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ASSESSMENT OF PLASTIC WASTE ACCUMULATION IN THE DENSU DELTA RAMSAR SITE IN GHANA: A DPSIR APPROACH

BY:

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DECLARATION

I hereby declare that this thesis is the result of my original research conducted under supervision, except for references from other sources which have been duly acknowledged and that this thesis has not been presented in part or whole for the award of a degree in any other institution.

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ABSTRACT

Ramsar sites, wetlands of international importance under the Ramsar Convention, provide numerous benefits such as flood and climate control, water storage and purification and serve as the habitat for native and migratory water birds. However, the sustainability of Ramsar sites is threatened by their high susceptibility to plastic waste accumulation. This study assessed the trend of macroplastic and microplastic accumulation in the Densu Delta Ramsar Site in Ghana, and investigated the perceptions of key stakeholders on plastic waste accumulation using the drivers, pressures (i.e. anthropogenic activities), state, impacts and response (DPSIR) approach. Macroplastic and microplastic accumulation was investigated at three (3) sampling locations in the Ramsar site: Panbros, Tsokome and Densu Estuary. Macroplastic litter monitoring surveys were undertaken within established transects along the bank of the Densu River at the three (3) sampling locations over a three (3)-month period spanning August to October, 2023. For microplastic accumulation assessment, sediment core samples were taken from the three (3) locations and subjected to laboratory analysis to examine their microplastic content while the age determination of the sediment cores was carried out through the deployment of sediment traps. Perception assessment was carried out using questionnaires administered to 397 persons living and/or working within the catchment of the Ramsar site while semi-structured interviews were conducted with six (6) institutions in charge of the protection of the Ramsar site. Across all locations, the total macroplastic litter abundance ranged between 762 to 1908 macroplastic items while total microplastic abundance ranged between 267 to 304. The Densu Estuary sampling location recorded the highest abundance for both macroplastics and microplastics across the three (3) locations, reflecting its status as a hotspot for plastic waste accumulation. The historical trend in microplastic accumulation in the Ramsar site revealed a largely growing abundance from 1975 to 2023, corresponding with the growth in plastic consumption in Ghana from the 1970s to date. Results of the social assessment indicated that the main drivers of plastic waste accumulation are population growth and economic growth associated with the needs for shelter and income respectively, while the main perceived pressures included urban growth activities, petty trading and fishing. The state of plastic waste accumulation was also perceived to be on the rise. Perceived impacts included reduction in the tourism potential of the Ramsar site, adverse impacts on livelihoods such as fishing and reduction in water quality. Key among the response measures suggested by stakeholders included the banning of single-use plastics, attitudinal change towards plastic waste management and provision of waste bins. Recommendations of this study include the phasing out of specific single-use plastics such as plastic carrier bags in Ghana and their replacement with environmentally-friendly alternatives such as paper bags and jute bags. There also needs to be curtailment of plastic importation and the establishment of plastic buy-back centres within the catchment of the Ramsar site and in upstream areas by the government to encourage recycling. Additionally, there should be the strict enforcement of the waste management provisions of the Wetlands (Ramsar Sites) Management Regulations (L. I. 1659) by the government and attitudinal change on the part of persons within the Ramsar site and in upstream areas.

DEDICATION

This thesis is dedicated to the Almighty God, my family: Dr. Ronald Abrahams, Mrs. Grace Abrahams and Mr. Jude Abrahams, and my research supervisors: Prof. Daniel Nukpezah, Dr. Samuel Senyo Koranteng and Dr. Adelina Mensah.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
DPSIR	Driver-Pressure-State-Impact-Response
FTIR	Fourier Transform Infrared Spectroscopy
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
LLDPE	Linear Low Density Polyethylene
NaCl	Sodium Chloride
PE	Polyethylene
PET	Polyethylene Terephthalate
POPs	Persistent Organic Pollutants
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
SDGs	Sustainable Development Goals
UHMWPE	Ultra-High Molecular Weight Polyethylene

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CHAPTER ONE

INTRODUCTION

1.1 Background

Plastics are currently one of the most commonly used materials globally. The massive production and usage of plastics is due to the advantageous qualities they possess: their versatility, durability, insulative ability and relative affordability (Blankson *et al*., 2022; Miranda *et al*., 2019; Thompson *et al*., 2009a). Extensive production of plastics commenced in the 1950s at the end of the Second World War (Andrady & Neal, 2009). Since then, the increase in the world's population and change in lifestyle choices have facilitated the increase in the demand for plastic products (Musah *et al*., 2021). Its extensive usage has contributed to present-day societal development and threatened the use of other materials such as wood, glass and metal for various previously accepted purposes (de Sousa, 2021; Napper & Thompson, 2020). Thus, the use of plastics has pervaded all facets of human living – this is proven by their extensive use in several sectors such as the construction industry, packaging industry, medical field, transportation industry, amongst other diverse fields (Lebreton & Andrady, 2019; Thompson *et al*., 2009b). This widespread production and usage of plastics has led to the naming of these times as the 'Plastic Age' (Thompson *et al*., 2009b).

The extensive use of plastics has however served as a precursor for the generation and release of high volumes of plastic waste into the environment, which in turn causes environmental pollution and negatively affects the wellbeing of biodiversity and the thriving of crucial sectors like the tourism industry (Benyathiar *et al*., 2022; Mattsson *et al*., 2015; Napper & Thompson, 2020). The principal factor accounting for the persistence and harm caused by plastics in the environment is their durability which leads to them taking several years to degrade. Another issue which exacerbates plastic waste accumulation is the manner in which plastics are used. A large proportion of manufactured plastics are discarded after only one use (Musah *et al*., 2021; Thompson *et al*., 2009a). These types of plastics are referred to as single-use plastics. Moreover, the aforementioned issues are compounded by worldwide plastic waste management systems which are largely unsustainable and ineffective. Like the carbon cycle, plastic waste accumulation caused by anthropogenic activities over a long period of time has led to the creation of a 'plastic cycle' which involves the circulation of plastics between land, oceans and the atmosphere (Li *et al*., 2023). Hence, it has become a major issue plaguing the world today due to the detrimental impacts it has on the earth's vital ecosystems and global socio-economic conditions.

Currently, plastic waste is the fourth (4^{th}) largest type of waste generated globally (World Bank Group, 2018). In 2016, worldwide plastic waste production stood at 242 million tonnes and rose to 250 million tonnes by 2018, of which 25.2% was indiscriminately discarded in the environment (World Bank Group, 2018). The yearly generation of plastic waste worldwide experienced a two-fold increment from 156 million tonnes in the year 2000 to 353 million tonnes in the year 2019 (OECD, 2022). It has been predicted that 33 billion tonnes of plastic waste would end up in the environment by 2050 (Andrady, 2011).

In spite of the extensive scope of plastic waste accumulation, there is no United Nations Sustainable Development Goal (SDG) that primarily addresses this, although it has implications on the achievement of a significant number of SDGs (de Sousa, 2021; Walker, 2021). For instance, the accomplishment of Goal Twelve (12) which focuses on the attainment of responsible and sustainable patterns of production and consumption has been jeopardised by the unsustainable manner in which plastics are produced, made use of and discarded (de Sousa, 2021; Walker, 2021). Again, majority of plastics originate from fossil fuels and contain carbon and hydrogen as their main constituents (Andrady & Neal, 2009; Walker, 2021). They also represent approximately 6% of the world's oil consumption (Walker, 2021). This leads to the high contribution of plastics to the emission of greenhouse gases in all stages of its life cycle, thereby threatening the achievement of Goal Thirteen (13) which is concerned with the tackling of climate change and its effects (Walker, 2021). Furthermore, the indiscriminate disposal of plastic litter in the environment and the accumulation of macroplastics and microplastics in aquatic ecosystems threaten the realisation of Goal Six (6) which is aimed at attaining clean water and sanitation for all persons (Walker, 2021). Parts of the targets of Goals Fourteen (14) and Fifteen (15) which focus on preventing the loss of biodiversity in water and on land respectively, are hampered by the plastic waste problem due to the impacts that ingested plastics have on biodiversity. Targets Six (6), Two (2) and One (1) of Goals Six (6), Fourteen (14) and Fifteen (15) respectively, specifically mandate nations to ensure the restoration, protection and sustainable usage of water-associated ecosystems like wetlands. The achievement of these targets has however been impeded by the detrimental effects of plastic waste on the water resources, plants, animal species and overall sustainability of wetlands. This is proven by how microplastics limit the synthesis of chlorophyll and normal height and weight of some wetland plants and by how they also lead to histological changes in the gonads of fish which results in damage to their reproductive ability (Li *et al.*, 2023; Oehlmann *et al.*, 2009; Qiang & Cheng, 2021; Yu *et al.*, 2021).

Wetlands are ecosystems which are characterised by an association between aquatic ecosystems and terrestrial ecosystems (Hu *et al.*, 2017; Huang *et al.*, 2022). They form part of the most important ecosystems globally (Cadier *et al.*, 2020; Hu *et al.*, 2017; Ramsar Convention Secretariat, 2013). They play a key role in the provision of ecosystem services like the provision of food, the control of the occurrence of floods, climate control, serving as the habitat for a wide range of plant and animal species, storage and purification of water, amongst many others (de Groot *et al*., 2012; Ramsar Convention Secretariat, 2013; Russi *et al*., 2013). Coastal wetlands are situated at the transitional zones between terrestrial ecosystems and marine ecosystems (Pérez-Ruzafa *et al*., 2011). In spite of the additional benefits derived from coastal wetlands such as their protection of shorelines from erosion, protection of populated coastal regions from the effects of intense storms and sea waves and serving as the abode for a unique range of biodiversity, they are highly susceptible to various environmental issues such as plastic waste accumulation, especially when they are located close to areas with high human population (Li *et al*., 2023; Ramsar Convention Secretariat, 2013; Reisser *et al*., 2013; Wong *et al*., 2014).

