to decompose (Barnes et *al.*, 2009; Moore, 2008). For example, 60% of all plastics produced between 1950 and 2015 (or 4,900 Mt) were disposed of in landfill sites and the natural environment, and 3.4 billion tonnes are expected to suffer the same fate over the next 30 years (Geyer et *al.*, 2017).

The Helmoltz Centre for Environmental Research study found that 88-95% of plastic waste in the oceans comes from just ten rivers, eight of which are in Asia and two in Africa (Schmidt *et al.,* 2017). China's Yangtze River is considered to carry the most plastic waste in the world. It carries an estimated 1.5 million tonnes of plastic every year. The second study conducted jointly by the Dutch foundation The Ocean Cleanup and the University of North Carolina confirms the responsibility of Asian rivers, but to a lesser extent (Laurent *et al.,* 2017). According to this study, 20 rivers, mainly in Asia, are responsible for 67% of the plastic waste dumped in the oceans. As for the Yangtze, it remains the most polluting river, but it is said to carry "only" 300,000 tonnes of plastic waste per year, five times less than the figure obtained by the German study. According to their estimates, at global level, rivers discharge between 6,000 and 7,000 tonnes of microplastics per year into the oceans, with a balanced distribution between the oceans: 28% of discharges would be to the North Pacific via rivers in Asia and North America, 24% of discharges would reach the North Atlantic via rivers in Europe and North America, 23% of discharges would be to the Indian Ocean, 12% of discharges would be to the South Pacific and 13% to the South Atlantic.

As well as posing an aesthetic problem, plastic waste poses numerous economic problems, with repercussions for the tourism industry, and a risk for many industries such as shipping and fishing (Barnes et *al*., 2009), but also affects marine wildlife. These impacts include the injury and death of seabirds, mammals, fish and reptiles as a result of entanglement or ingestion (Derraik, 2002) or the transport of 'non-native' marine species (Winston, 1982). More recently, it has been shown that, once in the aquatic environment, plastic debris can concentrate pollutants such as persistent organic pollutants and metals (Mato et *al*., 2001; Teuten et *al*., 2009), represent potential vectors for micro-organisms (Masó et *al*., 2003; Zettler et *al*., 2013) and, under certain conditions, carry invasive species capable of upsetting the biological balance of the regions they colonise (Rech et *al*., 2016). In addition, although plastics are generally considered to be biochemically inert (Teuten et *al*., 2009), additives, known as 'plasticisers', may be incorporated into them during manufacture to modify their properties or extend their lifespan by providing resistance to heat, oxidative damage or microbial degradation (Groh et *al*., 2019). These additives are also an environmental concern, as as well as extending the degradation time of the plastic, they can also introduce potentially harmful chemicals into the environment (Rochman, 2015).

Societal and scientific concern about plastic pollution in the marine environment is currently growing in response to estimates of the astronomical amount of this waste entering the oceans. Indeed, Jambeck et *al* (2015) estimated that 275 million tonnes of plastic waste were generated in 192 coastal countries in 2010, with between 4.8 and 12.7 million tonnes entering the ocean. Without improvements to waste management infrastructures, the cumulative amount of available plastic waste entering the oceans is predicted to increase by an order of magnitude by 2025. The problem of macroplastics, which is visible and relatively well documented, is now giving way to another concern linked to plastic pollution, which is less visible and therefore more difficult to grasp: that of microplastics (MP).

II.1.9- Fate of plastic in water

In the Mediterranean Sea, the average concentration of plastics is 115,000 fragments per km², reaching 600,000 fragments per km² off Nice and 2.5 to 8 million microplastics per km² off Cap Corse 2 (even though this area is part of the Pelagos sanctuary created by France, Italy and Monaco to protect marine mammals). It reaches 64 million microplastics/km² in the eastern basin. In total, between 259 and 680 billion pieces of plastic debris are said to be floating in the Mediterranean (469 billion on average), representing between 515 and 3,999 tonnes of microplastics (2,257 tonnes on average).

68.9% of the plastic debris collected and analysed is polyethylene, 20.2% polypropylene, 3.2% polystyrene and 2.6% polyamide. The Mediterranean Sea is thought to be the most polluted in the world, accounting for just 1% of the oceans but concentrating 7% of microplastics. (National geographic, 2020).

There are many reasons for this situation:

- The Mediterranean is a semi-enclosed sea whose waters take 90 years to renew themselves;
- it accounts for 30% of global tourism;
- It carries 30% of the world's maritime traffic between the Straits of Gibraltar and the Suez Canal;
- The Mediterranean region is under heavy demographic pressure. In many Mediterranean countries, water treatment infrastructures are inadequate, household waste collection is often non-existent and dumping of waste into the sea is chronic;

- Major rivers flow into the Mediterranean (Nile, Rhône, Po, etc.) carrying 700 tonnes of plastic waste every year.

The Greenland Sea and the Barents Sea are also areas where plastic waste from the North Atlantic gyre is accumulating. During its expedition around the Arctic Circle in 2013, Tara Océans discovered an accumulation zone of 300 billion pieces of debris in the Arctic, representing around 400 tonnes.

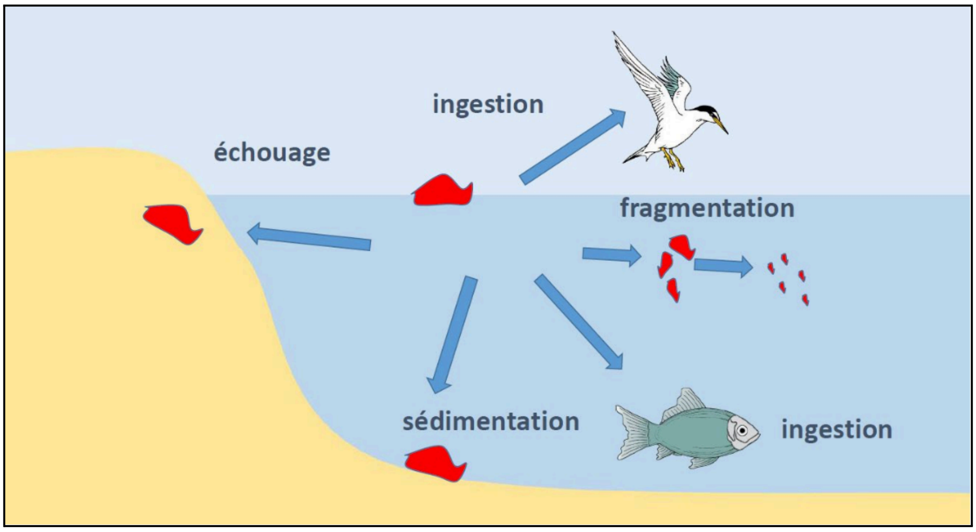


Figure 6: Fate of plastic waste in water (Parliamentary Report, 2020)

The proportion of plastics present in surface waters and sediments varies according to biological (e.g. bacterial/algal attachment), physico-chemical (e.g. plastic density) and hydrodynamic (e.g. water column mixing) conditions (Alimi et *al*., 2018). Factors such as wind, surface water circulation, temperature and salinity influence the distribution of microplastics (Zbyszewski et *al*., 2014; Corcoran et *al*., 2015; Anderson et *al.*, 2016). In the aquatic environment, the speed of plastic degradation depends on temperature. Degradation is slower in cold water (Andrady, 2015). Plastics found below the photic zone[1] of the water column degrade very slowly, resulting in high persistence of plastics in the aphotic zone, particularly on the seabed. In addition, the biodegradation of plastics by micro-organisms is negligible due to the slow kinetics of biodegradation at sea and the limited oxygen supply required for these processes (Andrady, 2015). A study by Leonas and Gorden (1993) investigated the rate of disintegration of low-density PE (LDPE), PS and a 2% ethylene-carbon monoxide polymer and other blends in aqueous media. The results showed that, while the ethylene-carbon monoxide polymer disintegrated faster than the other films evaluated, the aqueous medium significantly delayed or even prevented the degradation of the other polymers. Biber et *al* (2019) studied the deterioration of various plastics in air and seawater. Macroscopic fragments of PE, PS, PET and a material marketed as a degradable plastic were exposed to the environmental conditions prevailing in air and water. All the materials deteriorated more slowly in seawater than in air, probably due to reduced exposure to sunlight, and therefore reduced photo-oxidation in seawater. The authors found that PS showed the fastest deterioration and often decomposes into microplastics faster than the other materials tested, but that all the materials tested did deteriorate into microplastics. Given the requirements for decomposition, it is to be expected that plastic objects will remain in seawater and that microplastics will form in areas where the plastic is exposed to oxygen and UV radiation, such as the intertidal zone and at the surface of the water.

[1] The photic zone, also known as the euphotic zone or epipelagic zone, is the part of a watercourse exposed to sufficient light for photosynthesis to take place.

II.1.10- Consequences of plastic pollution

The consequences of plastic pollution are numerous, but fundamentally they affect the life of living beings by degrading the quality of soil, water and air.

- Giant plastic islands :

The ocean's rubbish has ended up creating huge islands of plastic in the oceans of our blue planet. There are currently 05 plastic islands that have formed where ocean currents converge. The largest island is in the Pacific and is similar in size to Spain, France and Germany combined. With around 4 billion tonnes of waste generated around the world every year, and annual plastic production reaching 300 million tonnes in 2015, the world's oceans receive around 20 million tonnes each year, 8 million tonnes of which is plastic from the continents. Depending on the area, these materials can account for up to 100% of waste at sea, and their increase in the marine environment has long been ignored, reinforced by economic policies that favour single-use, disposable and non-repairable products. In just a few years, this has led to the emergence of a global problem (Galgani et *al.,* 2016). Further offshore and deeper down, the presence of accumulation zones in trenches is known, but the phenomenon remains very poorly described. The accumulation of several tonnes of waste has been demonstrated in certain underwater areas, sometimes several dozen miles offshore. In some areas of the Mediterranean, densities of up to 100,000 items of waste per km2 have been reported.

- Loss of biodiversity :

Ingestion of plastics rarely leads to the immediate death of animals, but does cause lacerations, internal injuries and death. Seabirds may be one of the species most vulnerable to plastic ingestion, as they rarely regurgitate undigested hard materials, including plastics. The resulting accumulation of plastic in their gastrointestinal tract can lead to problems with feeding stimuli. Surface-feeding species such as gulls, shearwaters and fulmars are vulnerable to micro-plastics, entanglement and ingestion of floating plastic, as it can be difficult for them to distinguish zooplankton. The debris accumulates in the intestine, similar to the effects caused by large plastic particles in larger organisms. Aquatic organisms don't just die from ingesting plastics, in other cases they die from getting caught in abandoned fishing nets, for example, or they suffer deformities or amputation of extremities for the same reason. The physiology of the animals can also be affected; for example, some sea turtles that have eaten too much plastic float and are unable to submerge to look for food (Houenagnon et *al.,* 2009).

- Threats to public health :

During the manufacture of plastics, compounds hazardous to human health, such as bisphenol A, phthalates, flame retardants, hardeners, paints, myriads and other substances are released (Eubeler et *al.,* 2010), many of which are carcinogenic. These compounds are also released when plastics are degraded, recycled or burnt inappropriately, exposing animals and humans to consumption of these hazardous substances through bioaccumulation in the food chain (Houenagnon et *al.,* 2009).

- Contribution to global warming :

One of the most polluting stages in plastics production is the ethane 'cracking' process. Steam cracking is a petrochemical process which consists of obtaining alkenes, i.e. unsaturated hydrocarbons such as ethylene or propylene, from petroleum fractions. These alkenes form the basis of the plastics industry (polyethylene, polypropylene, etc.). Facilities with ethane cracking plants released 70 million tonnes of CO2 in 2020, roughly what 35 medium-sized coal-fired power stations released. The expansion of this sector is expected to add a further 42 million tonnes of greenhouse gases per year by 2025 (Lautre, 2021).

- Association with hazardous organic pollutants :

Plastics can absorb other pollutants previously present in the environment. Among these pollutants, the dangerous insecticides DDT and other organochlorine and organophosphate insecticides, polycyclic aromatic hydrocarbons such as benzene, dioxins and heavy metals stand out. In addition, these pollutants have the capacity to bio-accumulate and bio-amplify in the food chain, so that their effect can be amplified and reach other species, including humans. High concentrations of additives can lead to the disruption of biological processes, such as endocrinology (Simon et *al.,* 2019).

- Environmental and socio-economic impacts :

Plastic pollution has considerable environmental, social and economic impacts. Within national borders, and particularly in urban areas, plastic bags and bottles can clog sewers and other drainage systems, increasing the risk of flooding during heavy rains. Plastic objects in the streets or in fields can hold water and become a "breeding ground" for mosquitoes, causing health problems by helping to spread malaria, the Zika virus or many other diseases (Simon et *al.*, 2019). Plastics can leach chemicals into the soil, contaminating agricultural areas and reaching groundwater.

By making the soil impermeable, plastics considerably reduce infiltration, with a negative impact on plants and agricultural productivity. Symmetrically, the increase in the run-off coefficient due to the drop in infiltration is responsible for the worsening of the erosion phenomenon, especially in steeply sloping areas, resulting in the destruction of property (homes, shops, bridges, roads, etc.) and a drop in agricultural yields. Ecosystem degradation, in particular, includes both the effects of marine litter on biodiversity, but also its impact on the 'services' provided by the ecosystem, such as food supply or tourism as an economic driver.

Figure 7: Stagnation of wastewater due to plastic waste

II.2- Legislative, regulatory and institutional framework for plastic waste management in Cameroon

There is no specific legal text on plastic waste management in Cameroon. However, this waste is taken into account in the overall legislation governing waste management and environmental protection. Plastic waste is mentioned in several legal texts in Cameroon, the most important of which will be examined in this section.

II.2.1- Legislative and regulatory framework

Waste management in Cameroon is governed by a number of laws, decrees, orders and circulars that have been drawn up with a view to reducing the quantities of waste produced or imported into the country in order to mitigate its negative effects on the environment and human health. These include

- Law no. 96/12 of 05 August 1996 on the framework law for environmental management

This is the main law that sets the framework for environmental protection in the Republic of Cameroon. Article 46 of this law stipulates that "decentralised local authorities shall ensure the elimination of waste produced by households, ensure that all illegal dumping is stopped and ensure the elimination of abandoned dumps". In addition, article 42 states that "waste must be treated in an environmentally sound manner to eliminate or limit its harmful effects on human health, natural resources, fauna and flora, and on the quality of the environment in general". It includes several implementing decrees, some of which are specific to plastic materials and/or waste.

- Decree no. 2012 / 2809 / PM of 26 September 2012 setting out the conditions for sorting, collecting, storing, transporting, recovering, recycling, treating and finally disposing of waste.

Article 34 of this decree prohibits the dumping or open burning of plastic waste or any other spoiled product.

Article 27(1) states that "any natural or legal person wishing to carry out the activity of recycling, treatment and ultimate elimination of waste is subject to obtaining an environmental permit issued by the administration in charge of the environment".

Article 4(1) states that "household waste collection and storage activities are carried out by local authorities and decentralised territorial authorities in conjunction with the relevant State department";

- Joint Order No. 004 MINEPDED/MINCOMMERCE of 24 October 2012 regulating the manufacture, import and marketing of non-biodegradable packaging.

Article 7(2) of this decree sets out the regulations governing the manufacture, import and marketing of non-biodegradable packaging and states that "the production, import, holding and marketing of non-biodegradable plastic packaging in particles of more than 60 microns and the granules used in their manufacture are subject to obtaining an environmental permit. Despite the ban on the production, import, distribution and marketing of plastics with a thickness of less than 60 microns, this law has unfortunately failed in ten years to curb the proliferation of plastic waste in Cameroon's metropolises.

II.2.2- Institutional framework

Analysis of the institutional framework takes into account the categorisation of players according to their different functions. Three main categories can be distinguished:

- Planning, guidance and control institutions ;
- The implementing bodies ;
- Funding bodies.