The accumulation of plastic waste in coastal wetlands is largely as a result of the generation and inadequate management of plastic waste from the undertaking of anthropogenic activities such as urban growth activities and fishing in and around coastal wetlands and also through the transport of plastic waste through surface runoff, tidal and wind action and through the flow of rivers and other water bodies (Hu *et al*., 2017; Kumar *et al*., 2021; Li *et al*., 2023; Niu *et al*., 2012; Pérez-Ruzafa *et al*., 2011; Wei *et al*., 2021; Zhou *et al*., 2015). The main categories of plastic debris which are often found in coastal wetlands, and which are hazardous to their wellbeing include plastic bottles, food packaging and carrier bags (Cozzolino *et al*., 2020). When left for long periods of time in the coastal wetlands, such plastic debris usually undergo fragmentation to form microplastics (Li *et al*., 2023). The prevalence of plastic debris in coastal wetlands has adverse effects on their provision of ecosystem services as well as their overall sustainability (Ramsar Convention Secretariat, 2013).

Among the components of coastal wetlands that are negatively impacted by plastic waste are their plant and animal species, soil, sediments and water (Li *et al*., 2023). Animal species such as various kinds of wetland fish and water birds tend to consume plastic debris either in the form of microplastics or macroplastics, leading to malnutrition, suffocation, damage of their reproductive ability and death (Blankson *et al*., 2022; Deng *et al*., 2020; Qiang & Cheng, 2021; Thompson *et al*., 2009a; Werner *et al*., 2016). Microplastic consumption by animal species like fish also poses a threat to other species in their food webs (Li *et al*., 2023; Thompson *et al*., 2009a; Werner *et al*., 2016). The presence of macroplastic debris in aquatic ecosystems also causes fish to get entangled in them, thereby limiting their movement and making them more vulnerable to predators (Nukpezah *et al*., 2022; Werner *et al*., 2016). Macroplastic ingestion by water birds also leads to their starvation and death (Nukpezah *et al*., 2022; Werner *et al*., 2016).

Most studies on the plastic waste problem have been carried out in the marine ecosystem and more recently in terrestrial ecosystems (Li *et al*., 2023; Miranda *et al*., 2019; Thompson *et al*., 2009b; Wagner *et al*., 2014). Conversely, very little research has been conducted on plastic waste accumulation facing transitional ecosystems like coastal wetlands (Kumar *et al*., 2021; Li *et al*., 2023; Ouyang *et al*., 2022). Majority of studies on microplastics largely focus on water, biota and surface sediments and this has resulted in a limited amount of microplastic studies on sediment cores which offer insight into historical trends in microplastic contamination in the environment (Culligan *et al*., 2021). There is limited research on the sources and factors influencing the plastic waste issue in coastal wetlands, its impacts, the perceptions of key stakeholders on the issue, as well as the appropriate policy interventions for addressing it (Kumar *et al*., 2021). With regard to the perceptions of stakeholders, how the plastic waste problem in the coastal environment is perceived, significantly impacts the effectiveness of policy interventions and informal measures by individuals and communities to address it. Very few studies have been found to jointly conduct research on both macroplastics and microplastics as well as the perceptions of key stakeholders on the issue, in spite of its ability to provide comprehensive information on the plastic waste problem in the environment (United Nations Environment Programme, 2020).

1.2 Problem Statement

Ghana's increasing population and the quest to develop convenient and better materials for manufacturing and packaging products for the improvement of quality of life has led to the extensive usage of plastics. The widespread usage of plastics, improper waste discarding habits by the populace and the lack of effective plastic waste management systems in Ghana, has resulted in intense accumulation of plastic waste (Musah *et al*., 2021; World Bank Group, 2020). The National Plastics Management Policy was introduced in 2020 by the Ministry of Environment, Science, Technology and Innovation (MESTI) of Ghana, to ensure the effective and thorough management of plastic waste in Ghana, in order to mitigate the growing environmental problems related to it while fostering sustainable development (Ministry of Environment, Science, Technology and Innovation – Republic of Ghana, 2020).

Despite the introduction of this policy, the plastic waste situation is still prevalent in the country. The plastic waste stream in Ghana has been reported to exceed three thousand (3000) metric tonnes on a daily basis and 1.1 million tonnes on an annual basis (World Bank Group, 2020). In terms of proportion of municipal solid waste in Ghana, plastic waste makes up approximately 14% (Miezah *et al*., 2015; World Bank Group, 2020). The generation of huge volumes of plastic waste in Ghana is compounded by improper plastic waste disposal habits practiced by the Ghanaian populace and the inadequate solid waste management systems in operation in the country (Musah *et al*., 2021; World Bank Group, 2020). Of the large amount of plastic waste produced in Ghana, approximately 86% which corresponds to an annual volume of one (1) million tonnes is improperly discarded

(World Bank Group, 2020). It has also been reported that, plastic packaging forms the majority of plastic waste that is indiscriminately discarded in Ghana (World Bank Group, 2020). Plastic waste which is indiscriminately discarded has continuously had environmental and socio-economic repercussions in Ghana.

Important ecosystems like wetlands, the marine ecosystem and terrestrial ecosystems in Ghana have been greatly affected (Blankson *et al*., 2022; Debrah *et al*., 2021; Musah *et al*., 2021; Nukpezah *et al*., 2022). Additionally, sanitation conditions have deteriorated as a result of indiscriminate discarding of plastic waste into the environment and this has resulted in a spike in sanitation-related diseases like malaria and cholera (Debrah *et al*., 2021; Musah *et al*., 2021; World Bank Group, 2020). The indiscriminate discarding of plastic waste has also resulted in a drop in tourism and caused the blocking of drains which has exacerbated the occurrence of flooding incidents in the country (Musah *et al*., 2021; Werner *et al*., 2016; World Bank Group, 2020).

Ghana has a significant number of wetlands, some of which are internationally recognised as Ramsar sites. A study conducted by Nukpezah *et al*. (2022) at the banks of some lagoons in wetlands along Ghana's eastern coast showed that the plastic waste issue is relatively more prevalent in coastal lagoons which are situated close to densely populated regions. Factors include indiscriminate discarding of plastic waste and lack of effective waste management systems (Nukpezah *et al*., 2022). Such coastal wetlands would experience higher levels of detrimental impacts on their functions and overall sustainability.

Wetlands which have been greatly affected by plastic waste include the Densu Delta Ramsar Site, Sakumo Ramsar Site, Songor Ramsar Site, Keta Lagoon Complex Ramsar Site, amongst others (Nukpezah *et al*., 2022). The Densu Delta Ramsar Site is a coastal wetland located in the western portion of the densely populated coastal capital city of Ghana – Accra. Its close proximity to human settlements and the marine environment makes it highly susceptible to the accumulation of plastic waste (Zhou *et al*., 2015). Environmental contamination studies undertaken in the Ramsar site have been largely focused on assessing the deterioration of the quality of its water resources in terms of its physico-chemical parameters and heavy metal contamination (e.g., Denutsui *et al*., 2011; Osei *et al*., 2010). One crucial but largely neglected environmental issue in the Ramsar site is plastic waste accumulation despite its vulnerability. The Ramsar site has also been recognised as a flood-prone region (Frick-Trzebitzky & Bruns, 2017). The occurrence of flooding either due to heavy rainfall or the occasional spilling of the Weija Reservoir (which is located a few kilometres upstream) exacerbates the plastic waste problem through the transportation of plastic waste from upstream areas to the Ramsar site.

Findings of one of the limited studies conducted so far by Blankson *et al*. (2022) indicates that there is microplastic contamination in surface sediments in the Densu Delta. However, there is a gap in knowledge with regard to the state of macroplastic litter accumulation in the Ramsar site, the historical trend in microplastic accumulation, the polymer composition of the microplastics, the perceived underlying causes and impacts of the problem as well as the advisable measures to put in place to mitigate it (Li *et al*., 2023). To address these gaps, this research therefore seeks to holistically examine the problem of plastic waste accumulation in the Densu Delta Ramsar Site, a coastal wetland situated in Accra, using the Driver-Pressure-State-Impact-Response (DPSIR) model to recommend appropriate measures.

1.3 Research Questions

This research seeks to answer these questions:

1. What is the state of the abundance, diversity and sources of macroplastic litter in the Densu Delta Ramsar Site?
2. What is the microplastic abundance in sediment cores and the historical trend in microplastic accumulation in the Ramsar site?
3. What are the characteristics of microplastics in sediments in the Ramsar site in terms of shape, size, colour and polymer composition?
4. What are the perceptions of stakeholders on the drivers, pressures (anthropogenic activities), state and impacts of plastic waste accumulation in the Ramsar site and the appropriate responses to address this?

1.4 Aim of Research

The principal aim of this research is to assess plastic waste accumulation in the Densu Delta Ramsar Site in Ghana using the Driver-Pressure-State-Impact-Response (DPSIR) approach to recommend solutions.

1.4.1 Specific Objectives

The specific objectives of this research are to:

- Assess the state of the abundance, diversity and sources of macroplastic litter in the Densu Delta Ramsar Site.
- Determine the historical trend in microplastic accumulation in the Ramsar site.
- Characterize microplastics in sediments in the Ramsar site in terms of shape, size, colour and polymer composition.

- Evaluate perceptions of stakeholders on the drivers, pressures (anthropogenic activities), state and impacts of plastic waste accumulation in the Ramsar site and the appropriate responses to address this.

1.5 Justification

Plastic waste accumulation has become an issue of global concern due to the adverse effects it has on several ecosystems worldwide (Fan *et al*., 2019). This is evident in studies which have found negative impacts of plastic debris on water quality, sediments and biota wellbeing in marine and terrestrial ecosystems (Andrady, 2011; Bakir *et al*. 2023; Fan *et al*., 2019). Despite the vital services provided by transitional ecosystems such as coastal wetlands, their proximity to both marine and terrestrial ecosystems make them highly susceptible to the accumulation of plastic waste (Kumar *et al*., 2021; Li *et al*., 2023; Zhou *et al*., 2015).

Various size ranges of plastic debris such as macroplastics and microplastics which accumulate in coastal wetlands result in a diverse range of detrimental effects which eventually lead to a disruption in their provision of ecosystem services (Mattsson *et al*., 2015). According to Barnes *et al*. (2009), macroplastic and microplastic accumulation have steadily increased on shores and in sediments respectively over the last forty (40) years. In order to have a comprehensive understanding of the impact of both macroplastics and microplastics on coastal wetlands, it is important that they are jointly studied (Hoellein & Rochman, 2021; United Nations Environment Programme, 2020). Majority of studies on the plastic waste issue in coastal wetlands however solely focus on studying either macroplastics or microplastics in isolation (Hoellein & Rochman, 2021; United Nations Environment Programme, 2020). Again, to have a holistic understanding of microplastic accumulation in coastal wetlands, it is imperative that the historical trend in microplastic accumulation is studied in long-term environmental sinks such as sediment cores. Most studies on microplastics have however largely focused on relatively short-term sinks such as water, biota and surface sediments and this has resulted in a limited number of studies on microplastics in sediment cores in coastal wetlands despite their ability to shed light on the history of microplastic accumulation (Culligan *et al*., 2021; Yuan *et al*., 2023). Apart from these, the social perceptions of plastic waste accumulation in coastal wetlands in terms of the driving forces, state, impacts as well as the perceptions of the appropriate response to the problem has not been extensively studied.

A review of existing literature revealed a lack of research which combines the study of macroplastics, the historical trend in microplastic accumulation and the social perceptions of the driving forces, state, impacts and potential solutions to the problem in the Ramsar site. This lack of research necessitates the conduct of this study. This research therefore aims to study macroplastic accumulation and the historical trend in microplastic accumulation in the Ramsar site. It also aims to use the Integrated Environmental Assessment framework known as the DPSIR framework to serve as a systematic guide in studying the social perceptions of the driving forces, state, impacts and potential solutions to the plastic waste problem in the Ramsar site. This study would thus provide a holistic understanding of plastic waste accumulation in the Ramsar site. The findings of the study would also inform the recommendation of suitable measures that can be put in place to mitigate this problem, in a manner that strikes a balance between improving quality of life and protecting the Ramsar site's ecosystem health and sustainability.

The response measures will be recommended to key formal institutions as well as informal institutions for the formulation and implementation of policies and informal regulations to curb the problem. Additionally, formal and informal institutions' adoption of the recommended response measures from this research could make headway in the contribution of Ghana's quota to the attainment of the United Nations SDGs regarding the restoration and protection of wetlands and also the attainment of the protection of Ramsar sites under the Ramsar Convention on Wetlands. This research could serve as a pivotal reference point for the future undertaking of Integrated Environmental Assessments of the plastic waste problem in other wetlands.

1.6 Thesis Structure

This thesis is made up of six (6) chapters. Chapter One (1) covers the introduction which is composed of a background providing context for the research, a problem statement, research questions, aim and specific objectives of the research as well as a justification for the conduction of the study. Chapter Two (2) covers the literature review which consists of a detailed review of existing literature on the history of the production of plastics, plastic waste situation worldwide and in Ghana, coastal wetlands and their ecological importance, the effects of plastic waste accumulation on various components of coastal wetlands and a breakdown of the DPSIR conceptual model. The methodology is discussed in Chapter Three (3). This includes an overview of the study area and provision of details on the employed methods as well as materials used for the research. Chapter Four (4) entails a presentation of the findings from the field studies, laboratory work and stakeholder engagement undertaken during this study and an analysis of the data generated from this research. Chapter Five (5) encompasses a discussion of the results of the study as well as its significance and implications. Lastly, Chapter Six (6) covers the summary and conclusions as well as the recommendation of appropriate response measures based on the findings of the study, which can be used by formal and informal institutions to tackle the plastic waste problem facing the Ramsar site.

CHAPTER TWO

LITERATURE REVIEW

2.1 History of the Production of Plastics

The term 'plastic' was derived from the phrase in Greek: 'plasticos' which describes the capability of substances to be malleable enough to be moulded into various shapes when their temperature is sufficiently increased (Kehinde *et al*., 2020). The use of plastics began with the testing of resins, waxes, natural rubber and natural polymers by humans after 1600 BC (Andrady & Neal, 2009). The use of thermoplastics, a type of plastic that can undergo several heating episodes to be remoulded, however started in the nineteenth century (Andrady & Neal, 2009). Thermoplastics like polystyrene was developed in 1839 (Andrady & Neal, 2009). Polyvinyl chloride (PVC) was also invented in 1872 and its large-scale manufacture began in the United States of America in the second half of the 1920s (Andrady & Neal, 2009). The production of present-day plastics grew in the twentieth century with the synthesisation of over fifteen (15) novel polymer groups (Andrady & Neal, 2009). Among the polymers invented in the twentieth century are polyethylene which was invented in 1933, polyethylene terephthalate (PET) invented in 1941 as well as polypropylene which was invented in 1954 and its large-scale manufacture commenced in 1957 (Andrady & Neal, 2009). Production of plastics further intensified at the end of the Second World War in the 1950s, with an estimated yearly production of between one (1) million tonnes and five (5) million tonnes (Andrady & Neal, 2009; Musah *et al*., 2021).

Global manufacturing of plastics has experienced a substantial two hundred (200) fold growth over a time frame of sixty-five (65) years from 1950 to 2015 (Musah *et al*., 2021). In 2016, worldwide yearly production stood at 335 million tonnes (Plastics Europe, 2021). In 2017, it increased to 349 million tonnes (Plastics Europe, 2021). By 2018, this figure had increased to 359 million tonnes (Kim *et al*., 2023; Plastics Europe, 2020; Plastics Europe, 2021). By the following year 2019, the worldwide annual production of plastics was 368 million tonnes (Plastics Europe, 2020; Plastics Europe, 2021). In 2020, it stood at 367 million tonnes (Plastics Europe, 2021). The slowdown in the worldwide production of plastics in 2020 was as a result of the COVID-19 pandemic (OECD, 2022; Plastics Europe, 2022). However, fast growth in worldwide production resumed in 2021 by reaching 390.7 million tonnes (Plastics Europe, 2022). Due to the continuous rise in the demand for plastics, it has been projected that the manufacture of plastics would become twice as much as its current growth rate within two decades (Lebreton & Andrady, 2019). In spite of the several advantages derived from the usage of plastics, it is evident that overdependence on plastics would inevitably lead to the release of huge volumes of plastic waste into the environment (Napper & Thompson, 2020).

2.2 Plastic Waste Globally

Several studies have shown that, there has been a great increase in the demand, production and usage of plastics worldwide (Blankson *et al*., 2022; Miranda *et al*., 2019; Thompson *et al*., 2009a). This is due to the advantageous properties they possess: their versatility, durability, insulative ability and relative affordability (Blankson *et al*., 2022; Miranda *et al*., 2019; Thompson *et al*., 2009a). Other studies have also attributed the high demand to the sharp increase in the world's population and current lifestyle choices (de Sousa, 2021; Musah *et al*., 2021). The extensive production and usage of plastics – particularly, single use plastics and the lack of effective plastic waste management practices, has inevitably led to the generation and release of huge volumes of plastic waste into the environment (Lebreton & Andrady, 2019; Mattsson *et al*., 2015; Musah *et* *al*., 2021; Napper & Thompson, 2020). Plastic waste has been reportedly found in the most remote of environments such as the bottom of oceans and the apex of mountains (Kukkola *et al*., 2022). This serves as an indicator of the expansive nature of the plastic waste problem. Plastic waste generation is expected to exponentially rise due to the predicted growth in the demand and consumption of plastic products (Lebreton & Andrady, 2019).

Of all solid waste produced worldwide, plastic waste is the fourth (4^{th}) largest waste produced yearly (Musah *et al*., 2021). According to Lebreton & Andrady (2019) as well as Benyathiar *et al*. (2022), the main types of polymers that constitute municipal waste are PET, polypropylene, polystyrene and polyethylene. One of the manufacturing sectors that utilises the most plastics is the packaging industry (Mattsson *et al*., 2015). A study by Benyathiar *et al*. (2022) indicates that, packaging made from plastics represents 70% of the consumer products market. For this reason, municipal waste is typically composed of a large percentage of packaging-associated plastic waste (Lebreton & Andrady, 2019). In 2015 for example, the packaging industry produced 141 million tonnes of plastic waste which made it the industry that produced the largest amount of plastic waste globally that year (Musah *et al*., 2021). Plastic products used for a period lesser than five (5) years make up more than half of the total plastic waste produced worldwide (OECD, 2022). Of this proportion, packaging waste makes up 40% while textiles and consumer products waste make up 11% and 12% respectively (OECD, 2022). In 2016, the total amount of plastic waste produced globally was 242 million tonnes and by 2018, this figure rose to 250 million tonnes (Musah *et al*., 2021). Of the 2018 figure, 25.2% was indiscriminately discarded in the environment (Musah *et al*., 2021). OECD (2022) indicated that the yearly generation of plastic waste worldwide experienced a two-fold increment from 156 million tonnes in the year 2000 to 353 million tonnes in the year 2019. It has been projected that by 2050, about 33 billion tonnes of plastic debris would end up in the environment (Andrady, 2011).