II.2.2.1- Planning, guidance and control institutions

Government departments are involved in waste management to varying degrees. They are :

- **Ministry of the Environment and Nature Protection (MINEP)**

According to Decree No. 2005/117 of 14 April 2005 on the organisation of the Ministry of the Environment and Nature Protection, the responsibilities of this ministerial department in relation to waste management are as follows:

- Negotiating and implementing international agreements and conventions on environmental protection;
- Drawing up and monitoring compliance with environmental norms, guidelines and standards;
- Monitoring and compliance with environmental standards for wastewater treatment;
- Examining files relating to waste disposal, recycling and burial in liaison with the relevant authorities;

- Informing the public with a view to encouraging their participation in the management, protection and restoration of the environment;
- Periodic inspection of landfill sites ;
- Collecting and centralising statistical data on the environment and nature protection.

❖ Ministry of Territorial Administration and Decentralisation

Under Decree No. 2005/104 of 13 April 2005, MINATD is responsible for municipal waste management through the decentralised local authorities under its supervision.

❖ Ministry of Energy and Water (MINEE)

According to decree 2005/087 of 29 MARCH 2005, MINEE is responsible for :

- Designing and implementing rural sanitation programmes;
- Drawing up and monitoring urban sanitation master plans, in conjunction with the relevant technical ministries;
- monitoring the maintenance of wastewater treatment facilities in urban areas, in liaison with the relevant technical ministries;
- monitoring compliance with the technical rules governing the operation of sewerage networks in urban areas, in conjunction with the decentralised local authorities;
- raising awareness among decentralised local authorities of the need to maintain sanitation facilities.

❖ Ministry of Urban Development and Housing (MINDUH)

Created by decree Nº 2004/320 of 08 December 2004, this ministry is responsible for implementing national policy on urban development and housing. As such, it is responsible for, among other things:

- Drainage, waste collection and treatment, the development of hygiene and sanitation standards and the development of sanitation standards in cities in collaboration with the other administrations concerned;
- Setting standards for drainage systems and monitoring compliance with these standards;
- Setting hygiene and sanitation standards, collecting and/or treating household waste, and monitoring compliance with these standards;
- Setting up a database and updating urban data;
- Monitoring the application of health and safety regulations and the removal and processing of household waste.

- **Ministry of Health (MINSANTE)**

MINSANTE's missions, as defined by decree N02004/320 of 08 December 2004, include the following:

- Sanitation.

- **Ministry of Industry, Mines and Technological Development (MINIMIDT)**

Under Decree No. 2005/260 of 15 July 2005, MINMIDT is responsible for :

- Administrative supervision and technical control of dangerous, unhealthy or inconvenient establishments in terms of safety, hygiene, health and sanitation, in liaison with the relevant authorities;
- Developing and implementing the quality control programme.

II.2.2.2- Implementing and managing institutions

- Decentralised local authorities

The commune is a decentralised public authority and a legal entity under public law. Law n°2004 /018 of July 2004 laying down the rules applicable to communes, article 16 of which defines the powers transferred to communes, including :

Cleaning the streets, paths and public spaces of the municipality;

- Combating unhealthy living conditions, pollution and nuisance ;
- Drawing up local environmental action plans ;
- Local management of household waste.

- Non-Governmental Actors (NGA)

Non-governmental actors are natural or legal persons who, in accordance with the laws and regulations in force, in particular **Law No. 90/053 of 19 December 1990** on freedom of association in Cameroon, participate in the performance of missions of general interest. This category includes :

- ❖ Associations and/or non-governmental organisations (NGOs) involved in waste collection and/or treatment;
- ❖ The private sector is essentially made up of individual companies or groups of people.

II.2.2.3- Funding bodies

Waste management funding bodies include national funding structures and international donors.

- ❖ **National funding structures**

They are made up of the Ministry of Finance and the Fonds Spécial d'Équipement et d'Intervention Intercommunale (FEICOM) :

- The Ministry of Finance (MINFI) intervenes indirectly through the financing of the State's share in the payment of services provided by concessionary companies, and through its role as collector and distributor of additional municipal levies, which constitute the main source of municipal revenue for waste management.
- The FEICOM (Fonds spécial d'équipement et d'intervention intercommunale) was set up by **Law 74/23 of 05 December 1974** on the organisation of local authorities in Cameroon. Its main mission is to support decentralised local authorities (CTDs) in the development process by providing them with technical and financial assistance.

- ❖ **External donors (IMF, ADB, AFD, IDB, etc.)**

The main sources of external support for waste management in Cameroon's major cities include :

- Designing and building infrastructure, in particular treatment units (composting plant) and landfill sites;
- Operational support for labour-intensive sanitation projects;
- Feasibility studies for treatment plants and urban development master plans;
- Technical assistance for project management and the drafting of local regulations.

Although the literature on plastics and plastic waste is particularly abundant, there are very few studies on the situation in Cameroon or the city of Yaoundé. To this day, statistics from 1998 show that Cameroon produces six million tonnes of waste a year, 10% of which is plastic waste. It was therefore more than ever time to carry out a new study to present the current situation of plastic waste management in Yaoundé, characterise the types of plastic waste found in nature and analyse their impacts in order to plan a sustainable management strategy.

III. MATERIALS AND METHODS

III.1. EQUIPMENT

III.1.1. Geographical location

The capital of Cameroon and the country's second largest city after Douala, Yaoundé is home to most of the country's administrative structure and some of the head offices of major companies. It is also the capital of the Centre region. Its geographical location and transport infrastructure give Yaoundé a central role. In particular, the city is one of the Transcamerounais trunk roads serving Chad and the Central African Republic from the port of Douala and even the deep-water port of Kribi. This leads to heavy goods traffic and logs being transported right through the city centre. Yaoundé is located in the southern part of the country between latitude 3°52'N and longitude 11°31E. The average altitude is estimated at 726 m, with a minimum altitude of 650 m and a maximum altitude of 1,200 m (Mont Fébé). The city comprises seven arrondissements, with an estimated population of 4,509,287,000 in 2023, covering an estimated area of 304 km², 183 km² of which is urbanised (UN World Urbanisation prospects, 2023).

Figure 8 below shows the location of the city, in particular, the geographical limits of Yaoundé are :

- To the west, the district of Mbankomo ;
- To the east, the Mefou-Afamba department;
- In the south, the Mefou-Akono department;
- In the north, the Okola district.

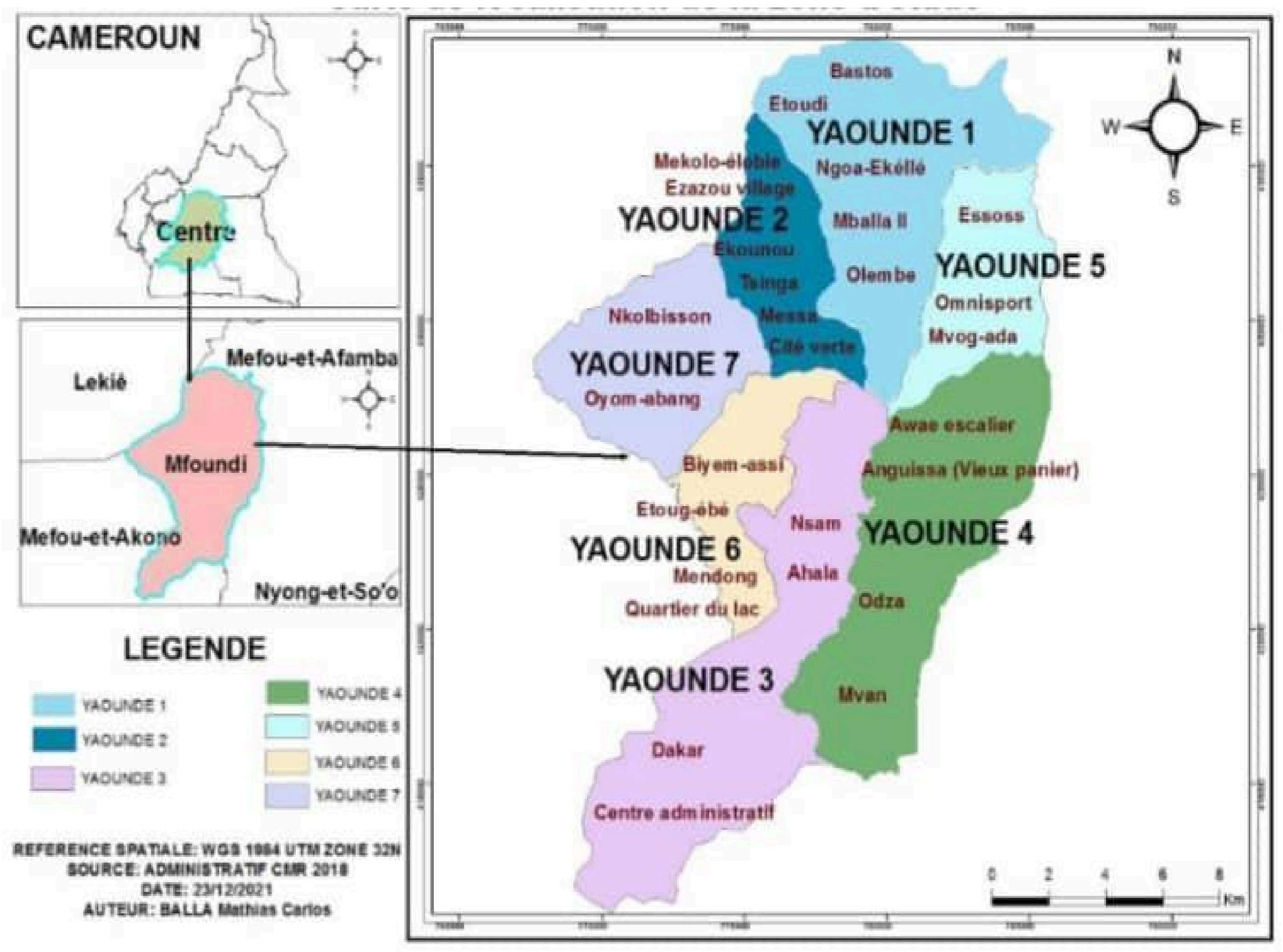


Figure 8: Location map of the city of Yaoundé

III.1.2. The climate

The climate in the city of Yaoundé is equatorial (Yaoundé), with two dry seasons and two rainy seasons alternating. The average temperature is 23.5°C, varying between 16 and 31°C depending on the season, and the annual rainfall is 1,600 mm. Average humidity is 80% and varies between 35 and 98% during the day. In recent years, however, there has been a decrease in rainfall in Yaoundé (-2.2% per decade since 1960), coupled with a gradual increase in temperature (+0.7°C from 1960 to 2007) (Wéthé J., 1999; 2001) .

III.1.3. Relief

The city's topography is fairly rugged. The city of Yaoundé is located on a series of hills at an average altitude of between 700 and 800 m, which are backed up on the western and north-western edges by mountain ranges up to 1,200 m high. The highest peaks are Mount Bankolo in the north-west and Mount Eloumdem in the south-west, which reaches an altitude of 1,200m. The town has the distinctive feature of being very hilly, earning it the name of the "town of seven hills". The relief pattern is characterised by narrow, rounded interfluves of varying sizes, generally oriented NNW - SSE and NE - SW. The valley bottoms are often marshy and regularly flooded in the wet season (Wéthé J., 1999; 2001).

III.1.4. The hydrographic network

Intense rainfall in the city of Yaoundé feeds a very dense hydrographic network, the main watercourse of which is the Mfoundi, which has a catchment area of 45 km² and is part of the Mefou catchment area.

The city of Yaoundé is located in three river basins, the largest of which is the Mfoundi basin. This river rises in the city of Yaoundé (on the slopes of Mount Fébé) and flows into the Mefou, also within the city. The other catchment areas are the Foulou to the north of the city, which flows into the Sanaga river, and the Mefou to the west and south-west of the city. These three main catchment areas are fed by numerous streams, which are the source of flooding in several districts of Yaoundé.

The Mfoundi occupies the whole of the central part of the city of Yaoundé and runs southwards, and "its tributaries have created oblong hills running NW-SE and NW-SE, all converging towards this north-south axis which forms a sort of backbone of the city". The tributaries of the Mfoundi are: the Tongolo, the Ntem, the Ekozoa, the Abiergueu, the

Mingoa, the Akée, the Ebogo, the Ewoué, the Olézoa and the Djoungolo (Wéthé J., 1999; 2001).

III.1.5. Demographic situation

Generally speaking, the population of Yaoundé, like that of the rest of Cameroon, is young. Demographic growth between 1976 and 2005 was very high (5.7% per year), with the city's population doubling every 7 to 10 years. For information, Yaoundé had a surface area of 13,614 ha / 136.14 km^2 in 2002 and a population of approximately 1.739 million inhabitants in 2009 (demographic projection, BUCREP 2009).

III.2. METHODOLOGY

Multidisciplinary research requires an informed choice of methods in each of the areas contributing to the achievement of the objectives and a good match between them (Cissé, 1997). The documentation of plastic waste management in the city of Yaoundé was informed by a cartographic, qualitative and quantitative approach. The potential and actual impacts on environmental components, in particular surface water, air and agricultural soils, were assessed by analysing visual and actual data collected in the field and in the laboratory (physico-chemical and microbiological data).

An empirical method was used to understand plastic waste management in the city of Yaoundé. It is based on a set of activities such as documentary research, direct observations, household surveys, interviews with stakeholders in waste management in general and plastic waste management in particular, as well as data collection in the field, in particular on :

- ✔ Characterisation of plastic waste in households and in the city's heavily polluted drains;
- ✔ Physico-chemical analysis and aquatic biodiversity of surface waters (drains) with a high accumulation of plastic waste in the seven districts of the city of Yaoundé;
- ✔ Air analysis at sites where plastic waste accumulates heavily, particularly drains;
- ✔ Analysis of agricultural soils in some lowlands.

This approach was adopted in order to maintain consistency between data collection, processing, analysis and interpretation throughout the investigations.

III.2.1. Justification of the methodology used

Questionnaire surveys are among the best data collection techniques in social science. They give respondents the opportunity to express themselves freely, away from the influence of others as in the case of group meetings (meetings, focus groups, etc.). Another advantage here is that the interviewer can provide on-the-spot clarifications for a better understanding of certain questions, if necessary.

In addition, by supplementing the surveys with semi-structured interviews, the mass data can be combined with the opinions of professionals, resulting in more accurate information. Stratifying households according to their standing and surveying a large number of households also helps to reduce bias, as the study sample is fairly representative of the city's population.

Mobile data collection using the *Kobocollect* software has the advantage of automatically geolocating the households surveyed. The data collected is transferred to a server as it is collected, which saves data entry time and reduces the consumption of natural resources and energy.

As far as the processing and statistical analysis of the data is concerned, Microsoft Excel is an easy-to-use tool that has proven its effectiveness for small-scale databases. The same applies to ArcGIS software, which was used for mapping.

As regards the characterisation of plastic waste in households and in the field, the MODECOM method is the main characterisation technique used in rudology (ADEME, 1993). It has the merit of enabling the types and proportions of waste produced by a population to be determined with a high degree of accuracy.

Finally, the other methods used to measure physico-chemical and biological parameters of the aquatic environment and to determine phytoplankton density (dosimetric method, spectrophotometry, direct measurements, microscopic observation, etc.), the characterisation of plastic waste (MODECOM) and the measurement of air pollution parameters (direct measurements) are classic scientific methods used throughout the world by research communities. The equipment used for these purposes is state-of-the-art, highly reliable and has proven its worth in benchmark studies.

III.2.2. Project execution

Three main phases were adopted to achieve the objectives of this study:

- ✔ A preparatory phase: this consisted of a documentary study and working sessions within the research team set up at the University of Yaoundé 1, in particular within the Waste and Wastewater Research Unit of the Biotechnology and Environment Laboratory of the Plant Biology and Physiology Department. A documentary collection on the subject has been compiled;

- ✔ Missions to gather and process information in the field: Several missions were carried out in the seven districts of the Mfoundi department. During these missions, field visits were made and interviews were held with officials from the supervisory authorities, environmental and sanitation agencies and departments, plastic waste production and recovery companies, university and research institute lecturers, consumer associations and producers' associations, and their views on the issue of plastic waste management were collected. At the end of this information gathering, provisional reports were submitted on a quarterly basis to the project partners, in particular the members of the 3 E's4Africa and Footprint associations;
- ✔ A validation phase: this report has been submitted to all stakeholders for assessment and validation.