Lebreton & Andrady (2019) highlighted Asia, Europe and America as principal generators of plastic waste. In the United States of America for example, 35.7 million tonnes of plastic debris was produced in the year 2018 (Benyathiar *et al*., 2022). Of this figure, 18.5% was disposed of in landfill sites, 4.5% underwent recycling and a more significant percentage is suspected to have ended up in the environment both through direct and indirect means (Benyathiar *et al*., 2022). Africa's high generation of plastic waste is evident in the 174 million tonnes of solid waste which was produced in Sub-Saharan Africa in 2016, of which a large portion is plastic waste (Lebreton & Andrady, 2019; Musah *et al*., 2021). It is projected that this figure would triple by the year 2050 due to the exponential growth in Sub-Saharan Africa's population and development of its urban areas (Musah *et al*., 2021). This high plastic waste generation rate creates an issue of concern since the predominant mode of solid waste disposal in Sub-Saharan Africa is dumping in open areas and un-engineered landfill sites (Musah *et al*., 2021).

Of all plastic waste generated globally, the rate of improperly disposed plastic waste is highest in Africa and Asia (Lebreton & Andrady, 2019). Asia's rate of improper disposal of plastic waste is generally consistent with their rate of production of plastics (Lebreton & Andrady, 2019). Africa's huge rate of indiscriminate disposal is however inconsistent with its relatively low production rate (Lebreton & Andrady, 2019). Schmidt (2006) and Walker (2021) largely attributed the disproportionately high rate of improper disposal of plastic waste in Africa to the importation of different forms of plastic waste into Africa from developed countries. The improper plastic waste management witnessed around the world today is an indication of the global challenge faced in producing, using and discarding plastics in an environmentally sound manner (Walker, 2021). The global occurrence of indiscriminate release of large volumes of plastic waste has resulted in the permeation of plastic waste into almost all vital ecosystems worldwide, thereby causing repercussions on the provision of crucial ecosystem services. Organisations like the European Union have however proposed means by which plastic waste discharge into the environment can be minimised; the proposed methods include: encouraging attitudinal change among consumers through the use of incentives and enhancing the efficiency and quantity of waste management systems (Benyathiar *et al*., 2022).

2.2.1 Plastic Waste in Ghana

Ghana is faced with the pressing issue of intense release of huge volumes of plastic waste into the environment due to the improper solid waste management systems in the country (Fobil & Hogarh, 2006; Musah *et al*., 2021; World Bank Group, 2020). This situation in Ghana has also been attributed to the mass importation as well as domestic production of plastics in the country and the way in which plastic products are used and discarded (Fobil & Hogarh, 2006; World Bank Group, 2020). A larger proportion of plastics imported into Ghana are discarded after only one use with only a small percentage undergoing recycling (Musah *et al*., 2021). This is evident in the reported 73% of yearly raw plastics imports which end up being discarded as waste and the estimated 2 to 5% of all plastic waste generated in the country which undergoes recycling (Musah *et al*., 2021; World Bank Group, 2020). According to Owusu-Sekyere *et al*. (2013), plastic composition in Ghana's waste stream was 1.4% in 1979 and increased to 4% by 1993. By 1997, it represented 5% of the national waste stream and in the year 2000, it rose to 8% (Owusu-Sekyere *et al*., 2013). World Bank Group (2020) reports that, plastic waste currently produced in the country daily is above three thousand (3000) tonnes and 1.1 million tonnes annually. These figures account for averagely 14% of Ghana's waste stream (Miezah *et al*., 2015; World Bank Group, 2020). The main methods by which solid waste is disposed of in Ghana are via landfill sites which are largely un-engineered, large public waste disposal containers placed in some communities, deposition in open dumpsites which undergo periodic burning and indiscriminate disposal into the open environment (Musah *et al*., 2021; World Bank Group, 2020). There is the lack of well distributed provision of sustainable solid waste disposal avenues in the country (World Bank Group, 2020). This has resulted in the development of improper waste disposal habits among the Ghanaian populace.

Approximately 86% of all plastic debris produced in Ghana, which corresponds to an annual volume of one (1) million tonnes is indiscriminately discarded (World Bank Group, 2020). Of this amount, plastic packaging is the most dominant category (World Bank Group, 2020). Indiscriminately discarded plastic waste in Ghana ends up in crucial ecosystems like wetlands and terrestrial water bodies like rivers which ultimately flow into the Atlantic Ocean (World Bank Group, 2020). A report by World Bank Group (2020) states that the volume of plastic debris which finds its way into the Atlantic Ocean is estimated to range between ninety-two thousand (92,000) and two hundred and sixty thousand (260,000) tonnes annually. Plastic waste which ends up in drainage systems causes the blocking of the drain channels which inevitably results in the rampant incidence of flooding (Debrah *et al*., 2021; Musah *et al*., 2021; World Bank Group, 2020). Again, it greatly contributes to the poor sanitation conditions prevalent in Ghana and exacerbates the occurrence of illnesses like malaria and cholera by facilitating the creation of breeding sites for disease-causing organisms like mosquitoes and cholera-causing bacteria (Debrah *et al*., 2021; Musah *et al*., 2021; World Bank Group, 2020). The practice of openly burning plastic waste has implications on air quality conditions in the country due to the emission of greenhouse gases which also gives rise to the occurrence of climate change (World Bank Group, 2020). Tourist sites littered with plastic debris are also faced with a drop in their tourism potential (Musah *et al*., 2021).

The main governmental institutions primarily in charge of the management of plastic waste in Ghana include the Ministry of Environment, Science, Technology and Innovation, Ministry of Sanitation and Water Resources, the Ministry of Local Government, Decentralisation and Rural Development and its associated district assemblies and the Environmental Protection Authority (World Bank Group, 2020). There are also other institutions like the Water Resources Commission and Wildlife Division of Forestry Commission, who are indirectly responsible for ensuring the protection of specific areas like water bodies and wetlands respectively from plastic waste contamination. Effective undertaking of the duties of these institutions is however impeded by their shared mandate in managing plastic waste (World Bank Group, 2020). Other institutional problems accounting for the poor management of plastic waste in Ghana are insufficient resources as well as inadequate formulation and ineffective execution of policies pertaining to the importation, production, use and disposal of plastics (World Bank Group, 2020). In the year 2020, the Ministry of Environment, Science, Technology and Innovation introduced the National Plastics Management Policy to ensure the effective management of plastic waste in Ghana in order to tackle the rising environmental issues related to plastic waste accumulation (Ministry of Environment, Science, Technology and Innovation – Republic of Ghana, 2020). However, the management of plastic waste in Ghana remains a persistent problem, especially in vital ecosystems like wetlands, necessitating the conduction of this study.

2.3 Composition and Properties of Plastics

Plastics are composed of polymers which are defined as molecules that are interconnected to create long chains, consisting of recurring duplicate chemical structures (Kehinde *et al*., 2020; Napper & Thompson, 2020). These polymers originate predominantly from organic and semi-organic compounds (Kehinde *et al*., 2020; Napper & Thompson, 2020). The organic compounds from which plastics are typically produced from are the liquid component of natural gas and gas of lower quality derived from the refinement of petroleum (Lebreton & Andrady, 2019). A large number of polymers have hydrogen and carbon as their major constituents (Andrady & Neal, 2009). However, some polymers like polyvinyl chloride (PVC) possess chlorine in addition to their hydrogen and carbon (Andrady & Neal, 2009).

As stated earlier, plastics are inherently versatile, light, durable, equipped with an insulative ability, and are relatively affordable (Andrady & Neal, 2009; Blankson *et al*., 2022; Miranda *et al*., 2019; Napper & Thompson, 2020; Thompson *et al*., 2009a). To improve the appearance and durability of plastics, certain substances known as plastic additives are usually added to them (Andrady & Neal, 2009; Miranda *et al*., 2019; Wagner *et al*., 2014; Werner *et al*., 2016). Plastic additives like silica and carbon are added to strengthen plastics; other additives like colour, opacifying and matting additives are added to improve their look while others are added to balance their thermal properties and to improve their resistance to the effects of prolonged exposure to sunlight; again, others known as plasticisers are included to enhance their ability to be flexible and easily moulded during processing (Andrady & Neal, 2009; Sastri, 2010). Due to the high cost of plastic additives, the lowest amount required to attain the desired look and durability of plastics is usually applied (Andrady & Neal, 2009).

The composition and properties of plastics, as well as their grouping into plastic types is environmentally relevant due to the differences in their modes of persistence and degradation to form microplastics in the natural environment (Andrady, 2011; Mattsson *et al*., 2015). The categorisation is vital for studies aimed at characterising types of polymers in environmental samples.

2.4 Types of Plastics

According to Kehinde *et al*. (2020), there are three (3) main groups of plastics namely: natural plastics, synthetic plastics and semi-synthetic plastics. Natural plastics refer to natural materials which become malleable enough to be moulded into various shapes, when they are exposed to increased temperature (Kehinde *et al*., 2020). Synthetic plastics which are the largest group of plastics, refer to plastics derived from the carrying out of decomposition processes on petroleum products like crude oil, coal and natural gas (Andrady & Neal, 2009; Kehinde *et al*., 2020). Semi-synthetic plastics refer to plastics acquired from the application of chemical procedures and substances to natural plastics (Kehinde *et al*., 2020).

In terms of the manner in which synthetic and semi-synthetic plastics respond to increased temperature, they can be further grouped into thermoplastics and thermosetting plastics (Kehinde *et al*., 2020). Thermoplastics and thermosetting plastics are differentiated based on the fact that, thermoplastics can be exposed to multiple episodes of increased temperatures for the purpose of remoulding while thermosetting plastics have the ability to be malleable only once when exposed to increased temperature (Kehinde *et al*., 2020). Subsequent exposure of thermosetting plastics to multiple episodes of heating would result in them becoming brittle (Kehinde *et al*., 2020). Several studies such as Andrady & Neal (2009) and Napper & Thompson (2020) have also grouped plastics according to the types of polymers they are composed of. The principal types of polymers are five (5) in number namely: polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), polyethylene terephthalate (PET) and polystyrene. These types of polymers are often expanded and considered to be seven (7) in number as follows: polypropylene (PP), low density polyethylene (LDPE), high density polyethylene (HDPE), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polystyrene (PS) and a last type referred to as 'other' which encompasses lesser known polymers which do not fall under the aforementioned six (6) types (Yani *et al*., 2020). The five (5) main types of polymers previously mentioned fall within the category of thermoplastics and are usually specifically termed as commodity thermoplastics due to their extensive usage (Sastri, 2010). Commodity thermoplastics possess advantageous properties and are relatively affordable (Sastri, 2010). Plastic classification plays an important role in the determination of their durability, possibility of them undergoing fragmentation to form microplastics and their environmental impacts. However, there is limited research on polymer composition of plastic waste in sensitive ecosystems like wetlands, which may be caused by plastic waste management practices.

2.4.1 Polypropylene (PP)

Polypropylene (PP) is one of the most commonly used polymers for plastic production (Andrady & Neal, 2009). Among the major types of thermoplastics, it is the least dense (Andrady, 2015). Polypropylene polymerisation is usually undertaken with metallocene catalysts or Ziegler-Natta catalysts (Andrady, 2015; Sastri, 2010). Andrady (2015) and Sastri (2010) highlight that this polymer is generally known for its light weight, toughness, impressive dielectric properties, transparency, high thermal resistance and high resistance to water and chemical absorption. Sastri (2010) states that there are three (3) main grades of PP namely: atactic PP, isotactic PP and syndiotactic PP. The variations in the polymer structures of the three (3) grades of PP causes them to have differing mechanical and physical properties (Sastri, 2010).

Atactic PP possesses considerable elastomeric properties and is non-crystalline; isotactic PP is relatively dense, is semi-crystalline, tough and possesses high tensile strength, high melting point and high resistance to chemicals; syndiotactic PP on the other hand possesses substantial elastomeric properties, is transparent and is relatively more ductile in comparison to isotactic PP (Sastri, 2010). The most extensively used grade is isotactic PP and the least used grade is atactic PP (Sastri, 2010). Polypropylene grades like syndiotactic PP are manufactured with metallocene catalysts (Andrady, 2015). Such PP grades are greatly employed in high-end purposes (Andrady, 2015). Apart from the advantageous properties of PP, Andrady & Neal (2009) also emphasise that other reasons accounting for its widespread usage are its cost effectiveness and its ability to be thermoformed, injection moulded, extruded and blow moulded for the manufacture of various items in the food packaging industry, agricultural sector, construction industry, amongst other diverse sectors. Polypropylene is employed in the manufacture of plastic containers such as bowls, trays and bottles (Andrady, 2015; Andrady & Neal, 2009). Again, it is employed in the production of mulch films, toys, soil sieves, textile fibre, vehicle components, door frames, pipes and window frames (Andrady, 2015; Andrady & Neal, 2009). They are also used in the medical sector for the production of medical tubes and trays, syringes and blister packs (Sastri, 2010).

2.4.2 Polyethylene (PE)

Polyethylene (PE) is another very commonly used polymer worldwide (Andrady & Neal, 2009). Similar to polypropylene, it is also cost effective (Andrady & Neal, 2009). Polyethylene is manufactured from the ethylene monomer which is obtained from natural gas and other fossil fuels

(Andrady, 2015). Andrady & Neal (2009) and Sastri (2010) indicate that there are five (5) main grades of PE based on mean density namely: low density polyethylene (LDPE), linear low density polyethylene (LLDPE), medium density polyethylene (MDPE) and high density polyethylene - HDPE. Ultra-high molecular weight polyethylene (UHMWPE) is also considered as another grade of PE (Sastri, 2010).

Low density polyethylene (LDPE) is formed from the subjection of ethylene to relatively higher pressures (Andrady, 2015; Sastri, 2010). As the name implies, this type of PE possesses low density and low crystallinity (Sastri, 2010). Low density polyethylene (LDPE) has high resistance to water absorption, chemicals and corrosion and is flexible, affordable and has impressive dielectric properties; it however has a tensile strength which is low and it also has the tendency of cracking under stress (Sastri, 2010). Linear low density polyethylene (LLDPE) is a durable type of PE which is made with the help of sophisticated catalyst systems (Andrady, 2015). This type of PE comprises many short chain branches on the backbone of the polymer (Andrady, 2015; Sastri, 2010). The short chain branches reduce the occurrence of packing and alignment of chains; however, the chains are largely linear (Sastri, 2010). Thus, the key difference between LLDPE and LDPE is the observed relatively shorter chain branching in LLDPE which contrasts with the relatively longer chain branching present in LDPE (Andrady, 2015; Sastri, 2010). A more recently formulated group of metallocene catalysts is also being used to produce a new type of LLDPE known as the Metallocene Linear Low Density Polyethylene (mLLDPE), which possesses superior homogeneity in its molecular structure in comparison to the usual LLDPE (Andrady, 2015). Metallocene Linear Low Density Polyethylene (mLLDPE) is more durable and this enables it to be used for the production of thin packaging films (Andrady, 2015; Sastri, 2010).

High density polyethylene (HDPE) is produced from the subjection of ethylene to relatively lower pressures, in the presence of catalysts like Ziegler-Natta catalysts (Andrady, 2015; Sastri, 2010). The polymerisation of HDPE at low pressures reduces its extent of chain branching to approximately four (4) to ten (10) short chain branches on the backbone of the polymer (Andrady, 2015; Sastri, 2010). The smaller number of short chain branches permits the packing and alignment on the backbone of the polymer, which in turn leads to the creation of a plastic material which is crystalline and has a substantially high density (Andrady, 2015; Sastri, 2010). High Density Polyethylene (HDPE) possesses high resistance to chemicals, has great toughness, is affordable, has favourable dielectric properties and is relatively easy to extrude and mould (Sastri, 2010). Ultra-high molecular weight polyethylene (UHMWPE) is a type of linear PE which possesses short chain branches on the backbone of the polymer (Sastri, 2010). As the name implies, this type of PE has an extremely high molecular weight of a value between two (2) million and six (6) million (Sastri, 2010). This equips it with very high durability in comparison to other PE types (Sastri, 2010). Ultra-high molecular weight polyethylene (UHMWPE) is highly resistant to chemicals, abrasion and cracking (Sastri, 2010). It is used in the medical sector for the manufacturing of components for knee, hip and shoulder joint replacement (Sastri, 2010).

Andrady & Neal (2009) reports that there are approximately twenty-five (25) methods by which the various grades of PE can be produced. Approximately 40% of manufactured PE undergoes blow-moulding for the production of bottles while an estimated 15% is dedicated to the production of plastic film and the remaining percentage undergoes extrusion and injection moulding for the creation of pipes (Andrady, 2015). Polyethylene (PE) is used for manufacturing other goods such as electric cables, cling wrap, carrier bags and irrigation pipes (Andrady & Neal, 2009). Low density polyethylene (LDPE) and LLDPE are mainly employed in the manufacture of plastic film, plastic covering for cables and a smaller percentage is employed in the production of plastic containers (Andrady, 2015). High density polyethylene (HDPE) is used for the production of liquid-holding containers like milk jugs due to its superior specific strength and relatively high resistance to water absorption (Andrady, 2015).

2.4.3 Polyvinyl Chloride (PVC)

Polyvinyl chloride (PVC) is a durable and widely used thermoplastic (Andrady, 2015). It is produced from the vinyl chloride monomer which is gaseous under room temperature conditions (Sastri, 2010). Vinyl chloride can be produced exothermically by two (2) means: the first method is undertaken through the chlorination of ethylene with the aid of iron salt catalyst while the second method is undertaken through the oxychlorination of ethylene which involves the addition of cupric chloride ($CuCl_2$) and hydrochloric acid (HCl) (Andrady, 2015). The polymerisation of vinyl chloride occurs as a result of the polymerisation of free radicals through emulsion method, suspension method, solution method and bulk method (Sastri, 2010). Polyvinyl chloride (PVC) is relatively easier to process, is durable, accommodates a significant temperature range, has high resistance to chemicals and water absorption, is attractive in appearance and is also relatively affordable (Sastri, 2010). Again, it is versatile and is capable of being combined with a wide variety of plastic additives (Andrady, 2015; Sastri, 2010). This enables the production of different types of PVC with a corresponding wide variety of properties (Andrady, 2015; Sastri, 2010).

Polyvinyl chloride (PVC) can be either hard and stiff or soft and flexible (Sastri, 2010). Polyvinyl chloride (PVC) which contains plasticisers tends to be relatively soft and flexible while PVC which does not contain plasticisers are relatively hard (Sastri, 2010). Unplasticised PVC has however been found to have relatively higher resistance to chemicals than plasticised PVC (Sastri, 2010).

Polyvinyl chloride (PVC) contains chlorine which equips it with fire resistant abilities, making it the preferred choice for a large number of purposes in the construction industry (Andrady & Neal, 2009; Sastri, 2010). This is seen in its use for the production of water pipes and components of windows and furniture (Andrady, 2015; Andrady & Neal, 2009). Sastri (2010) documents its extensive use in the medical field for the production of equipment and materials like gloves, equipment for oxygen delivery, equipment for carrying out dialysis, masks and bags for containing blood. Its usage in the medical field accounts for an estimated 25% of plastic medical materials and equipment (Sastri, 2010). Polyvinyl chloride (PVC) which contains plasticisers is employed in the insulation of wires and for the making of packaging for products (Andrady, 2015; Sastri, 2010). In spite of the benefits derived from PVC, its production poses a threat to the environment and human wellbeing (Andrady, 2015). Its production is often accompanied by the release of toxic volatile gases (Andrady, 2015). Again, the monomer of PVC as well as some of the plasticisers used in the production of PVC have been found to be carcinogenic and also capable of interfering with the function of some hormones in the human body (Andrady, 2015; Sastri, 2010).