The inventory of plastic waste management in the city of Yaoundé includes the following activities:

- Establish the socio-economic and demographic profile of households ;
- Identify the behaviour, practices and attitudes of households with regard to plastic waste management;
- Establish the typology and sources of plastic waste within households, as well as its management;
- Establish the typology and sources of plastic waste in sites where there is a high accumulation of this waste;
- Identify awareness-raising messages to which households are sensitive;
- Characterise the operators/companies involved in the recovery, reuse and recycling of plastic waste in the city (number of operators, status, equipment used, areas served, problems encountered, etc.);

- Identify dumping sites and/or final disposal points for plastic waste collected from households.

These objectives were achieved through surveys and interviews with the main players in the plastic waste management chain, i.e. households, collectors, plastic waste recovery, reuse and recycling companies operating in the city, interviews with resource persons identified in the technical departments of the Communes, etc.

The approach developed includes: i) the development of data collection tools for the various target groups; ii) a questionnaire survey of households; iii) semi-structured interviews with collectors and plastic waste recovery, reuse and recycling companies; iv) documentary research and visual observations to supplement the data collected; v) processing and analysis of the data collected.

III.3. Presentation of data sources

III.3.1. Qualitative approach

"Qualitative methods are characterised by an open procedure, aimed at determining "what exists" and "why it exists" rather than "how many exist". By allowing people to express their opinions, points of view and experiences freely, qualitative methods aim to capture reality as defined by the group being studied, without imposing a questionnaire or pre-structured framework (always devised by the researchers) on the population". (Maier and Goergen 1994 *in* Schumacher *et al.,* 2002). The aim of this section is to understand plastic waste management. It also gives us an idea of the perceptions, knowledge and practices of stakeholders with regard to the risks of pollution of the physical and human environment.

This section used three methods:

- Document study ;
- Comments;
- Interviews.

According to Patton (1990) in (Schumacher et al., 2002), qualitative methods offer three ways of collecting data: interviews, observations and document studies.

III.3.2. Quantitative approach

This involves interviewing a large number of people using a closed questioning system, with a view to carrying out a statistical analysis of their responses. Quantitative methods are used to verify knowledge of the field being studied and to validate or invalidate hypotheses. The advantage of quantitative methods is that they provide precise answers to the study hypotheses. Based on a large number of questions, statistical analyses can be carried out and the results extrapolated to the total population. In formulating the objectives of the study, the terms "measure", "evaluate", "share", "rank" and "awareness" often call for the choice of quantitative methods. They are based on surveys (questioning a representative sample) and on three types of tools: one-off surveys, panels and barometers.

We have used the one-off survey, which is carried out only once. Comparisons are limited by the different wording of the questions.

III.3.3. Documentary approach

The aim of this documentary collection phase was to obtain secondary data that could be used to analyse the information obtained from the field surveys. To this end, study reports, activity reports, experience capitalisation documents and other documents available from public institutions, NGOs and development projects were collected and used on the Internet and in a number of libraries, notably that of the University of Yaoundé 1 and that of the Department of Plant Biology and Physiology of the Faculty of Science of the University of Yaoundé 1. The search for information was directed towards gathering information on :

- ✔ Legislation governing the management of solid and plastic waste (laws, decrees and orders);
- ✔ Current solid and plastic waste management policies and strategies;
- ✔ The players in the sector and their roles ;
- ✔ Experiences gained in other countries in managing solid waste, especially plastic waste.

Documentary research was carried out continuously throughout the project. Scientific publications (articles, books, theses, dissertations, reports on specialised work and studies, etc.) were consulted and used to broaden the scope of the research. It also enabled us to master our research problem by making links with other social sciences such as sociology and economics.

To initiate the collection of information, a start-up meeting was organised by the research team, with a view to designing the data collection tools (survey sheets and interview guides) and guiding the team in its documentary collection phase. The purpose of the meeting was to review the terms of reference for the assignment and to clarify the methodology adopted for the study. This review was supplemented by research on the Internet and in institutional libraries.

Figure 9: Photo of a meeting to train interviewers in the use of Kobocollect

III.3.4. Direct observation and photography

Observation is a qualitative method that has been used for hundreds of years. Moreover, observation is a human capacity which, from childhood onwards, enables us to learn a multitude of things. The word "observe" implies that we observe an action or an actor with particular attention (Obrist, 2002).

An observation cannot be passed on to another person except in words (Schumacher 1991). This process of transforming observations into words is, in effect, interpretation. We cannot describe without interpreting what we observe. In the course of our surveys, we had to interpret observations in order to draw up our interview guides.

There are several types of observation:

- Free (or unstructured) direct observation is useful for exploring and discovering a new line of enquiry;
- Methodical (or structured) direct observation as soon as a formalised observation grid has been drawn up, in which the elements set out in the grid are systematically recorded;
- Participatory observation in the strict sense of the term requires the researcher to immerse himself in a given culture, so that he can think and act in the same way as the members of that group.

Free direct observation was used as part of this study to find out about the management of plastic waste and its impact on the environment in the city of Yaoundé, and also to prepare the interview guide.

Direct observation is a dynamic process which, unlike an idle or passive gaze, enables facts to be assessed qualitatively. In this case, it enabled us to observe on the ground the extent of the damage caused by plastic waste and the ways in which solid and plastic waste are managed. It also enabled the investigators to assess and qualify the attitude of the authorities and the practices of economic operators involved in solid waste management in general and plastic waste in particular.

III.3.5. Mapping of sites with a high accumulation of plastic waste

It consisted of collecting various types of data on the study site. It lasted three weeks and enabled direct observations to be made in the field, as well as taking photographs which were later used to better elucidate the problems previously identified.

Heavily polluted drains were located by visual observation, and GPS coordinates were then recorded using a Garmin 64s differential GPS.

The geographical coordinates of the households surveyed, the businesses visited and the polluted drains having been recorded during the fieldwork, a database was created by entering this data into Excel. The maps were then produced using ArcGIS software.

III.3.6. Household surveys

III.6.1. Design of data collection tools

Once the players in the plastic waste management chain had been identified, it was a matter of designing data collection tools specific to each player, given that their roles differ according to their level of involvement in the chain. Three forms were therefore designed, corresponding to consumers (households), farmers and companies/associations. These different forms are presented in the appendix to this report (Appendix 1).

III.3.6.2. Calculation of the base sample size

The sample size calculation for a population-based survey is based on 2 factors: the estimated prevalence of the variable being studied, the target confidence level and the acceptable margin of error. For a survey model based on a simple random sample, the required sample size is given by the following formula.

$$n = \frac{\frac{z^2 * p(1-p)}{e^2}}{1 + \left(\frac{z^2 * p(1-p)}{e^2 N}\right)}$$

Where:

n = required sample size

z = 95% confidence level (standard value of 1.96)

p = estimated proportion of the parameters to be researched (access and type of wastewater facility, factors influencing plastic waste management, willingness and ability to pay for the service, etc.). It is set at 0.5 when the value of the parameter is unknown.

e = margin of error at 5% (standard value of 0.05)

N = estimated population size in the 7 communes based on the strong presence/absence of waste at various sites criterion, approximately 199986 souls.

$$n = \frac{(1{,}96 * 1{,}96 * 0{,}5 * (1 - 0{,}5))/((0{,}05) * (0{,}05))}{1 + (1{,}96 * 1{,}96 * 0{,}5 * 0{,}5)/(0{,}05 * 0{,}05 * 2000000)}$$

$n = 383{,}43 \approx 383$

III.3.6.3 Unforeseeable events

We add 10% to the sample to take account of imponderables such as non-responses, false declarations or registration errors.

$$n_2 = n_1 + (n_1 * 10\%) = 383 + (383 * 10\%) = 421$$

Thus the size of a representative sample for the study with a confidence level of 95% and a margin of error of 5% is 421 households. However, in order to improve this level of confidence and reduce the margin of error as much as possible, a surplus of households will be added to obtain a sample of 440 households.

III.3.7. Training of interviewers

The data was collected using a digital tool called Kobocollect. This is a downloadable application that enables the form to be shared on several terminals (smartphones or tablets) from which the data can be collected without the need for a physical medium in paper form. Two training sessions were organised at the Laboratory of Plant Biotechnology and Environment at the University of Yaoundé I:

- The main purpose of the first session was to familiarise the members of the project team with the digital data collection tool. At the start of the session, the application was first downloaded and then installed on all the members' phones. Its functions were then explained in detail and answers were given to the questions asked.
- The second session was used firstly to refine the explanations given in the first session and to evaluate them in the light of the questions asked, which enabled us to gauge members' level of understanding. The data collection forms were then reviewed and adjustments made.

Figure 10: Interviewer training sessions

III.3.8. Setting up pairs, reconnaissance and pre-investigation

Given the large number of stakeholders to be surveyed, and in order to increase the reliability of the data collected, 4 pairs were formed, giving a total team of 8 interviewers. This also had the advantage of ensuring the safety of the interviewers in the field, especially in the context of data collection by smartphone, given that these devices are still very popular in our cities.

In order to facilitate the progress of the surveys, on the one hand, and to check that the questions were properly understood, on the other, a reconnaissance visit to the site was carried out by all the interviewers on 23 December 2022. This helped to identify ambiguous questions that were confusing or misunderstood by the interviewees, which were then rephrased.

III.3.9. Choice of survey areas and allocation of interviewers

Given the impossibility of carrying out surveys in all of the city's neighbourhoods, a judicious choice had to be made, taking into account a number of criteria: geographical location (ridge, low-lying area, valley, etc.), population, type of housing (high, medium or low standard), location (municipality) and, above all, the identification of the neighbourhood as an area of high plastic waste accumulation. Surveys were carried out in 30 neighbourhoods.

The actual data collection took place over 5 days, from 27 to 31 December 2021. It was conducted by a team of 8 interviewers organised into 4 pairs, and was coordinated by the Supervisor and the Project Manager. The questionnaire was administered to 440 households constituting a representative sample of the entire population of the city of Yaoundé. The size of the population considered here was based on the areas identified in the districts as being the most affected by the accumulation of plastic waste in the environment.

Table V: Breakdown of neighbourhoods (by housing type) covered by household surveys

Municipality	**Neighbourhoods**			**Number**
	Low standing	**Medium standing**	**High standing**	
CAY 1	Emana; Etoudi,	Olembé; Ngoa Ekellé	Bastos; Mballa II	**6**
CAY 2	Mokolo Elobi; Ezazou village ;	Tsinga	Tsinga; Messa; Camp SIC Cité verte	**5**
CAY 3	Nsam; Dakar	Ahala; Dakar	Administrative centre	**4**
CAY 4	Ekounou; Mvan	Anguissa; Awae escalier	Odza	**5**
CAY 5	Mvog-Ada	Essos	Mfandena	**3**

CAY 6	Etoug-Ebé	Camp SIC Biyem Assi; Mendong	Lake district	**4**
CAY 7	Oyomabang; Nkolbisson	Oyomabang	Oyomabang	**3**
TOTAL				**30**

III.3.10. Interviews with other waste management stakeholders

The collectors and recovery and recycling companies operating in Yaoundé's Communes were first listed, followed by a visit to these companies to talk to the heads of these structures about their involvement in plastic waste management in the city. The issues discussed included

- Identifying and locating the structure ;
- general information on the activities carried out, the plastic raw materials used and the products produced by these structures;
- the profitability of their operations;
- difficulties related to the business ;
- interactions with government and other stakeholders.

A total of six companies and/or associations were interviewed:

- ✔ **Sarl option:** essentially collects waste from households, then sorts it before reselling it to companies according to their needs;
- ✔ **Duplascam:** produces plastic bottles made from high-density polyethylene (HDPE) granules;
- ✔ **NAMé recycling:** collects, processes (sorting and industrial hot and cold washing) and recycles plastic waste into flakes and rolls for local and foreign markets;
- ✔ **CIPRE:** which raises awareness, collects, treats (sorts and washes all types of plastic waste) and sells to recovery companies;
- ✔ **Action pour la Restauration de l'Environnement:** this company collects waste from households and illegal heaps, sorts it and sells it to recycling companies;
- ✔ **Collectors' groups:** these are individuals who collect and sell waste to businesses.

It should be noted that this limited number of companies interviewed is linked to the refusal of certain companies to comment on their activities; the interviewers were categorically rejected by certain managers of the structures.

III.3.11. Characterisation of plastic waste

III.3.11.1. Characterisation of plastic waste from households surveyed

The characterisation of plastic waste in households was based on plastic waste produced directly by households. To do this, bin bags were distributed to 300 representative households in the city of Yaoundé, divided into high, medium and low-status dwellings. Instructions were then given to put only plastic waste in the bin bags. Finally, a household manager was told when the bin bags would be collected. The bin bags containing the household plastic waste were then removed and the characterisation was carried out in the same way as in the drains.

III.3.11.2 Characterisation of plastic waste in identified drains

As regards drains, 06 heavily polluted drains were characterised. Here, the choice depended on the level of plastic pollution observed in or around the drain. Characterisation was then carried out on site using a methodology adapted from MODECOM (ADEME, 1993) as follows:

- All types of plastic material were collected vertically in the drain and progressively packaged in mosquito nets. Here, personal protective equipment (boots, gloves, mufflers, helmets, etc.) was essential;
- Weigh the nets filled with plastic waste using a calibrated mechanical scale, taking care to obtain a net quantity of 250 kg of plastic waste in each drain;
- Deposit plastic waste not far from the drain, in a bare, more or less flat area;
- Sorting plastic waste by type, by recognition with the naked eye, using information from the literature;
- Weighing the respective quantities of the different types of plastic waste sorted using an electronic scale.

Table VI: Breakdown of drains analysed by district

Types of	Municipality	Neighbourhood

environment		
Drains	Yaoundé I	Mballa II
	Yaoundé II	Green City
	Yaoundé III	Ngoa Ekellé (Cité des nations); Ahala
	Yaoundé IV	Mvan (Tropicana)
	Yaoundé VI	Etoug Ebé

Figure 11: Weighing a net of plastic waste collected in a drain before characterisation

III.4. Physico-chemical, phytoplanktonic and zooplanktonic analyses of water in drains polluted by plastic waste

III.4.1. Physico-chemical analyses

III.4.1.1. Sampling

Samples were collected from 08 drains in the city of Yaoundé that are subject to major spills of plastic waste and one control site, making a total of 9 sites.

Water samples were collected in sterilised 1 L sampling bottles. The bottles were held in the middle and then immersed approximately 15-20 cm in water against the current (Anonymous, 1998). The samples were collected and labelled after each sampling and placed in a cooler. They were then transported to the biotechnology and environment laboratory at the University of Yaoundé I and stored in a refrigerator at -4°C for analysis.

III.4.1.2. Laboratory analysis

Physico-chemical analyses were carried out in the laboratory on the samples collected, including: pH, temperature, electrical conductivity, salinity, total dissolved solids, resistivity, biological oxygen demand, chemical oxygen demand, phytoplankton and zooplankton. Analyses were carried out using the standard procedures described by Eaton et *al.* 2005.

III.4.2. Determination of phytoplankton density

The phytoplankton was collected in the field by washing the submerged bottles and then filtering through a 20 µm mesh plankton sieve. The filtrate obtained (approximately 200 mL) was fixed directly with a solution of lugol. To ensure that the phytoplankton communities in the samples used for systematic identification of algae were representative, our samples were concentrated beforehand. This process consisted of allowing the algae contained in a known volume of sample to sediment for at least 48 hours. After sedimentation, the supernatant was carefully removed. The lower phase, which is denser and essentially made up of the[2] seston, is retained. From the concentrated samples, an initial observation of the deposit of the lugol-fixed sample was carried out between slide and coverslip using an ordinary Ivymen microscope for a fine identification of the phytoplankton organisms. The taxa[3] were identified in as much detail as possible using the appropriate literature.

To count the algae identified, a sub-sampling was carried out after homogenisation, by filling Sedwig-Rafter type counting cells. Sedimentation in these cells lasted at least 45 minutes. Depending on the type of organism, the counting unit chosen was the cell, colony or filament. Counting was carried out using an inverted OLYMPUS CK2 microscope at 200x magnification. To minimise the risk of error, counting was carried out in duplicate.

III.5. Characterisation of subsoil plastic waste

The plastic waste in the subsoil was characterised by creating 1 m² quadrats in the market garden plantations (Figure 12), the number of quadrats depending on the size of the plantation. Within each quadrat, the soil was stirred up to a depth of 30 cm using a hoe or machete, and all types of plastic waste found were then removed. Once all the impurities have been removed, they are sorted by type and weighed using a balance.

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[2] All particles of any kind, mineral, dead or alive, of organic or inorganic origin suspended in water.

[3] Any unit (genus, family, species, subspecies, etc.) of the hierarchical classifications of living organisms.

Figure 12: Creation of a quadrat to characterise subsoil plastic waste

III.6. Measurement of air parameters in environments with high levels of plastic pollution

Air parameters were measured using an X-sense model COO3D *air quality detector* (Figure 13). Two gases were assessed: carbon dioxide and volatile organic compounds. Measurements were taken directly at sites with high levels of plastic pollution, in particular Ahala, Mvan - Tropicana, Cité des nations, Cité verte and Mballa II.

Figure 13: Air quality detector

III.7. Limits of the study

The study carried out on plastic waste management in the city of Yaoundé has a number of limitations, particularly those relating to :

- ✔ the refusal of certain households and companies involved in plastic waste management to cooperate.
- ✔ the lack of a technical platform for measuring air parameters. Only two parameters could be analysed, namely CO_2 and volatile organic compounds (VOCs), although gases such as CH_4 and NH_3 were among the main targets of the study;
- ✔ rainfall, which also had an impact on the quality of certain results, particularly those relating to the physico-chemical quality of the water, notably through dilution or the addition of external pollutants.
- ✔ Health establishments were not included in these field surveys, as the team focused on waste produced by households and businesses.

III.8. Data processing and analysis

The data collected by *kobocollect* and transferred to the server have been used to create a database. Incomplete, erroneous or implausible data were removed from the database. Finally, the analysis was carried out using Microsoft Excel 2016 to obtain results in figures or illustrated in the form of graphs.

IV. RESULTS

IV.1 Overview of plastic waste management in the city of Yaoundé

IV.1.1. Socio-demographic characteristics of households surveyed

The status of the people interviewed for this study revealed that 78% are married, with 44% spouses and 34% heads of household. Children accounted for 15%, compared with 7% who were family members. Most of them rent the houses they live in (52%). The majority of the sample are women (60%). Of the total, 48% have a secondary education, 30% a higher education and 18% no education. 39% of respondents had lived in the neighbourhood for 1-5 years, 27% for more than 15 years and 22% for 6-10 years. The homes surveyed were 56% low standard, 25% medium standard and 19% high standard.

Table VII: Socio-demographic characteristics of people surveyed (n= 432)

Parameters		**Percentages (%)**
Respondent status	Family member	7 %
	Head of household	34 %
	Child	15 %
	Spouse	44 %
Type	Male	40 %
	Female	60 %
Level of education	Not enrolled	4 %
	Primary	18 %
	Secondary	48 %
	Superior	30 %
Years in the neighbourhood	1-5 years	39 %
	6-10 years	22 %
	11-15 years	12 %
	Over 15 years	27 %
Housing tenure status	Tenant	52 %
	Owner	48 %
Type of habitat	High standing	19 %
	Medium standing	25 %
	Low standing	56 %
Topographical position	Crete	30 %
	Mid-slope	48 %
	Lowland	22 %

IV.1.2. Description of household solid waste management in the city of Yaoundé

According to the stakeholders interviewed and the observations made during data collection in the field, plastic waste produced by households is mixed with other solid household waste (according to 99% of respondents); there is therefore no systematic sorting at source. The circuit followed by this plastic waste produced by households is therefore that of household waste management, which comprises 4 main stages, namely: (1) the production of waste by households, (2) pre-collection, (3) collection and (4) transport and landfill in a Technical Landfill Centre (Centre d'Enfouissement Technique - CET) located in Nkofoulou, a suburb of the city of Yaoundé (Figure 14).

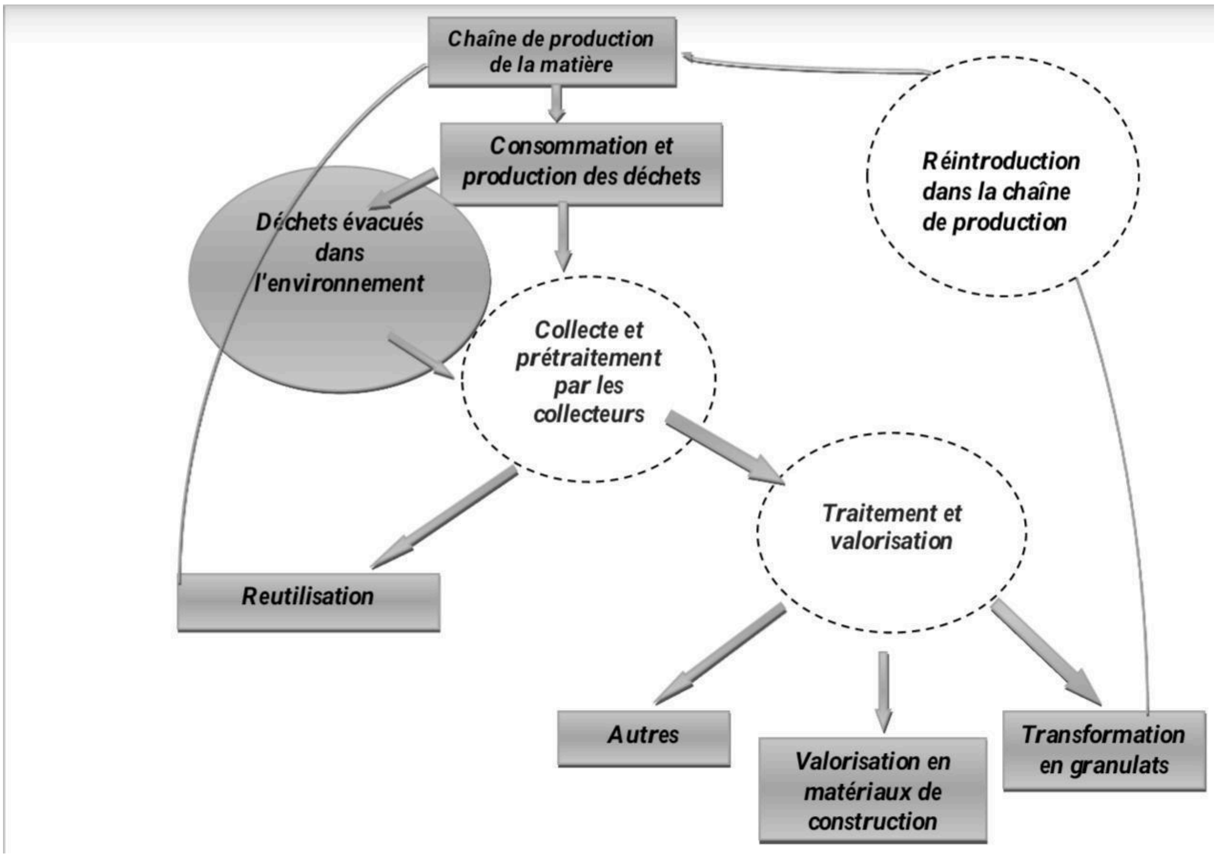

Figure 14: Major stages in household solid waste management in the city of Yaoundé (source: Simo, 2023)

IV.1.3. Origin of plastics used by households surveyed

Almost all the people surveyed (99%) said that they use plastics in their households. According to them, most of these materials come from shops (49%), supermarkets (26.29%)

and chemists (14.24%). However, around 6% came from electrical and electronic equipment packaging, 3.13% from recycling and only 1.41% from street vendors (Fig. 15).

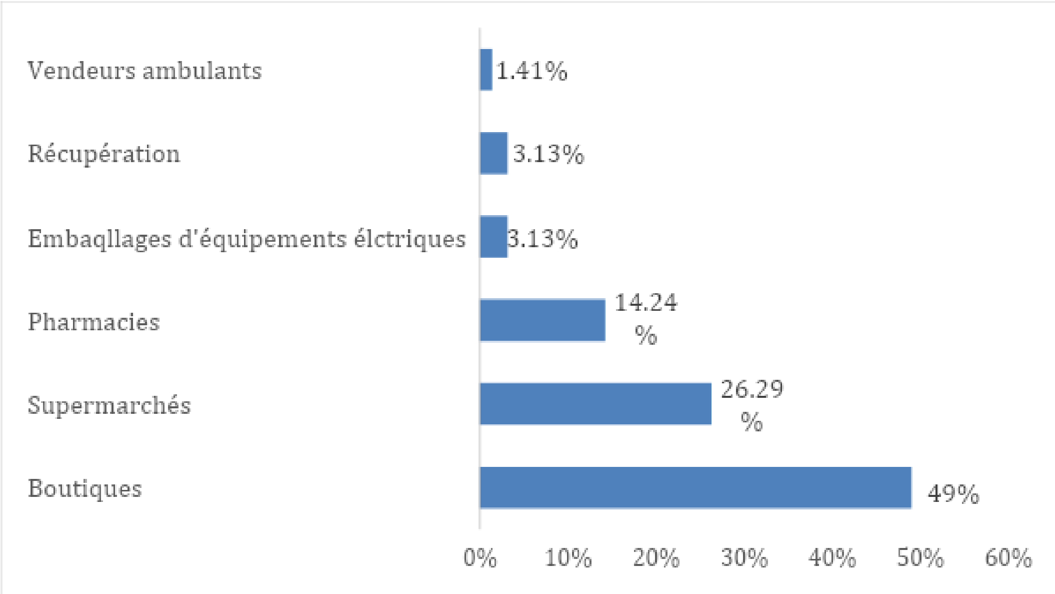

Figure 15. Main sources of household plastics supply

IV.1.4. Frequency of plastic use by households

According to the surveys, 1% of households surveyed claim not to use plastic at home. Of the 99% of households that say they use plastic, 48% receive or buy plastic every day, 30% do so once or twice a week, 13% more than twice a week and 9% five times a week (Fig. 16).

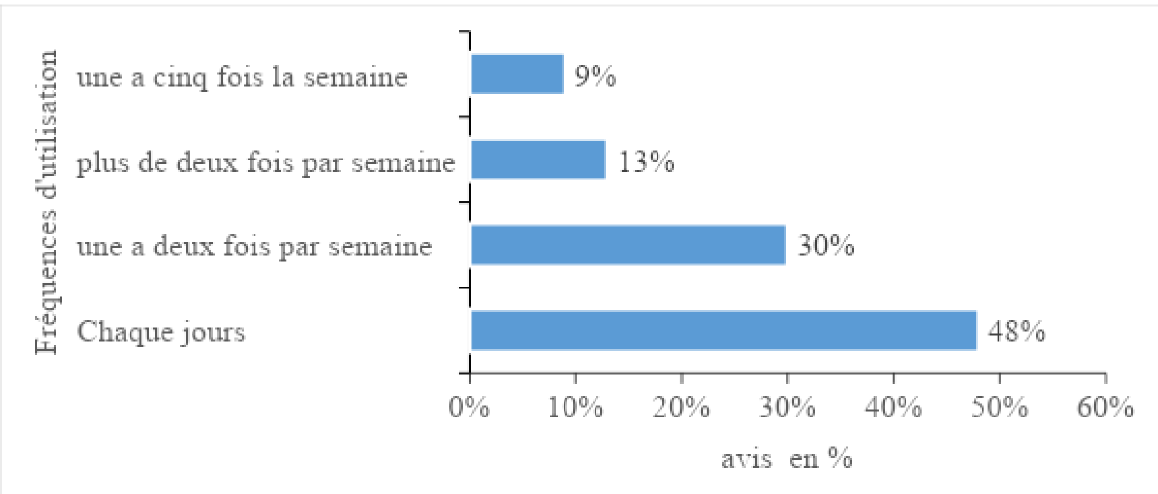

Figure 16: Frequency of plastic use by households

IV.1.5. Fate of plastics after use by households

Once plastics have been used, 44% of households surveyed dispose of them in the bin (Hysacam collection points), 34% reuse them, 10% burn them, 5% dispose of them in uncontrolled dumps, 3% make them available to pre-collectors (door-to-door), 2% sell them and 2% dispose of them in the street (Fig. 17).

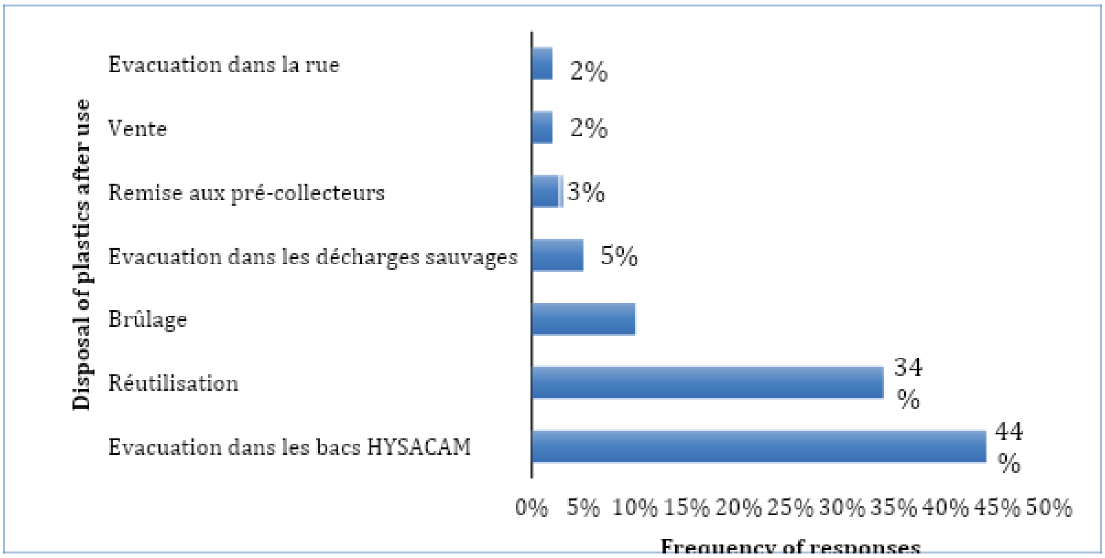

Figure 17*:* Purposes of plastic waste *according to households* surveyed

IV.1.6. Reuse of plastics by households in the city of Yaoundé

Of the 34% of people surveyed who claim to reuse plastics after use, 51% use them to preserve food, 16% to preserve water, 11% for commercial and fuel purposes respectively, and 6% for ornaments (Fig. 18).

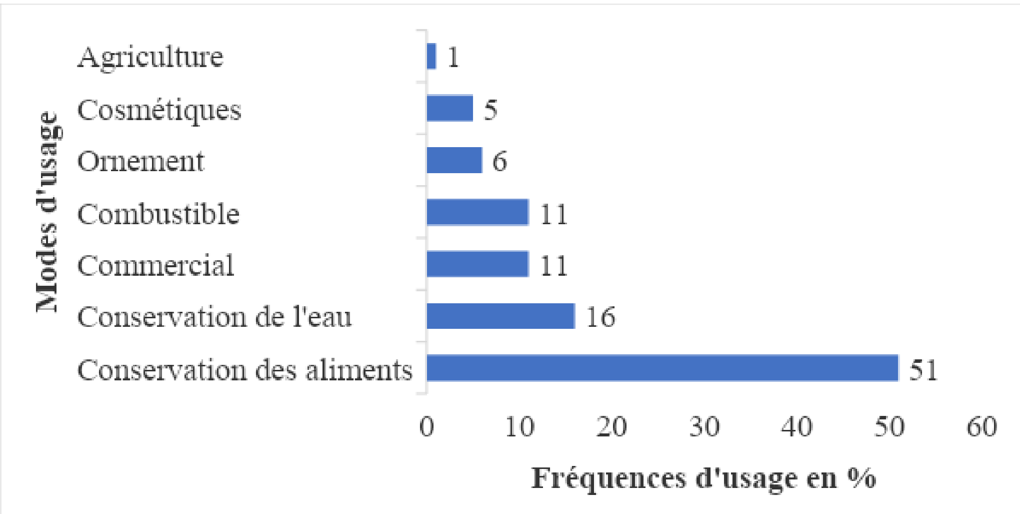

Figure 18: Household use of plastics in Yaoundé

The "cosmetic" use corresponds to the use of plastic-based beauty products (false nails, false eyelashes, synthetic highlights, etc.).