2.4.4 Polyethylene Terephthalate (PET)

Polyethylene terephthalate (PET) is a commonly used polyester thermoplastic (Benyathiar *et al*., 2022; Olam, 2021; Panowicz *et al*., 2021). The principal polymer structure of PET contains benzene which makes the polymer tough and slows down the rate at which it crystallises during cooling (Benyathiar *et al*., 2022; Olam, 2021). The initial product of polymerisation of PET is in a viscous liquid state which then undergoes blow moulding, injection moulding or extrusion to produce a final product (Olam, 2021). There are two (2) main forms of PET based on the type of processing and thermal conditions they are subjected to; the two forms are: the semi-crystalline form and the non-crystalline (amorphous) form (Benyathiar *et al*., 2022; Olam, 2021; Panowicz *et al*., 2021). Amorphous PET is transparent while semi-crystalline PET is opaque (Panowicz *et al*., 2021). Semi-crystalline PET however possesses a relatively more complex polymer structure than amorphous PET (Panowicz *et al*., 2021).

Several studies have discussed the beneficial characteristics of PET including its light weight, durability, transparency (in the case of amorphous PET), high dimensional stability, attractive appearance, high processability and impressive resistance to chemicals, ultraviolet radiation and the penetration of water and gas (Andrady & Neal, 2009; Benyathiar *et al*., 2022; Olam, 2021; Panowicz *et al*., 2021). These characteristics have greatly contributed to the preference of PET for the manufacture of beverage bottles and other types of packaging such as films (Andrady & Neal, 2009; Benyathiar *et al*., 2022; Geyer *et al*., 2017; Olam, 2021). Olam (2021) reveals that, the market for PET packaging worldwide has been calculated to be worth approximately 64.5 billion dollars as at 2020 and is projected to increase to 82.9 billion dollars in 2027. Apart from the packaging industry, PET is useful in the electronic and automotive fields for purposes such as the manufacture of electrical components such as cables and automotive products like tyres, vehicle carpets, fuel filters and air bags (Olam, 2021; Panowicz *et al*., 2021). Again, it is employed in the manufacture of clothing fibre and also used as construction material (Olam, 2021; Panowicz *et al*., 2021). Other factors responsible for the extensive usage of PET are: its ability to be recycled and its reputation as being the environmentally-friendly synthetic polymer since its only principal by-product during its manufacturing is water (Benyathiar *et al*., 2022; Olam, 2021). Conversely, the resultant extensive usage of PET creates the problem of the generation of huge volumes of PET waste, most of which finds its way into the open environment (Benyathiar *et al*., 2022). Similar to other types of polymers, PET takes many years to degrade (Benyathiar *et al*., 2022; Olam, 2021).

2.4.5 Polystyrene (PS)

Polystyrene (PS) is a commonly used thermoplastic (Sastri, 2010). Polystyrene (PS) is generally known for its relatively low density and affordability (Sastri, 2010). Production of PS is undertaken by polymerising the styrene monomer at 120°C with the aid of free radicals, free-radical initiator and diluents (Sastri, 2010). Just like the other types of polymers described, PS has different grades (Andrady & Neal, 2009; Sastri, 2010). The three (3) main grades of PS are general purpose grade, expanded PS and high impact grade (Andrady & Neal, 2009; Sastri, 2010). In terms of polymer chain arrangement, PS is grouped into atactic PS, syndiotactic PS and isotactic PS, of which atactic PS is the most extensively used (Sastri, 2010). Again, expanded PS is one of the most used types of PS (Andrady, 2015). This type of PS possesses impressive shock absorbing abilities and high thermal insulative abilities (Andrady, 2015).

A large portion of manufactured PS is channeled into the creation of packaging for food products (Andrady, 2015). This is evident in the heavy reliance on expanded PS for making carry-out plastic containers for food, for making plastic soup bowls and plates and for manufacturing plastic products for serving hot beverages (Andrady, 2015). A significant amount of food packaging products made from PS are designed for single-use purposes (Andrady, 2015). Again, expanded PS is used in the construction industry due to its insulative ability and also used for manufacturing packaging for items such as washing machines and television sets (Andrady & Neal, 2009). General purpose grade of PS is equipped with high resistance to water absorption, high processability and dimensional stability, impressive dielectric characteristics, affordability and an attractive appearance (Sastri, 2010). It is employed in the manufacture of diverse items such as cutlery, packaging and diagnostic labware for the medical sector (Sastri, 2010).

High impact grade of PS is a translucent PS which is produced by undertaking polymerisation of styrene using 5 to 10% polybutadiene rubber and approximately 25% acrylonitrile, to make it more durable (Andrady, 2015; Andrady & Neal, 2009; Sastri, 2010). High impact PS is noted for its durability, high resistance to water absorption, significant dimensional stability, relative affordability and high processability and this has led to its usage for structural purposes that need machinability and high resistance to impact (Andrady, 2015; Andrady & Neal, 2009; Sastri, 2010). It is also employed in the manufacture of medical trays, plastic toys, bowls, lining of refrigerators, amongst others (Andrady, 2015; Andrady & Neal, 2009; Sastri, 2010). Atactic PS is a type of PS which is transparent and possesses considerable resistance to chemicals and water absorption (Andrady, 2015). In spite of these desirable properties of atactic PS, its large-scale usage for a variety of purposes is hampered by its brittle nature (Andrady, 2015). Syndiotactic PS undergoes synthesisation with metallocene catalysts (Andrady, 2015; Sastri, 2010). Syndiotactic PS also has the tendency of becoming brittle but this can be mitigated by combining it with another polymer or glass to increase its level of durability (Sastri, 2010). In addition to the ability to increase the durability of syndiotactic PS, it is again equipped with desirable mechanical, chemical and thermal properties such as its significant melting point of 270°C, high processability and high resistance to chemicals (Andrady, 2015; Sastri, 2010).

Plate 2.1 is an image showing examples of plastic products made from the various polymer types.

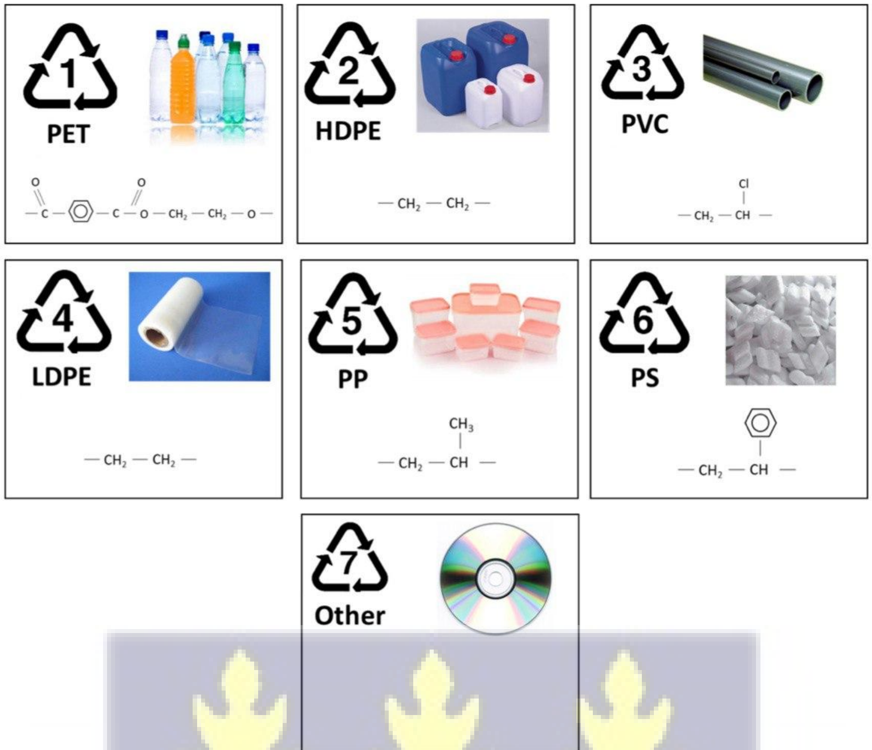


Plate 2.1: Examples of Plastic Products Made from the Various Polymer Types

Source: Dris (2016)

2.5 Degradation of Plastic Waste

Plastic degradation refers to the physical and chemical breakdown of plastic debris (Andrady, 2011; Mattsson *et al*., 2015). The process of degradation of plastics generally takes several years to occur due to their durability (Musah *et al*., 2021). The chemical breakdown of plastic debris often results in a decrease in their mean molecular weight (Andrady, 2011). A completed process of plastic degradation in which all of the carbon content of a plastic material has been transformed into biomass, carbon dioxide (CO_2) and water is termed as complete mineralisation (Andrady, 2011). However, it is worth noting that complete mineralisation of plastic waste is rarely achieved in the natural environment. There are seven (7) main ways in which plastic waste undergoes degradation. They are: mechanical degradation, thermal degradation, photodegradation, photo-oxidative degradation, hydrolysis, thermo-oxidative degradation and biodegradation (Andrady, 2011).