IV.1.7 Typology of plastics used in the households surveyed

According to the people surveyed, plastic bottles are used most by households (39%), followed by plastic buckets and basins (27%), then sandals (20%) and finally electrical and electronic equipment (14%) (Fig.19).

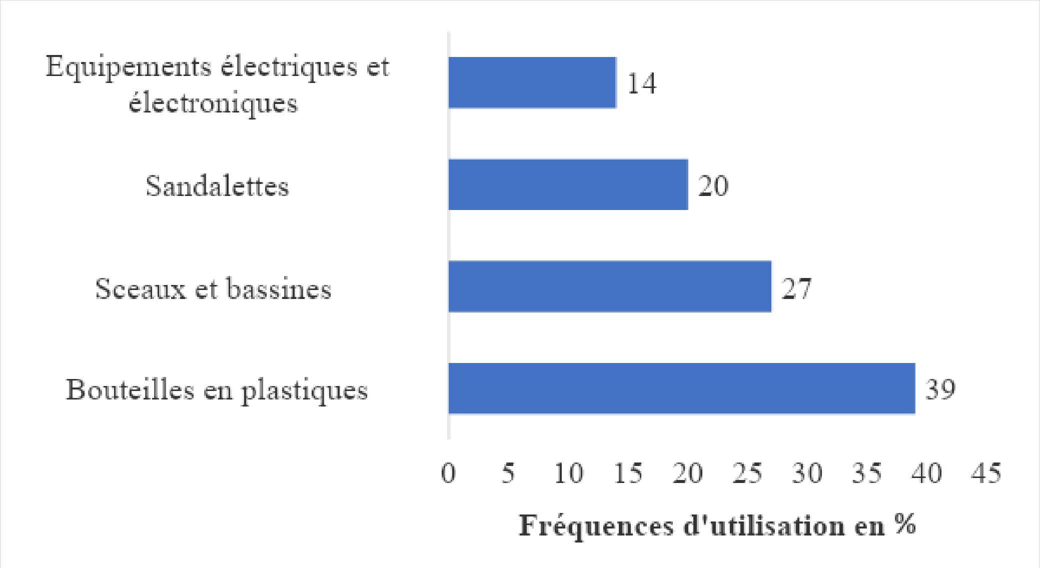

Figure 19: Typology of plastics used in households

IV.1.8 . Presence of companies, individuals and associations collecting and/or processing plastic waste in the neighbourhood

The presence of companies, private individuals and plastic waste collection and/or processing associations is necessary for the collection, disposal and even processing of plastic waste produced in the various neighbourhoods and the city as a whole. The results show that 58% of households surveyed stated that there was no such entity in their locality, 19% confirmed their presence and 23% had no idea (Fig. 20).

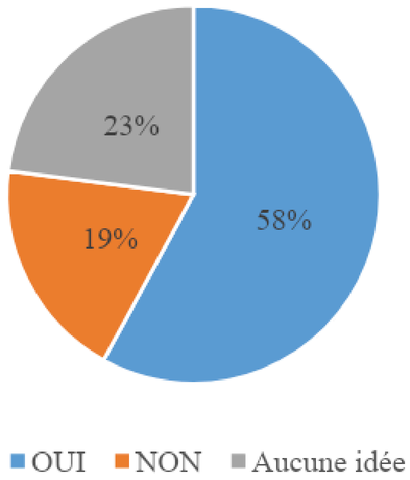

***Figure* 20:** Households' awareness of companies, associations or individuals that collect and/or treat plastic waste

IV.1.9. Frequency of collection of plastic waste by these companies

Only 19% of households surveyed confirmed the presence of a plastic waste collection or recycling facility in their locality. The majority of these (58%) said that these plastic waste collection structures collected waste once or twice a week, 21% said that collection was carried out once or twice a month, 15% said that waste was collected more than twice a week and only 6% said that it was collected several times a month (Fig.21).

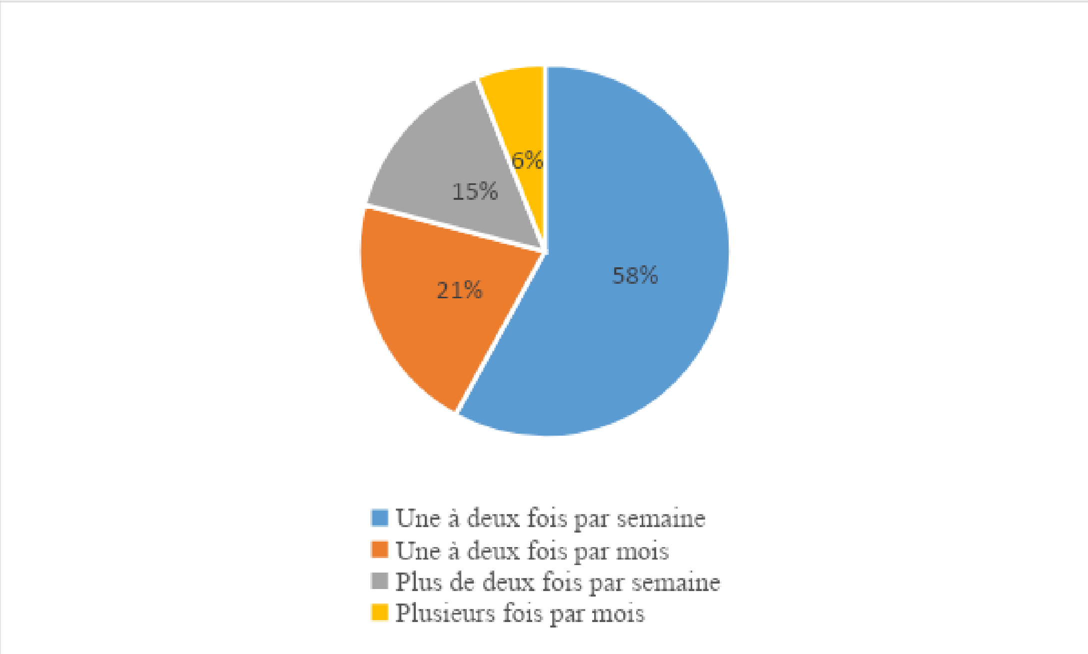

Figure 21: Frequency of plastic waste collection in households surveyed

IV.1.10. Fate of plastic waste after collection

In the absence of any sorting of waste by plastic waste producers at household level, it should be noted that almost all households mix it with other solid household waste in the pre-collection systems, then send it to Hysacam's collection bins. However, they do not know exactly what happens to this waste once it has been collected and transported by the Société d'Hygiène et de Salubrité du Cameroun.

IV.1.11. Field observations

Observations made in the field showed that plastic waste is abundant in several drains in the city of Yaoundé. Some dumps are incinerated to reduce the volume of waste. Moreover, a large proportion of this waste ends up in low-lying areas, polluting water and agricultural soil (Fig.23). It is therefore easy to see from these figures that there is an abundance of plastic bottles, particularly for mineral water and soft drinks. This state of affairs is thought to be linked to the absence of a proper system for managing this waste by producers and users, and also to a lack of knowledge about the harmful effects of pollution from this waste on environmental components, biodiversity and human health. Corrective action must therefore be taken in the short, medium and long term to remedy the damage caused.

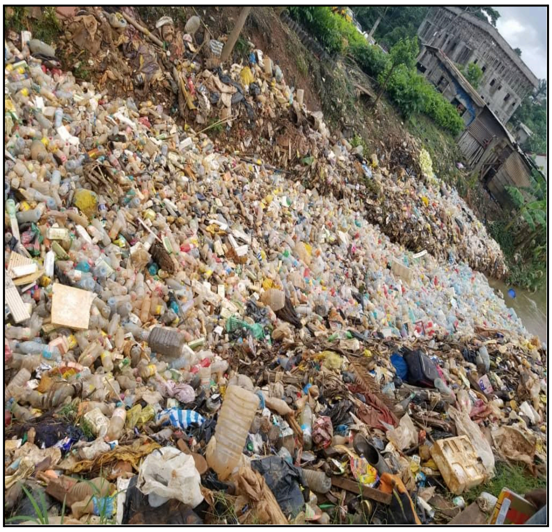	
A: Accumulation of plastic waste in the Ngoa Ekellé drain	**B:** Open-air incineration of plastic waste (Ngousso rails)

Figure 23: Identification of poor plastic waste management practices in Yaoundé

IV.1.12. Strengths, weaknesses, opportunities and threats of plastic waste management initiatives in Yaoundé

The study carried out in the field enabled a diagnosis to be made of the various initiatives to reduce plastic waste. The strengths and weaknesses identified and analysed are summarised in the table below. One of the major strengths is the exchange of experience of plastic waste recovery initiatives with foreign partners. However, the major weakness of these plastic waste recovery initiatives is the lack of support from municipalities and evaluation of their activities.

Table VIII: SWOT matrix of the plastic waste management system in Yaoundé

FORCES	WEAKNESSES
- The government's stated intention to help reduce waste by promoting the recovery of plastic waste - Existence of a legal framework for plastic waste management - More and more young entrepreneurs are interested in recycling plastic waste - Existence of an effective financing mechanism for plastic waste management (EPR, excise duties, etc.) - Regular operations to combat unapproved plastics	- Valorisation techniques are often archaic and do not respect the environment. environmental standards - Lack of widespread promotion of products made from recycled plastics - Lack of reliable data on production, existing sources and the proportion of recycled plastic waste - Recycling reduced to the artisanal stage, resulting in the transformation of small quantities of plastic waste - Lack of sorting and selective collection of plastic waste in households

- Availability of technical and financial partners to support plastic waste recovery initiatives - Reducing unemployment by creating a large number of jobs in the plastic waste management sector (collectors, transporters, buyers, retailers, recyclers, etc.).	- Lack of knowledge of the legal instruments governing plastic waste management by the vast majority of stakeholders - Widespread mismanagement of plastic waste (lack of sorting, uncontrolled dumping, open burning, etc.). - Weak support from public authorities and training adapted to the context - Lack of synergy between existing structures - Shortage of skilled labour - Negative view of waste and low regard for waste-related professions - Low demand for products made from recycled plastics - Limited resources dedicated to plastic waste management, resulting in low recovery and recycling rates - Increased difficulty in collecting waste dumped in certain uneven areas (watercourses, drains, shallows, etc.) - Deterioration in the quality of plastic waste thrown into the environment - Non-compliance with health and safety rules by a large majority of recovery and recycling companies - The main method of managing plastic waste is currently landfill, which causes heavy pollution of the subsoil and wastes large quantities of natural resources.
OPPORTUNITIES	**THREATS**
- International funding available to improve waste management	- Recovery companies not taken into account in the redistribution of funds from EPR, excise duty and additional levies

- Widespread international awareness of the negative impacts of plastic waste - Existence of local media to facilitate environmental education (IEC) - Easy access to the experiences of other countries via social networks (Facebook, Youtube, Whatsapp)	- Inadequate monitoring and evaluation of donor-supported initiatives - Strong competition on the domestic market from Asian products sold at very low prices - Untimely power cuts, which greatly disrupt rebreather operations

IV.2 Characterisation of plastic waste produced by households surveyed

IV.2.1. Characterisation within households

IV.2.1.1. Types of plastic waste (hard/soft) generated by households

The majority of plastic waste used by households is hard plastic (75%), while only 19% is soft plastic (Fig. 25). The "Other" category corresponds to objects in the sample of which only part was plastic (bags, helmets, shoes, etc.).

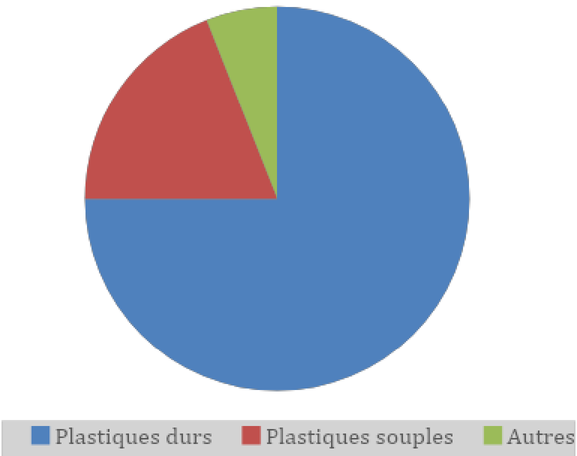

Figure 25: Types of plastic waste produced by households in the city of Yaoundé

IV.2.1.2. Types of polymers produced by households in Yaoundé

The survey results show that PET is the most abundant plastic produced in households (57%), followed by elastomers (14.8%). PVC, on the other hand, is the least produced (0.1%) (Figure 26).

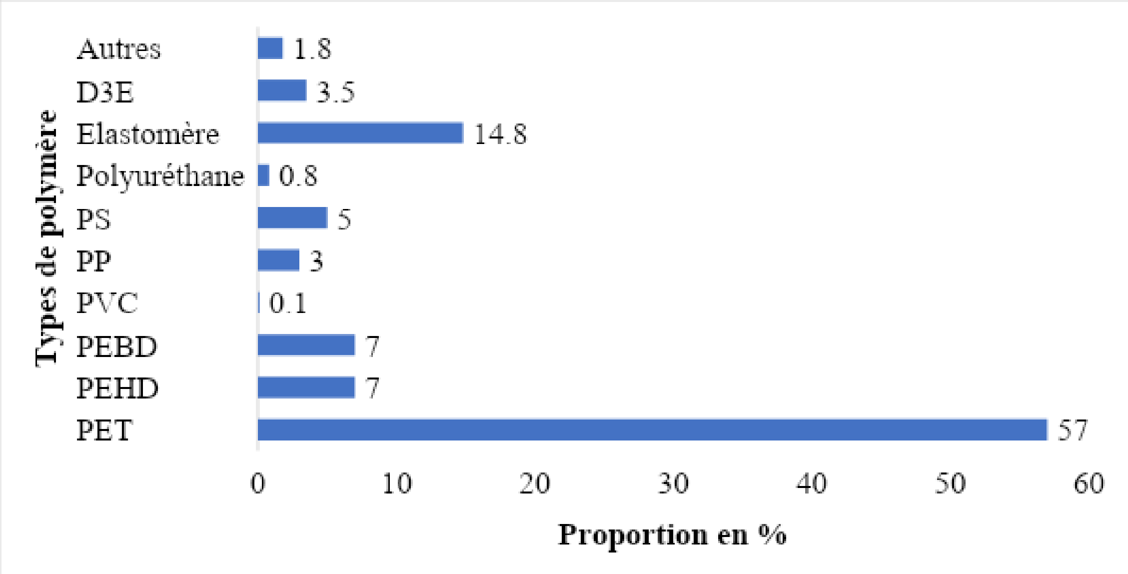

Figure 26: Types of polymers produced by households in **Yaoundé**

IV.2.1.3. Production of plastic waste by type of housing

This result comes from our survey data, which was stratified according to household standard of living. The survey reveals that high-status households produce twice as much plastic waste (42%) as low-status households (21%), as shown in Figure 27 below:

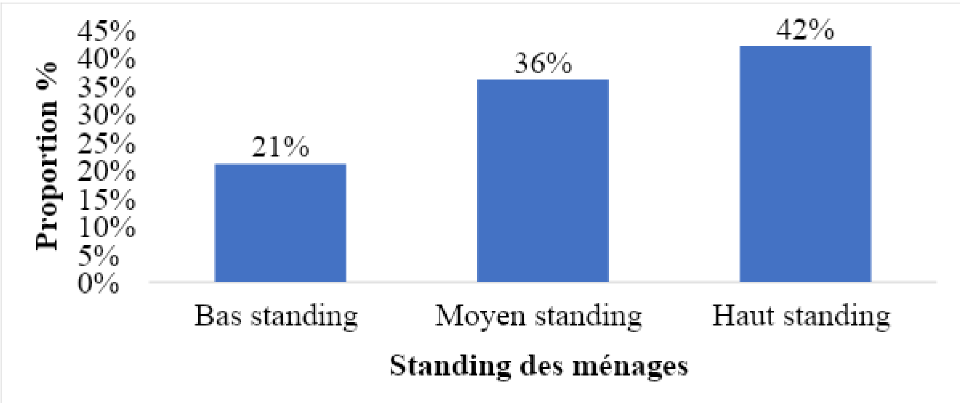

Figure 27: *Production of plastic waste by level of housing*

IV.2.1.4. Characterisation of plastic waste generated by households

The total quantity of plastic waste collected in 14 days from 145 households was 175 kg, which corresponds to an average daily production of around 0.09 ± 0.03 kg/household. This corresponds to an average annual production of around 31.5 ± 10 kg/household/year. Taking as a reference the population size given by the UN World Urbanisation Prospects for 2023, which is 4,509,287 inhabitants in the city of Yaoundé, and given that the average size of a household in this same city has been estimated at around 6 people, the corresponding number of households has been estimated at around 4,509,287 inhabitants/6 = 751,548. The annual production of plastic waste in the whole of the city of Yaoundé could therefore be deduced by calculating 751548 x 31.5 = 23,673,762 Kg and therefore 24,000 t. Using this data, we can show that this production can be estimated at 0.09/6x7 =0.105 Kg/inhabitant/week.

Taking into account the standard of the households, this average daily production is of the order of 0.104 kg/day for high standard dwellings, 0.094 kg/day for medium standard dwellings and 0.053 kg/day for low standard dwellings (Table IX).

Table IX: Quantity of plastic waste produced by households surveyed

Quantities Parameters	Quantities in Kg/day	Quantities in Kg/year
Low standing	0,05	18,25
Medium standing	0,09	32,
High standing	0,10	36,65
Average	0,086	313,9
Standard deviation	0,03	10,95

IV.2.1.5. Quantity of plastics collected from households by category

Households in the Yaoundé 4 arrondissement produce more plastic waste than those in the other arrondissements, with a value of 31.53 kg in 14 days (including 24.31 kg of hard plastics and 6.22 kg of soft plastics), followed by the arrondissements of Yaoundé 6 with 28,23 kg (including 24.08 kg of hard plastics and 4.15 kg of soft plastics), Yaoundé 3 with 27.14 kg (including 20.89 kg of hard plastics and 6.25 kg of soft plastics) and Yaoundé 5 with 25.37 kg (including 19.55 kg of hard plastics and 5.82 kg of soft plastics). The lowest values were recorded in households in the arrondissement communes of Yaoundé 7 with 21.97 kg (including 18.44 kg of hard plastics and 3.53 kg of soft plastics) and Yaoundé 1 with 16.17 kg (including 13.45 kg of hard plastics and 2.72 kg of soft plastics) (Fig.29).

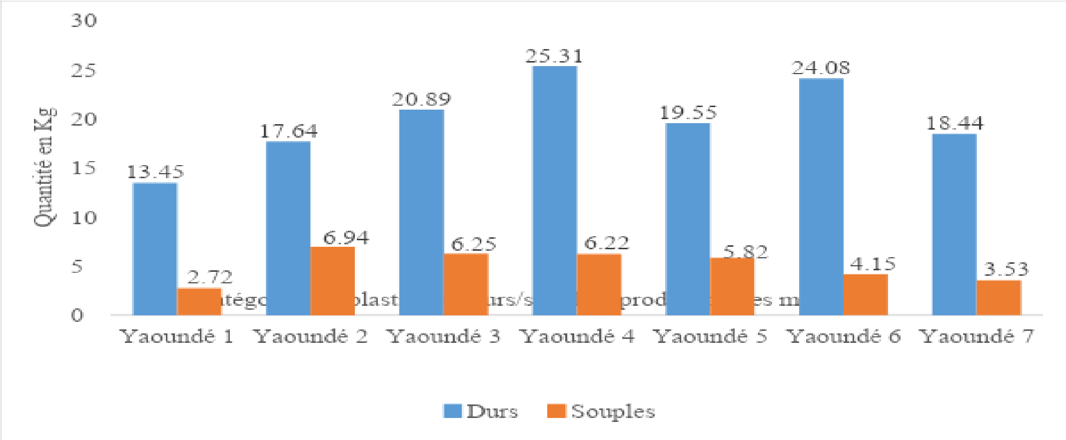

Figure 29: Breakdown of plastics produced by households in each arrondissement according to rigidity

IV.3 Characterisation of plastic waste in drains

IV.3.1. Hydrological map of the city of Yaoundé showing drains heavily polluted with plastics

Mapping of aquatic ecosystems, particularly drains in the city of Yaoundé, reveals around thirty sites heavily polluted by plastic waste. The arrondissements of Yaoundé 6 and Yaoundé 5 have the highest numbers of heavily plastic-polluted sites, with around 13 and 10 sites respectively (Figure 30). However, Yaoundé 4 appears to have the lowest number of sites heavily polluted by plastic waste. Finally, the largest and most polluted of the sites studied is in the Yaoundé 3 district, namely the Ahala drain on the Mfoundi river. This is certainly justified by the fact that this drain, which is located further downstream from the Mfoundi river than any of the others, is the natural receptacle for plastic pollution throughout the city, due to the transport of waste by the Mfoundi (the city's main watercourse) and its tributaries, as well as run-off water. All the waste from different parts of the city ends up here, where it gradually accumulates, which explains the heavy pollution of this drain.

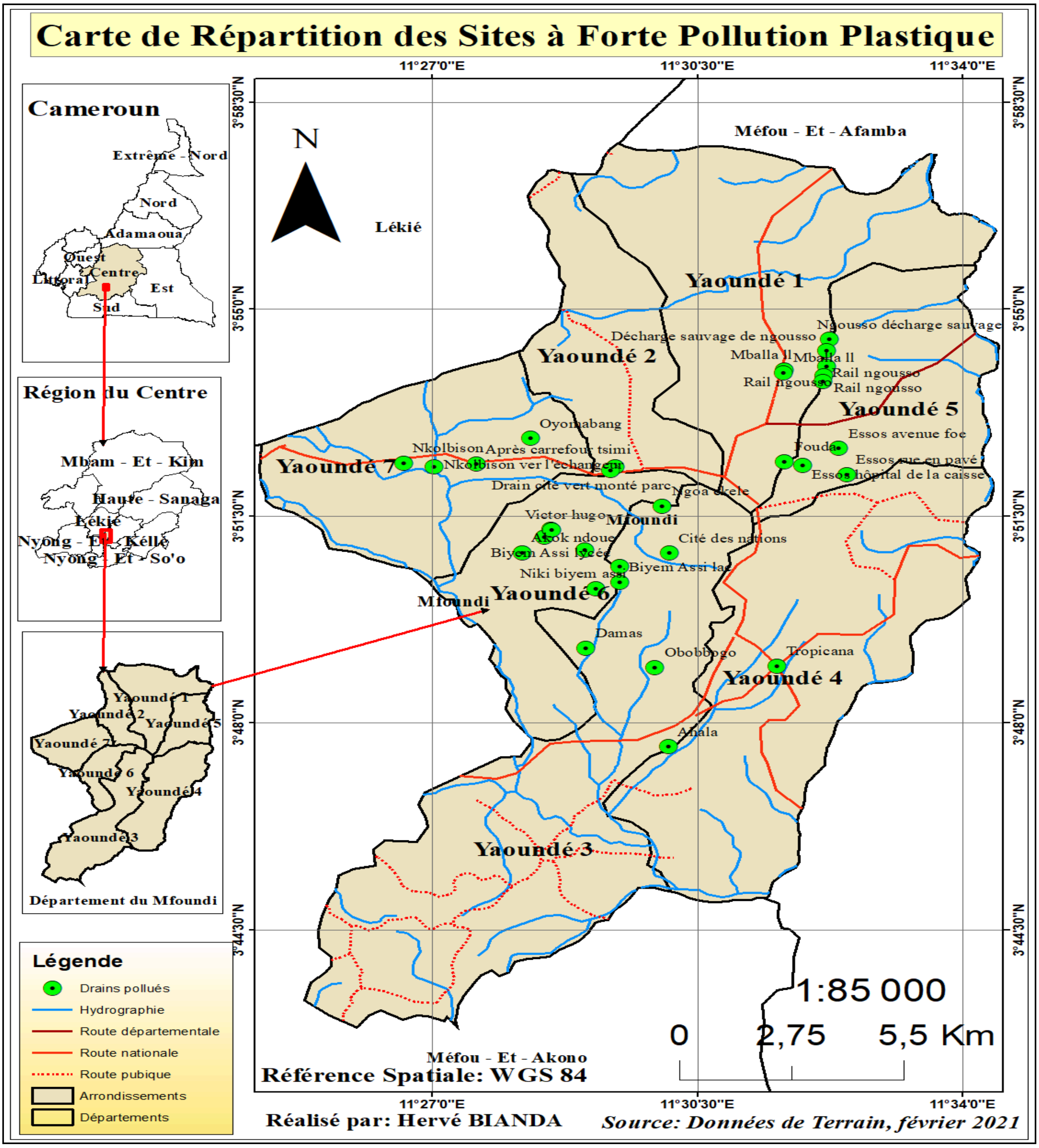

Figure 30: Hydrological map of the city of Yaoundé showing drains heavily polluted by plastic waste.

IV.3.2. Types of plastic identified in drains in the city of Yaoundé

The results showed that the plastic waste present in the Yaoundé drains consisted mainly of PET (57.2%), elastomers (14.8%) and high (7.0%) and low density (6.8%) polyethylene (Fig.31).

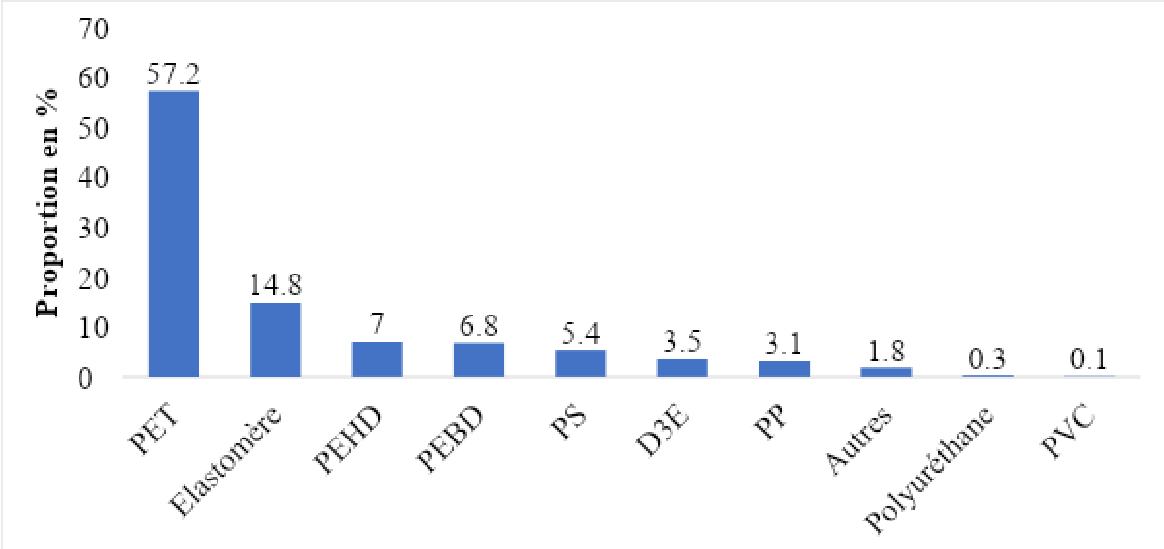

Figure 31: Types of plastic found in drains in the city of Yaoundé

IV.3.3. Characterisation of plastic waste collected from drains

During the characterisation of plastic waste in drains in the city of Yaoundé, 1,250 kg of waste were collected in 6 drains in the city. After sorting, 1179.69 kg of plastic waste was obtained. As a result, 5.96% of the initial mass was made up of intruders (sticks, mud and water present in certain bottles, etc.). Most of the waste was hard plastic (72.9%), followed by other types of plastic (20.3%) and soft plastic (6.8%) (Fig. 32).

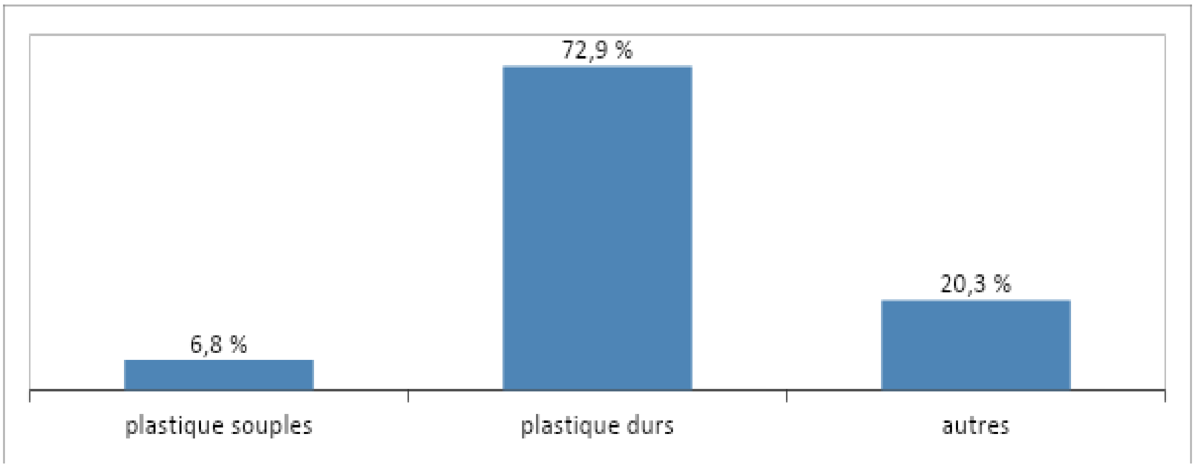

Figure 32: Proportion of types of plastic waste collected in drains according to hardness

IV.3.4. Quantity of plastics collected by category and by district from drains

In terms of drains, the difference in quantity within the same category of plastic was insignificant in all boroughs. However, this difference is very marked between the various categories of plastic (Fig. 33).

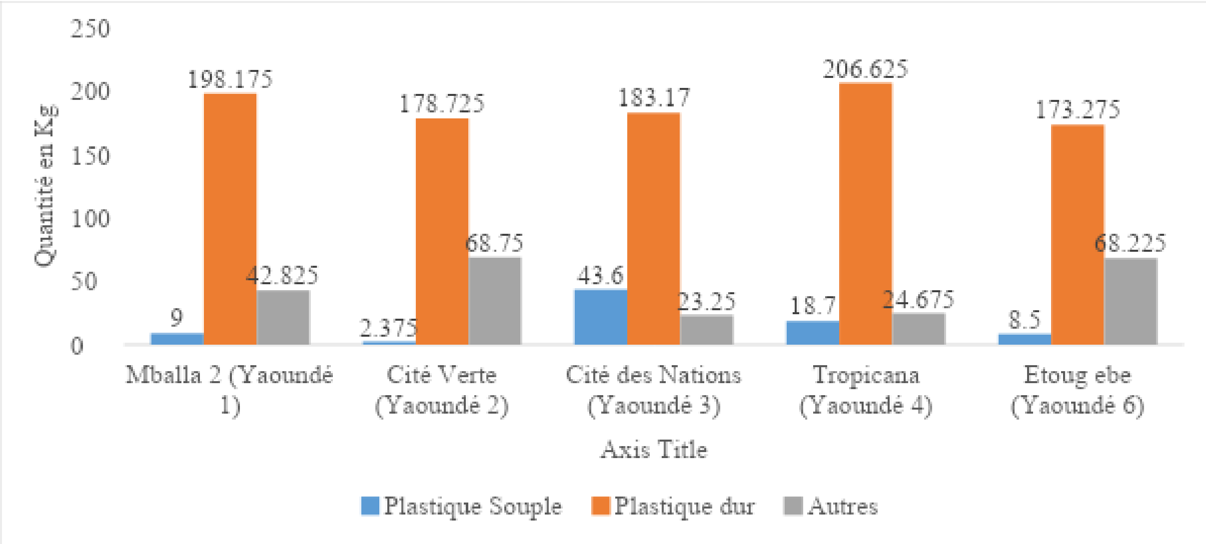

Figure 33: Types of plastic waste (by hardness) collected in each municipality

IV.3.5. Comparative analysis of types of plastic collected from households and drains

A comparative analysis of the results of the quantification of plastic waste in households and in the drains investigated shows that the different types of plastic waste are equally present in households and in drains, but in proportions that vary according to the type of material considered (Table X). PVC plastics (plumbing pipes in particular) are much more present in all the plastic waste inventoried in drains than in household waste, the differentiation factor being of the order of 70. The same applies to polyurethane (pieces of foam mattress), which is more abundant in drains with a magnitude factor of the order of 10. However, D3E (electrical or electronic appliances) are twice as present in the plastic waste produced in households than in that accumulated in drains. This could be justified by the fact that the plastic waste found in drains comes from several sectors of activity, including markets and businesses, unlike household waste, which is specific to households. In addition, PVC and polyurethane are plastics that are not recycled and therefore remain in the environment for a long time because they are not recovered by informal collectors. As for the abundance of WEEE in households, this could be justified by the sentimental value that many people attach to their electronic equipment, even when it is faulty.