Mattsson *et al*. (2015) defines mechanical degradation as a form of breakdown of plastics which is caused by physical processes such as abrasion and intense water currents. Thermal degradation refers to the human-induced breakdown of plastic debris caused by subjection to high heat (Andrady, 2011; Mattsson *et al*., 2015). Andrady (2011) defines photodegradation as plastic breakdown through exposure to ultraviolet radiation from the sun. Photo-oxidative degradation refers to plastic breakdown in the presence of oxygen and ultraviolet radiation from the sun. Hydrolysis is a form of plastic degradation caused by its interaction with water (Andrady, 2011; Mattsson *et al*., 2015). Thermo-oxidative degradation is plastic breakdown facilitated by mild heat and oxygen (Andrady, 2011). Biodegradation on the other hand refers to the breakdown of plastics through the activity of living organisms, especially microorganisms (Andrady, 2011; Mattsson *et al*., 2015). In comparison to the other forms of plastic degradation, biodegradation tends to be one of the slowest, while photo-oxidative degradation tends to be one of the fastest (Andrady, 2011).

A decrease in the concentration of oxygen and intensity of heat greatly hampers the occurrence of plastic debris degradation especially in a marine setting (Andrady, 2011; Mattsson *et al*., 2015). Lebreton & Andrady (2019) emphasised that parts of the world which experience relatively high ultraviolet radiation from the sun and high temperatures such as Africa, are more likely to facilitate the degradation of plastics. Thus, the rate at which a plastic material degrades depends on the type of environment and the type of plastic material (Andrady, 2011; Mattsson *et al*., 2015). The degradation of polymers like polypropylene, high and low density polyethylene and nylon, usually commences with photo-oxidative degradation and is followed by thermo-oxidative degradation (Andrady, 2011). The occurrence of plastic waste degradation is largely responsible for the variety of sizes of plastic waste found in the environment (Mattsson *et al*., 2015).

2.6 Size Ranges of Plastic Waste

Plastic waste is loosely grouped into two (2) classes based on sizes as macroplastics and microplastics. Macroplastics as the name denotes, refers to plastic waste that is relatively large in size (United Nations Environment Programme, 2020). Specifically, macroplastics are greater than five (5) millimetres (mm) in diameter (Munier & Bendell, 2018). Microplastics on the other hand refers to plastic debris that are less than five (5) mm in diameter (Blankson *et al*., 2022; GESAMP, 2016; Miranda *et al*., 2019; Munier & Bendell, 2018; United Nations Environment Programme, 2020). Microplastics can be further grouped into large microplastics which span 5 to 1 mm in diameter; small microplastics span 1 to 0.0001 mm while nanoplastics are between 100 nanometres and 1 nanometre (Blankson *et al*., 2022; Eriksen *et al*., 2014; Mattsson *et al*., 2015; Musah *et al*., 2021).

More detailed groupings for plastics were proposed by Ryan *et al*. (2009), Barnes *et al*. (2009) and Mattsson *et al*. (2015). The grouping by Ryan *et al*. (2009) entailed macroplastics being described as plastics greater than 20 mm in diameter, mesoplastics ranging from 20 to 2 mm and microplastics being less than 2 mm in diameter while the grouping by Barnes *et al*. (2009) provided a modified version: megaplastics being greater than 100 mm in diameter, macroplastics being between 100 and 20 mm, mesoplastics ranging between 20 and 5 mm and microplastics being smaller than 5 mm in diameter. According to Mattsson *et al*. (2015), the most widely used size definition for plastic litter is: mesoplastics as plastics with a diameter larger than 5 mm, microplastics as plastics ranging between 5 and 1 mm and nanoplastics as plastics between 100 nanometres and 1 nanometre. Aside these, there are other different plastic size classifications proposed by other researchers (Mattsson *et al*., 2015). However, in literature, the sub-groups of the larger plastics: mesoplastics and megaplastics are rarely used (United Nations Environment Programme, 2020). In the present study, macroplastics refer to plastic debris larger than 5 mm in diameter while plastic debris smaller than 5 mm are referred to as microplastics. This definition was chosen because it is a standard definition widely used in literature.

2.6.1 Macroplastics

Due to their relatively large sizes, macroplastics are the most visible form of plastic waste (Barnes *et al*., 2009; Napper & Thompson, 2020; Ryan *et al*., 2009). Macroplastic accumulation is an extensive occurrence globally that wreaks havoc in crucial ecosystems, national economies and the global economy. The substantial sizes of macroplastics, coupled with their impermeability is largely responsible for the regular incidence of flooding in countries where indiscriminate discarding of plastic waste is prevalent. Despite these, their large sizes enable relatively easier identification of the purpose for which the plastic material was used for before disposal (Napper & Thompson, 2020). Again, their large sizes make them relatively easier to be managed through clean-up programmes (Napper & Thompson, 2020).

Macroplastics in environments such as coastal areas are often monitored through litter surveys. Nukpezah *et al*. (2022) and OSPAR Commission (2010) demonstrate that litter surveys involve the determination of the abundance, diversity and sources of various types of debris such as macroplastics, metal, paper, glass, amongst others. Abundance is the overall quantity of litter at a given sampling location and diversity on the other hand is the range of litter types at a given location (Nukpezah *et al*., 2022). In litter surveys in coastal areas which involve the assessment of all types of debris, macroplastic debris often constitutes between 50 and 80% (Barnes *et al*., 2009; Nukpezah *et al*., 2022; Thompson *et al*., 2009a). Other types of coastal litter surveys focus on the determination of the abundance, diversity and sources of solely macroplastic litter (Blettler *et al*., 2017; Sajorne *et al*., 2021). There are two (2) main types of litter surveys namely: accumulation surveys and standing-stock surveys (Nukpezah *et al*., 2022; Opfer *et al*., 2012). Accumulation surveys involve the routine collection and assessment of solely freshly deposited litter at a given sampling location at regular time intervals such as monthly or seasonally (Barnes *et al*., 2009; Nukpezah *et al*., 2022; Opfer *et al*., 2012; OSPAR Commission, 2010). These surveys enable the determination of the temporal trends in macroplastic accumulation (Barnes *et al*., 2009; Nukpezah *et al*., 2022). To ensure that solely freshly deposited litter is collected and studied in accumulation surveys, all debris at the sampling location is cleared prior to the commencement of the routine monitoring of litter (Nukpezah *et al*., 2022). Standing-stock surveys on the other hand involve a single assessment of the total litter load present at a given sampling location (Nukpezah *et al*., 2022; Opfer *et al*., 2012). The assessment of macroplastic litter in both types of surveys involves the counting, weighing and classification of macroplastic litter according to their functional origin for the determination of their abundance, diversity and sources (Blettler *et al*., 2017; Nukpezah *et al*., 2022; Opfer *et al*., 2012; OSPAR Commission, 2010). MCS (2009) classification system is often employed in grouping macroplastic litter according to their respective sources: public litter, fishing sources, sewage-related debris, shipping sources, fly tipped sources, medical sources as well as non-sourced.

As the name denotes, public litter encompasses macroplastic litter deposited directly by the public in the coastal environment or in inland areas which is then transported to the coastal environment through surface runoff, river transport or by wind action (Veiga *et al*., 2016). It includes drinks/water bottles, plastic bags, caps/lids, crisp/sweets wrappers and lollipop sticks, food containers, plastic cutlery and straws, disposable drinking cups, pens, cigarette lighters, combs/plastic hair brushes as well as plastic shoes and flip-flops (MCS, 2009). The fishing category includes fishing nets, fishing lines, floats, ropes and strings while the sewage-related debris includes sanitary towels and diapers (MCS, 2009). The shipping category consists of strapping bands, oil bottles of plastic composition, amongst others while the fly tipped category comprises macroplastic items such as plastic car parts, appliances made of plastic and traffic cones (MCS, 2009). The medical category includes plastic syringes, inhalers and other medical items like plastic packaging for medicine (MCS, 2009). The non-sourced category on the other hand consists of foam, sacks as well as unidentifiable plastic items also referred to as 'others' (MCS, 2009). Brand audits are also often undertaken in macroplastic litter surveys. This involves the examination of brand details (brand name and country of production) on macroplastic litter for the determination of whether they were generated locally or whether they were possibly transported from a different geographical region (Veiga *et al*., 2016). It also aids in the determination of the main producers of plastic items which end up in the environment. Such audits serve as a basis for policymakers to address the plastic waste issue from the source.

2.6.2 Microplastics

Microplastics are formed when plastic litter of greater sizes (macroplastics) degrade over time through processes like abrasion and subjection to ultraviolet radiation; some on the other hand are originally manufactured in their small sizes and included in various products like soaps, toothpaste and facial cleansers (Li *et al*., 2023; Mattsson *et al*., 2015; Miranda *et al*., 2019; Musah *et al*., 2021; Napper & Thompson, 2020; Reisser *et al*., 2013; Wagner *et al*., 2014). The microplastics that are originally manufactured in their small sizes are referred to as primary microplastics while those formed from the degradation of macroplastics are referred to as secondary microplastics (Mattsson *et al*., 2015; Napper & Thompson, 2020; Wagner *et al*., 2014). Indiscriminate release of waste water containing microplastics from factories also contributes to their accumulation in the environment (Benyathiar *et al*., 2022; Mattsson *et al*., 2015; Musah *et al*., 2021). Several studies have highlighted the ability of microplastics to enable other pollutants such as heavy metals, persistent organic pollutants (POPs) and pathogens to become attached to them due to their large surface-volume ratio (Kumar *et al*., 2021; Miranda *et al*., 2019; Wagner *et al*., 2014; Werner *et al*., 2016). This further increases their potential toxicity. The attachment of pollutants to microplastics is however influenced by factors like pH, temperature and ionic strength conditions (Kumar *et al*., 2021).