Table X: Comparison of the types of plastic collected from households and drains

Types of plastics	Household (%)	Drains (%)
PET	57,2	57,0
HDPE	7,0	7,0
LDPE	7,0	6,8
PVC	0,1	7,0
PP	3,0	3,1
PS	3,1	5,4
PU	0,3	3,0
Elastomers	17,0	14,8
WEEE	7,0	3,5

IV.3.6. Characterisation of plastic waste from agricultural subsoil

The study showed that plastic waste was also present in the soil, generally at a depth of between 0 and 30 cm (Figure 34). In ascending order of subsoil pollution by plastic waste, we have the Ezazou village lowland (26.31%), followed by the Mokolo lowland (32.71%) and finally the Nkolbison lowland, which is the most polluted (40.98%).

Figure 34: Evidence of plastic waste in the subsoil

The results show a predominance of hard plastics (68.13%) in the soil, particularly PET, followed by other types of plastic (17.76%) and finally soft plastics (14.11%) as the plastics found in the subsoil of the shallows.

IV.3.7. Measurement of physico-chemical parameters of water samples

The water samples taken from drains with a high accumulation of plastic waste, as well as the controls, showed concentrations of physico-chemical parameters that were more or less low (Table XI) and, overall, all complied with Cameroonian standards (MINEPDED) laid down in 2008 for receiving environments. Analysis of the results compared between the control sites and the drains tested shows that there is no difference in concentration for almost all the parameters analysed. Moreover, this result suggests that pollution by plastic waste does not significantly affect water quality. However, the rainy climatic season in which the investigation was carried out would have had an influence on the results through the effect of dilution and leaching. Further on, it should be noted that the redox potential values were all negative in the water analysed in the drains and even in the control sites, indicating that the water was anoxic. Such an observation for the two types of sites compared could lead to the conclusion that the presence of plastic waste has no influence on the physicochemical quality of these waters. However, the negative values obtained show that there is a low level of oxygen in these waters, which could have a major influence on the biodiversity of the environment in terms of abundance and dominance, but also on the production of biomass, which could lead to a scarcity of food for fish and other species in the environment that feed on this biomass.

Table XI: Physico-chemical parameters of aquatic environments

Sampling points	Physicochemical parameters								
	Boroughs	T (∘C)	pH	Eh (mv)	Cnd (µS/Cm)	TDS (mg/l)	Sal (%∘)	BOD_5 (mg/l)	COD (mg/l)
City of Nations	Yaoundé 3	23,3	8,01	-47	246	175	0,12	16	40
Ahala	Yaoundé 3	25,9	8,12	-56	212	152	0,11	18	98
Tropicana	Yaoundé 4	25,4	7,94	-45	152,3	110	0,08	16	67
Mballa2	Yaoundé 1	27,5	8,12	-55	246	176	0,12	20	153
Cité-verte	Yaoundé 2	26,5	8,18	-60	374	268	0,19	16	33
Etoug-Ebé	Yaoundé 6	26,6	8,36	-69	389	277	0,2	15	42
Tropicana (control 1)	Yaoundé 4	26,1	7,95	-47	217	156	0,11	16	24
Mballa2 (control 2)	Yaoundé 1	27,4	8,05	-52	237	168	0,12	20	190
Olezoa/Olympia (witness 3)	Yaoundé 3	24,4	8,27	-64	175	125	0,09	8	35
Standards (MINEPDED)	/	30	6-9	/	/	/	/	50	200

Eh: Redox potential **;** **TDS:** Total dissolved solids; **Cnd:** Conductivity ;
Sal: Salinity; **BOD5:** Biochemical oxygen demand for 5 days; **COD:** Chemical Oxygen Demand

IV.3.8. Variation of biological parameters in drains according to their pollution level

The variation in biological parameters analysed in polluted drains compared with unpolluted drains (controls) showed slight differences in terms of the number of individuals per litre of sample. Most of the drains polluted by plastic waste, particularly those at Ngoa Ekellé (Cité des Nations), Ahala, Mvan (Tropicana) and Cité-verte, showed a phytoplankton population that was 1.5 to 2 times higher than at the control sites (Table XII). These observations suggest that the presence of plastic waste is favourable to the development of phytoplankton. This can be explained by the stagnation of water caused by the plastic waste, which favours the development of algae and other lower plants.

As far as zooplankton are concerned, it is difficult to say whether plastic waste has any influence on the populations, as the quantities in terms of numbers of individuals identified depending on the site are very small and vary very little whatever the level of pollution.

Table XII: *Variations in biological parameters analysed in polluted drains compared with unpolluted drains (controls)*

Parameters / Sampling points	Boroughs (Drains)	Phytoplankton (ind/L)	Zooplankton (ind/L)
City of Nations	Yaoundé 3	10450	5
Ahala	Yaoundé 3	7650	11
Tropicana	Yaoundé 4	10950	15
Mballa 2	Yaoundé 1	5700	0
Cité-verte	Yaoundé 2	8850	0
Etoug-Ebé	Yaoundé 6	4450	2
Tropicana (control 1)	Yaoundé 4	4850	25
Mballa 2 (witness 2)	Yaoundé 1	5800	0
Olezoa/Olympia (witness 3)	Yaoundé 3	2400	0

IV.3.9. Measurement of air parameters in environments with high levels of plastic pollution

As the technical platform used for air analysis was limited, only two parameters, namely carbon dioxide and volatile organic compounds, were analysed in areas with a high accumulation of plastic waste (table XIII). The values obtained by direct measurement were compared with those of the European standard considered here as the reference value in the absence of national standards. Overall, CO levels$_2$ are relatively high and all above the threshold value set by the European standard. The values obtained in descending order are 650 ppm (Ahala), 530 ppm (Cité-verte), 562 ppm (Tropicana) and 455 ppm (Mballa 2) respectively. However, it is important to note that the value at the control site (406 ppm) remains lower than that in the polluted areas, which suggests that plastic waste contributes to increasing the level of CO_2 in the atmosphere. The same applies to volatile organic compounds, which are generally higher above the polluted drains than above the control drain. These concentrations are higher in Yaoundé III (Ahala) (0.076 mg/m^3) and Yaoundé IV (Tropicana) (0.068 mg/m^3), than in Yaoundé II (Cité-verte) where the concentration is 0.049

mg/m^3 , unlike the control which has a lower value and is below the guide value considered (0.003 mg/m^3).

Table XIII: Concentration of different gases on air quality

Boroughs **Parameters**	**Yaoundé I**	**Yaoundé II Cité verte**	**Yaoundé III**	**Yaoundé IV**	**Yaoundé VI** (witness)	**Threshold value (European standard)**
CO_2 (ppm)	455	530	650	562	406	350-450
TVOC (mg/m)^3	0,021	0,049	0,076	0,068	0,003	0,02

V. DISCUSSION

According to the stakeholders interviewed and the observations made during data collection in the field, plastic waste produced in the majority of households surveyed (90%) is mixed with other solid household waste during pre-collection. Sorting is therefore almost non-existent, which is a significant barrier to the recovery of the various components of this waste and therefore of plastic waste. A study carried out in several West African cities revealed the same thing, with the exception of Lagos, which is the only city to have introduced selective collection of plastics, with a collection rate of 35%. In the other cities, plastics are sorted by local collectors. Artisanal and industrial forms of recycling coexist: sorting, shredding, washing, drying and extrusion to produce granules or flakes that can be recycled. In Dakar, rue Tolbiac is the preferred area for popular plastic recyclers, close to the port, the industrial zone and various markets. The plastics sorted in Dakar are mainly PE and PP, which are sold to local industries that use them to make bags, shoes, cutting boards and hair wicks (IWWA. 2011 and 2012). To compensate for this lack of waste sorting at the source of production, awareness-raising helps to change household behaviour, in particular by sorting waste, but also increases the commitment of citizens and the pressure they can exert on environmental issues (UNESCO, 2017).

A serious shortcoming observed in the waste management system in this study is therefore the lack of sorting, which is very important for the integrated and sustainable management and recovery of waste as a whole. It is worth noting the importance of collection and sorting for plastic recycling (S.M. Al-Salem, et al., 2009). In Belgium, for example, solid waste is collected door-to-door by municipalities in a separate waste bag that is less costly for the citizen than the household waste bag. The bag is used to package plastic bottles, metal cans and cardboard drinks packaging. The majority is made of polyethylene terephthalate (PET), followed by high-density polyethylene (HDPE) and a minority of polypropylene (PP) and low-density polyethylene (LDPE). The bags collected are delivered to sorting facilities (Ragaert et al., 2017). In addition to problems with the quality of the plastic produced, poor sorting can damage the equipment. In addition to the lack of sorting, several other factors are likely to compromise the management and recovery of waste, particularly plastic. UNEP (2018) identified a lack of public awareness, weak legislation and enforcement, insufficient budgets allocated to waste collection and disposal, unsuitable and malfunctioning equipment, lack of effective public participation and inadequate waste management governance frameworks as the main push factors affecting the state of waste management in Africa.

In an "ideal" scheme, waste collection is supposed to be carried out by formal private companies under contract with the municipalities. In practice, there are many problems: irregularity of service, inefficiency, poor road and weather conditions, poor condition of vehicles, which are often of unsuitable size, etc. In the case of this study, many shortcomings were observed with regard to this "ideal" scheme. In fact, the mixture of waste produced at household level is generally collected and transported by a single private company, the Société d'Hygiène et Salubrité du Cameroun (Hysacam), to the landfill site. There is therefore a lack of competitiveness in waste collection and transport, which could hinder its success. Moreover, the circuit followed by this plastic waste is identical to that of all household waste, which comprises 4 main stages: (1) the production of waste by households; (2) pre-collection; (3) collection; and (4) transport and disposal at the Centre d'Enfouissement Technique (CET) located in Nkofoulou, a suburb of the city of Yaoundé. This organisation is not only similar to that reported by Ngnikam et al. (2002) in the same city, but also by Topanou (2012) and Kple (2015) in the commune of Abomey Calavi and Ousmane Adamou (2015) in the city of Niamey.

With regard to household behaviour towards the plastic waste produced, it was noted that, once the plastics had been used, 44% of the households surveyed disposed of them in collection bins (Hysacam collection points), 34% reused them, 10% burned them, 5% disposed of them in unauthorised dumps, 3% made them available to pre-collectors (associations, individuals, etc.), 2% sold them and 2% disposed of them in the street. The lack of information and awareness would appear to be at the root of the behaviour of households who burn or dispose of their plastic waste in the environment. If this behaviour is not taken into account when corrective action is taken, it can lead to more waste being thrown away or burnt in open spaces, polluting the air and the environment, but also causing the tourist town to lose its aesthetic value. A related study in the town of Shambu in Oromia, Ethiopia, shows that solid waste dumping and incineration in open disposal sites are the main methods of waste disposal, with open incineration generating harmful dioxins and nitrogen oxides (Tsega, 2013).

In recent decades, the affordability of plastic production has led to a galloping rise in the global market. Today, plastics or plastic materials are used for a variety of purposes, from automotive parts to food packaging and electronic devices. However, the management of these items at the end of their useful life, particularly single-use plastics, is a cause for concern: to date, only around 9% of discarded plastics have been recycled. The rest is either burnt, landfilled or released into the environment (via waterways, streets, etc.) (Geyer et al., 2017).

Cameroon's annual production of plastic waste was 600,000 tonnes in 2018, according to the latest report published by the Ministry of the Environment, Nature and Sustainable Development. The increase in this production over the last two decades is impressive and is increasingly creating non-biodegradable waste dumps in ecosystems. Unfortunately, there is another less visible risk: the threat to human health from the toxic chemicals present in most plastic products. Inadequate waste management systems and human negligence are often cited as the main factors in the pollution of terrestrial and marine environments by plastic waste. (McKinsey and Ocean Conservancy, 2015). Faced with this threat, there is a growing awareness at international level, starting with the re-categorisation of plastic waste. At the last Conference of the Parties to the Basel Convention in 2019, the question of setting up a working group on hazardous plastic waste and another on presumed non-hazardous plastic waste, depending on whether or not it contains hazardous chemical additives, was raised, in order to control its movement from developed to developing countries. In addition, at the fifth session of the United Nations Environment Assembly, a historic resolution was adopted to draw up a legally binding international instrument on plastic pollution by the end of 2024, under the auspices of an Intergovernmental Negotiating Committee on Plastic Pollution. This will be based on a global approach covering the entire life cycle of plastics. The committee will seek ways to encourage sustainable production and consumption of plastics, from product design to environmentally sound waste management, using resource efficiency and circular economy approaches.

Pre-collection is now seen as a palliative to the shortcomings of public waste services, particularly those of municipalities that do not have the resources to ensure local waste management. In Yaoundé, pre-collection has encouraged the development of certain circular economy sectors such as composting and recycling.

More specifically, plastic waste is made up of polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polystyrene (PS), high and low density polyethylene (HDPE and LDPE), etc. They account for 15-20% of municipal waste, but are frequently thrown away with household refuse. IWWA Programme (Integrated Solid Waste Management in West Africa - www.iwwa.eu), 2012 Municipal solid waste in West Africa: between informal practices, privatisation and improvement of the public service.

Plastics have different melting temperatures and the presence of a plastic with lower melting temperatures than the recycled plastic can lead to carbonisation, which is harmful to the material (Leveque, 2018). It should be noted that, at the root of this system, it is the consumer who carries out the initial sorting, without whom all this would be impossible (McDonald et al., 1998). Other studies carried out in Kenya and Ethiopia have also reported a lack of waste sorting at source (Aurah, 2013; Odhiambo et al., 2014; Tiruneh et al., 2015), which reduces the effectiveness of recycling (Banerjee et al., 2014) due to the contamination of plastics by other materials.

The majority of plastic waste used by households is hard plastic (73%), compared with only 27% soft plastic. This could be explained by the choice of other alternatives following the implementation of joint Order No. 004 MINEPDED/MINCOMMERCE of 24 October 2012 regulating the manufacture, import and marketing of non-biodegradable packaging, Article 7 of which prohibits the production, import, possession and marketing of non-biodegradable plastic packaging with a thickness of less than 60 microns.

The results of the survey show that PET plastic waste is produced the most in households (57%), followed by elastomers (14.8%). PVC, on the other hand, is the least used (0.1%), which would be justified by the specific production of materials and tools of each type at national level; indeed, a study conducted by CREPD in 2017 in Cameroon found that Low Density Polyethylene (LDPE) is the most produced polymer (35%), followed by Polyethylene Terephthalate (PET) 31%, and High Density Polyethylene (HDPE) (10%). The study estimates production of PVC and polyisoprene at 8%.

The survey also revealed that high-status households produce twice as much plastic waste (42%) as low-status households (21%). This is probably due to the fact that these households, with their greater purchasing power, buy and produce more packaging/waste (the vast majority of which is plastic) than low-status households, whose purchases are generally limited to essential products, and usually in small quantities.

The annual production of plastic waste in the whole of the city of Yaoundé over one year could therefore be deducted by doing the calculation 751548 x 31.5 = 23 673 762 Kg and therefore 24 000 t. The annual production of plastic waste in Cameroon is 600,000 tonnes for 2018 according to the latest report published by the Ministry of the Environment, Nature and Sustainable Development. The annual quantity obtained for this study in the city of Yaoundé represents 1/25th of that estimated nationally in 2018. This could corroborate the forecasts in terms of increase if this quantity were to be brought down to national level. The data that could be used for such an estimate is the specific weekly production for each inhabitant, estimated at 0.105 kg/inhabitant/week.

Recent studies carried out in other African countries, notably Burkina-Faso, have produced higher specific production values than those obtained in the present study. Indeed, a study carried out in collaboration between the 2iE foundation and the PSRDO-CER project in June 2011 in the Sig-Noghin district revealed that one person's plastic waste production is 0.2 kg/week. Despite these figures, the common finding is that, in terms of volume, the plastic waste produced represents a significant fraction of the waste generated by households (Tezanou, 2003; Spinato et al., 2011).

The results of our work revealed that the waste present in Yaoundé drains consisted mainly of PET (57.2%), elastomers (14.8%) and high and low density polyethylene (7.0% and 6.8% respectively). The bulk of this is hard plastic (72.9%), followed by other types of plastic (20.3%) and soft plastic (6.8%). These results can be explained by the massive consumption of mineral water and soft drinks, coupled with the low rate of collection and recovery of plastic waste in the city. The gradual accumulation of plastic waste in low-lying areas and drains over time is facilitated by the overproduction of plastic waste by households, which are often so overburdened that they dispose of it in their immediate environment. Drainage into watercourses and other parts of the environment is thus facilitated by run-off water.

The findings from the field show that, in terms of composition, PVC plastics are much more present in all the plastic waste inventoried in drains than in household waste, with a differentiation factor of around 70. The same is true for polyurethane, with a differentiation factor of around 10. This result could be explained by the fact that PVC and polyurethane are not listed among the categories of plastics currently recovered by the few recycling operators identified. Consequently, even if they are not produced in large quantities by households, they have the time to accumulate in nature and ultimately constitute a significant source. However, there are twice as many WEEE in the plastic waste produced by households as in the waste accumulated in drains, which could be explained by the increasing number of recyclers who collect WEEE in the field and dismantle it to remove various fractions (metals, motherboards, electrical cables, etc.), which means that they are rare in nature.

The results of the study show the presence of plastics in agricultural soils, particularly in low-lying areas, with a predominance of hard plastics (68.13%), particularly PET. This result could be explained by the low density of soft plastics, which are lighter and tend to move over greater distances under the effect of wind and other vectors than hard plastics. What's more, flexible plastics are more fragile and therefore more likely to break down into smaller fragments (micro and nano plastics) under the effect of mechanical forces, chemical agents and the weather, unlike hard plastics which are more resilient. Finally, soft plastics are only used to make a few objects, particularly packaging, unlike hard plastics which are found in a wide range of products (containers, shoes, bumpers, electrical and electronic appliance shells, various utensils, etc.).

The water samples taken from drains with a high accumulation of plastic waste, as well as the controls, showed concentrations of physico-chemical parameters that were more or less low and, overall, all complied with Cameroonian standards (from MINEPDED) laid down in 2008 for receiving environments. This suggests that these waters do not appear to be under the influence of a major source of pollution.

The variation in biological parameters analysed in polluted drains compared with unpolluted drains (controls) showed slight differences in terms of the number of individuals per litre of sample analysed. Most of the drains polluted by this plastic waste, notably those at Cité des Nations, Ahala, Tropicana and Cité-verte, showed a phytoplankton population that was 1.5 to 2 times higher than at the control sites. These observations suggest that the presence of plastic waste is favourable to the development of phytoplankton.

The high presence of plastic waste in our drains could be explained by the direct discharge of waste into the water, or indirectly by the run-off of waste from upstream to downstream. The waste accumulated in watercourses in this way will degrade the properties of the environment, in particular by reducing the amount of light that penetrates it, which has a direct impact on photosynthesis and therefore primary production. The entire food chain is thus disrupted, with inevitable repercussions for the functioning and even maintenance of the ecosystems concerned. This is the case of the river Mfoundi in its downstream section at Ahala, particularly during the dry season, where the riverbed is literally covered in plastic waste. Over time, this plastic waste begins to break down into micro- and nano-plastics, which are the source of so-called invisible pollution of a second kind, reflected in the physico-chemical quality of the water and directly in the chemical oxygen demand (COD), the most widely used method for assessing the overall load of organic pollutants in water. The study reveals that in heavily polluted sites, there is a relationship between pH, COD, phytoplankton density and zooplankton population. Comparing two sites in the same arrondissement, the Tropicana site in the Yaoundé 4 arrondissement, we can say that, in the control site considered to be little polluted, the COD value is lower (24) compared with a heavily polluted site in the same arrondissement (COD 67).

Here we can see that the water at the lightly polluted site is less acidic (pH 7.96), warmer (T = 26.1o C), with a phytoplankton density of 4850 and a zooplankton population of 25 individuals, whereas the polluted water at the same site has a zooplankton population of 15 individuals, a phytoplankton density of 10950 and the water is more acidic (pH 7.94) and less warm (T = 25.4o C). A comparative study conducted by LECLERCQ in 2015 revealed that an increase in phytoplankton density would lead to an increase in the zooplankton population, whereas an increase in the zooplankton population would lead to a decrease in phytoplankton density. It is certain that a reduction in the zooplankton population in an area polluted by plastic is an indication that the environment is being polluted by degraded plastic waste, which is consumed along with the phytoplankton by the zooplankton, possibly causing their death and consequently the reduction or even extinction of the most sensitive species.

The problem of plastic pollution should no longer be seen simply in terms of its visible aspect, which in reality is only an apparent and partial pollution. It is important, if not necessary, to take account of global pollution, which already includes macroplastics, microplastics and nanoplastics.

VI. CONCLUSION, RECOMMENDATIONS AND OUTLOOK

VI.1 Conclusion

At the end of this study, the general objective of which was to analyse the impact of plastic waste on the ecology of the city of Yaoundé, we can state that the objectives have been achieved. The study made it possible to characterise the plastic waste produced by households on the one hand and present in the drains of the city of Yaoundé on the other. The characterisation revealed a predominance of hard plastics over soft plastics. The quantity of plastic waste produced in 14 days by the 145 households surveyed was 175.104 kg, or 0.084 kg/household/day. Of the hard plastics, PET plastics were the most dominant. It is important to relate these quantities obtained to the types of standing existing in the study area. The quantities produced differ according to the standard of living of the household and are proportional from the lowest to the highest standard.

The quantities of plastics produced have health and environmental impacts, as the respondents were quick to point out. Among the problems cited were soil and water pollution and odour nuisance. It is important to note that these impacts have upstream causes. The main cause is poor management of plastic waste. For one reason or another, some people throw their waste in the street, while others burn it in the open air. This undoubtedly causes a nuisance.

The study also provided an overview of the state of plastic waste in the city of Yaoundé, including the main sources and the current management system, which enabled its strengths and weaknesses to be identified. Firstly, the study shows that the plastics found in our households come from a variety of sources (packaging (plastic film), consumption (PVC, HDPE, polyurethane, etc.), transport (used tyres), etc.) and are made up mainly of plastic bottles, bags, plastic film and single-use plastics. After use, plastic waste is disposed of in a variety of ways, including open burning, dumping in streets, ditches, waterways and fields, and uncontrolled dumping, leading to uncontrolled piles of plastic waste. All these bad practices can be explained by the absence or difficulty of access to rubbish bins by local people, the poor state of existing roads in the neighbourhoods which do not always allow the circulation of rubbish collection lorries, and the ignorance of local people who are very little aware of the impacts linked to the bad management of plastic waste, etc.

VI.2 Recommendations

VI.2.1- Administrative authorities

In order to reverse the trend in plastic waste management, public authorities could take a number of measures in the areas of legislation, environmental education and promoting investment in the circular economy sector. In practical terms, the government could :

- Set up specific training courses geared towards the recovery of plastic waste in order to create a skilled workforce capable of effectively and sustainably resolving the problem of plastic pollution through green jobs. These jobs would replace the informal system that is widely used at the moment, but whose results are still slow to be felt.
- Raise people's awareness of the socio-economic and environmental impacts of plastic waste, and encourage them to follow good waste management practices (reduction at source, reuse, sorting, etc.).
- Involving local people in policies to combat plastic pollution through an inclusive and participatory approach.
- Support companies involved in the collection, treatment and recovery of plastic waste in order to increase their capacity and therefore the quantities of plastic waste treated. This could be done, for example, through tax exemptions or subsidies for investment in this sector of activity.
- Review the legal framework to adapt it better to the context, then ensure that it is strictly applied, in particular by banning the production, distribution and use of single-use plastic waste (less than 60 microns thick).
- Ensure compliance with the principle of extended producer responsibility, under which any producer (manufacturer or importer) of plastics must ensure that at least 80% of the quantities of plastic waste produced are collected and processed.
- Set up a selective collection system for plastic waste and penalise offenders responsible for perpetuating bad practices.
- Properly coordinate the national waste exchange so that it helps to achieve the desired objectives.

VI.2.2 - Producers

Producers are represented by manufacturers, importers or distributors of plastics. Depending on the case, these are industries, companies or commercial establishments. They are required to comply with legislative and regulatory requirements, in particular the principle of extended producer responsibility, which requires them to collect and recycle at least 80% of the plastic waste they produce, or to sign an agreement with an approved service provider who will do this on their behalf.

VI.2.3- The general public

To curb the rate at which plastic waste is produced, people are encouraged to :

- Reduce the amount of plastic waste at source by choosing alternatives to plastic wherever possible;
- Giving plastics a second life after use by reusing and re-using them several times before disposing of them
- Adopt good waste management practices, in particular by avoiding disposing of plastic waste in inappropriate places (uncontrolled heaps, gullies, waterways, etc.) or burning it in the open air, but rather by sorting it at source and making it available to structures/persons capable of recovering it properly.

VI.3 Outlook

This study has analysed the factors influencing plastic waste management in Yaoundé, characterised the types of plastic waste produced and the corresponding impacts, and estimated the amount generated. This work made it possible to update the statistics of very old studies, in particular that of MINDEPDED, which in 1998 estimated the production of plastic waste in Cameroon at 600,000 tonnes/year (10% of household waste), as well as a study by the Ecole Nationale Supérieure Polytechnique in 1995, according to which the production of this waste was estimated at 10,000 tonnes/year in the city of Yaoundé. It could be continued by :

- a study on revitalising the recovery, conversion and recycling of plastic waste.
- a local and long-term statistical study of the socio-economic impact of plastic waste in society.
- The main weaknesses of the plastic waste management system having been identified, future work could be more practical and focused on concrete solutions (research -

action) such as organising targeted awareness campaigns, coupled with improving the selective collection system for plastic waste to make it available to the appropriate structures for recovery.

- Optimising existing recovery processes to increase their efficiency and thus the quantities of plastic waste absorbed.

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APPENDICES

Appendix 1: Household survey questionnaire

Hello, we are Master's students in the Faculty of Science at the University of Yaoundé I. We are sending you this questionnaire to find out your views on plastic waste management in the city of Yaoundé. The information contained in this document is strictly confidential by virtue of law N°91/023 of December 1991 on censuses and statistical surveys, which stipulates in article 5 that "individual economic or financial information appearing on any statistical survey questionnaire may under no circumstances be used for purposes of economic control or repression".

Topic: Impact of plastic waste on surface water resources in the city of Yaoundé

ARTICLE 00-GENERAL

01-Yaoundé Borough Council /__/

02-Quartier /___________________________/

03-Investigator's name /__/

04-Age of respondent /__/

05-Maintenance date /__/__/__/

06- Form number/code /_______/

SECTION 1- IDENTIFYING THE SOCIAL AND EDUCATIONAL STANDARD OF LIVING

1.1 Type of habitat

1- High standing /__/2- Medium standing /__/3- Low standing/__/

1.2-Topographical position

1- Crête /__/ 2- Mi pente /__/3- Bas Fond /__/

1.3 Occupancy status of the house

1- Owner /__/2- Tenant /__/3- Other (please specify) /____________________/

1.4-Status of the respondent in the household

1- Head of household /__/ 2- Spouse of head of household /__/ 3- Other (please specify) /________________________________/

1.5-Number of years already spent in the neighbourhood /____/

1.6-Gender of head of household 1- Male/__/ 2- Female /__/

1.7-Level of education of head of household or respondent

1- Not at school /__/ 2 - Primary /__/ 3 - Secondary /__/ 4 - Higher education /__/

1.8-Number of people living in the household /____/

SECTION 2- HOUSEHOLD USE OF PLASTIC

2.1- Do you use plastic in your household? Yes /____/ No /____/

2.2- If yes, for what purpose? /__/

2.3-How often is plastic introduced into your household? /________/

1= every day /__/ 2= once a week /__/ 3 = twice a week /__/ 4= three times a week /__/

2.4- What are the most common types of plastic used in your household?

1= Plastic bags 2= Plastic bottles 3= Slippers 6= Other (specify)

2.5 a-What happens to your plastics after use?

1-sale of plastics /__/ 2-pre-collected by recycling companies /__/ 3-bulking /__/

4-Disposal in the bin /__/ 5-Disposal in the street /__/ 6-Disposal in a pit /__/ 7-Disposal in a rubbish dump /__/ 8-Other (please specify) /__/

2.5 a-In the case of pre-collection, to whom do you invite them?

2.6- Are you aware of the environmental pollution caused by plastic waste?

1-Yes /__/ 2-No /___/

2.7- Did you know that environmental pollution by plastic waste can have serious consequences for human health, animals, the air we breathe and even the plants we eat?

1-Yes /__/ 2-No /__/

2.8-Are you prepared to use other products instead of plastics?

1-Yes /__/ 2-No /__/

2.8a - If yes, (list alternatives to plastics)

2.8 b - If not, why not? /_______________________________________/

ARTICLE 3- PLASTIC MANAGEMENT BY PRODUCER COMPANIES

3.1- company name /___________/

3.2- What is your position within the company?

1-Company manager /__/ 2-Engineer/production manager /__/ 3-technician /__/

4- Labourer /__/ 5-Other /__/

If answer 1, 2, 3, go to interview. If 4, 5, go on to the next question (to be determined according to the design in the kobbotool box).

3.3- What types of plastic waste does your company handle?

1 = PET /__/ 2 = HDPE /__/ 3 = LDPE /__/ 4 = PVC /__/ 5 = elastomer /__/

6 = other (specify) /__/

3.4 Where do you get these materials from?

1= in the wild /__/ 2= from households /__/ 3 = from businesses /__/ 4= other (specify) /__/

3.5- What actions is your company taking?

1 = collection /__/ 2 = purchase /__/ 3 = sale /__/ 4 = pre-treatment /__/ 5 = recovery /__/ 6 = other (specify) /__________/

3.6- How many years have you worked in the plastic waste sector? /_______/

3.7- What exactly do you produce in terms of plastic-based materials? /__/

3.8- Who are your main customers?

1 = local market /__/ 2 = foreign market /__/ 3 = local and foreign markets /__/

3.9 a- Once your products have been delivered to customers, do you have a system for recovering and recycling the plastic waste resulting from their use?

1 = Yes /__/ 2= No /__/

3.9 b- If not, why not?

2.10- What is the purchase cost (per kilo or per tonne) for each type of plastic waste?

3.11- What is your production process from raw material to semi-finished or finished product?

Interview question

3.12-What difficulties do you encounter with your waste suppliers?

3.13-What are the main difficulties encountered in carrying out your activities?

3.14-How do you deal with these difficulties?

3.15-Do you have an environmental permit? If so, which one?

3.16-Do your products comply with one or more standards? If so, which one(s)?

3.17- What do you think about the recycling of plastic waste in Yaoundé? /__________/

3.18- In your opinion, what should be done to improve the management of plastic waste in the city of Yaoundé? /____________/ .

Appendix 2. Characterisation sheet

Header of a waste characterisation sheet

Waste characterisation sheet		
District : Yaoundé 3	Date :23\03\22	Sorter: xxx
Bag drop-off day: xxx Bag collection day: xxx Quantity collected (kg): xxx	Neighbourhood: xxx Standing: xxx	Website: xxx

Showing the weight and percentage of plastic sub-categories

Categories	Subcategories	Weight in Kg	Percentage (%)
	Flexible		

Plastics	Hard		
	Other plastics		

Different numbers identifying types of plastic

Identification	PET(1)	HDPE(2)	PVC(3)	LDPE(4)	PP(5)	PS(6)	OTHER(7)	ELASTOMER	B3E
Weight in Kg									
Percentage (%)									

Identification	polyurethane	TOTAL
Weight in kg		
Percentage (%)		

Net weight :0.610 kg