Microplastic sources are diverse and have proven to be challenging to determine due to the several ways in which microplastics are transported in terrestrial, transitional and marine ecosystems (Bakir *et al*., 2023). For a long period of time, microplastics were often taken for granted due to their relatively small sizes (Napper & Thompson, 2020). However, in recent years, it has become a problem of great concern due to the discovery of its extensive nature and the dire consequences it has on the environment (Andrady, 2011; Blankson *et al*., 2022; Boateng *et al*., 2024; Li *et al*., 2023; Wagner *et al*., 2014). Microplastics are generally classified according to their shapes as: pellets, fibre, film, foam and fragments (Kumar *et al*., 2021; Li *et al*., 2023). The most widely used measurement units for microplastic abundance in sediments include microplastics per 50 grams and microplastics per kilogram while that of water is microplastics per litre (Li *et al*., 2020; Li *et al*., 2023).

2.6.3 Nanoplastics

Nanoplastics can also be initially manufactured in small sizes as primary nanoplastics or they can be formed from the degradation of macroplastics and microplastics, making them secondary nanoplastics (Andrady, 2011; Mattsson *et al*., 2015; Napper & Thompson, 2020). Nanoplastics are also released into the open environment through improper disposal of waste water containing them (Mattsson *et al*., 2015). Currently, they are reportedly widespread in terrestrial, marine and transitional ecosystems (Mattsson *et al*., 2015; World Bank Group, 2020).

Mattsson *et al*. (2015) highlighted their similarity to microplastics, in terms of their relatively small size, which makes them possess larger surface areas and increased surface reactivity, thereby heightening their potential toxicity by increasing the tendency of pollutants like persistent organic pollutants (POPs) getting attached to them. Again, their small size greatly enables their consumption by organisms, particularly at the first and second trophic levels of food webs, which then facilitates bioaccumulation (Mattsson *et al*., 2015; World Bank Group, 2020). One group of organisms that is greatly affected by nanoplastic exposure is aquatic animal species (Mattsson *et al*., 2015). Nanoplastics were also taken for granted for a long period of time (Andrady, 2011; Napper & Thompson, 2020). Currently, several studies have described it as an area of emerging concern due to the growing awareness of its detrimental impacts on the environment and on human wellbeing (Andrady, 2011; Napper & Thompson, 2020; World Bank Group, 2020).

2.7 Impacts of Plastic Waste

Mugilarasan *et al*. (2021) and Werner *et al*. (2016) indicate that indiscriminately discarded plastic waste limits the tourism potential of ecosystems such as coastal areas by lowering their level of attractiveness. This leads to a drop in revenue generated from the tourism sector in local economies and globally (Mugilarasan *et al*., 2021). Again, indiscriminately discarded plastic debris is largely responsible for the blocking of drains which increases the occurrence of floods and leads to the destruction of property and lives (Fobil & Hogarh, 2006; Lebreton & Andrady, 2019). The destruction of property and lives in turn has adverse impacts on the socio-economic conditions prevalent in countries. Additionally, plastic waste contributes to unsanitary conditions which facilitates the occurrence of diseases like cholera and malaria (Debrah *et al*., 2021; Kazuva *et al*., 2018; Musah *et al*., 2021; World Bank Group, 2020). Again, Abalansa *et al*. (2020) and Kazuva *et al*. (2018) report that plastic waste in the marine ecosystem leads to a reduction in the population of fish resulting in a decrease in the income of fishermen due to low fish catch. Countries also spend large sums of money on the removal of plastic debris from blocked drains, programmes for plastic waste clean-up in the environment and compensation of persons affected by flood incidents (Barnes *et al*., 2009). This results in the loss of funds that could have otherwise been used for developmental projects and overall improvement in the socio-economic conditions of countries.

2.8 Wetlands and their Importance

The association between aquatic and terrestrial ecosystems often results in the creation of wetlands (Hu *et al*., 2017; Huang *et al*., 2022). Ramsar Convention Secretariat (2013) also describes wetlands as regions in which the water table is located close to or at the earth's surface and has water as the most dominant component influencing the region and its biodiversity. They are mostly temporarily or permanently characterised by man-made or natural floodplains, fen, mangroves, peatland, coral reefs, marshes, sea grass as well as saline, brackish or fresh water which is either in motion or stationary (Ramsar Convention Secretariat, 2013). Coastal regions which are characterised by sea water that has a maximum depth of six (6) metres during low tides are also regarded as wetlands by Ramsar Convention Secretariat (2013).

There are five (5) main types of wetlands namely: lacustrine, marine, palustrine, estuarine and riverine wetlands (Ramsar Convention Secretariat, 2013). Lacustrine wetlands are related to lakes; marine wetlands are composed of features like coral reefs, lagoons and regions with sea water that does not go beyond six (6) metres in depth during low tides; palustrine wetlands comprise of swamps, marsh and bogs; estuarine wetlands consist of mangroves and deltas and riverine wetlands are associated with streams and rivers (Ramsar Convention Secretariat, 2013). In terms of location and origin, Ramsar Convention Secretariat (2013) discusses three (3) main types of wetlands namely: inland, coastal and artificial wetlands. As their names imply, inland wetlands are situated within terrestrial regions whereas coastal wetlands are located at the region of contact between marine ecosystems and terrestrial ecosystems. For this reason, coastal wetlands are often regarded as transitional regions. Artificial wetlands on the other hand are wetlands made by man like irrigated farm fields, aquaculture ponds, reservoirs, salt pans, amongst others (Ramsar Convention Secretariat, 2013).

Wetlands are crucial for the provision of vital ecosystem services. They serve as the habitat for various forms of biodiversity ranging from fish, to water birds, amphibians, mammals, mangroves, amongst many others (Ramsar Convention Secretariat, 2013; Russi *et al*., 2013). They are crucial for the minimisation of the effects of floods, storage and purification of water, regulation of the occurrence of erosion, regulation of local and global climate through carbon sequestration, replenishment of groundwater resources, preservation of sediments, nutrients and contaminants, protection of coastal shorelines from erosion, serving as a source of raw material for the manufacture of medical drugs as well as acting as cultural and tourist sites (Ramsar Convention

Secretariat, 2013; Russi *et al*., 2013; Wong *et al*., 2014). Again, they serve as archives for genetic materials of plants and grounds for the cultivation of basic food commodities such as rice (Ramsar Convention Secretariat, 2013).

In spite of their importance, there is a sharp decrease in the abundance of wetlands worldwide due to the strain put on them by anthropogenic activities (Hu *et al*., 2017; Huang *et al*., 2022). One of the main anthropogenic activities negatively impacting their abundance is urban growth activities (Hu *et al*., 2017; Niu *et al*., 2012). The destruction of wetlands has dire consequences on the provision of ecosystem services and socio-economic factors such as the provision of food and potable water, sustenance of human and biodiversity wellbeing as well as economic advancement (Ramsar Convention Secretariat, 2013).

2.8.1 Ramsar Convention on Wetlands of International Importance

'The convention on wetlands of international importance especially as waterfowl habitat', more commonly known as the Ramsar Convention, is an international agreement whose adoption took place on February 2nd, 1971 in Ramsar, Iran and entered into force in 1975 (Ramsar Convention Secretariat, 2013). As its actual name depicts, it is an international agreement which was initially aimed at the sustainable usage and development of safeguards for wetlands in order to protect them as water bird habitats (Ramsar Convention Secretariat, 2013). According to Ramsar Convention Secretariat (2013), the agreement has however evolved to include every facet of the responsible usage and protection of wetlands, in order to ensure their sustainability for biodiversity and man. The convention protects over 2500 wetlands worldwide which are referred to as Ramsar sites (Ramsar Convention Secretariat, 2013). Ramsar sites often tend to include regions surrounding the wetlands since they have direct impact on the wetlands (Ramsar Convention Secretariat, 2013).

2.9 Plastic Waste in Coastal Wetlands

One of the principal repercussions of anthropogenic activities on the sustainability of coastal wetlands is plastic waste accumulation (Wei *et al*., 2021). Studies such as Kumar *et al*. (2021) and Zhou *et al*. (2015) have emphasised on how proximity of coastal wetlands to oceans and populated terrestrial regions enables the movement of plastic waste from these areas to the coastal wetlands. Oceanic waves are principally responsible for the movement of plastic waste from oceans to coastal wetlands while factors like wind action, river flow and surface runoff play key roles in their movement from terrestrial regions to coastal wetlands (Kumar *et al*., 2021; Li *et al*., 2023; Zhou *et al*., 2015). Coastal wetlands generally possess relatively low levels of hydrodynamics which results in plastic debris accumulation (Li *et al*., 2023). The movement of macro-, micro- and nanoplastics in coastal wetlands is however greatly affected by alterations in the abundance and movement of surface water and pore water in sediments (Li *et al*., 2023). Additionally, Helcoski *et al*. (2019), Kumar *et al*. (2021) and Li *et al*. (2023) reported that plants found in coastal wetlands like mangroves, hinder plastic waste movement and facilitate their accumulation in coastal wetlands. In various regions worldwide, some of the polymer types found in plastic waste in coastal wetlands include polyethylene, polystyrene, polyvinyl chloride, polyethylene terephthalate, polypropylene and polyamide (Kumar *et al*., 2021).

2.9.1 Drivers, Pressures and State of Plastic Waste in Coastal Wetlands

Drivers in the context of plastic waste accumulation in coastal wetlands refer to fundamental socio-economic factors and needs required for life sustenance, which draws persons into coastal wetlands (Abalansa *et al*., 2020; United Nations Environment Programme, 2018a). A significant number of studies have identified primary drivers to include population growth, urbanisation and economic growth, which give rise to secondary drivers such as the needs for shelter, income, food and recreation or tourism (Abalansa *et al.*, 2020; Adu-Boahen, 2024; Akindele & Alimba, 2021; Federigi *et al.*, 2022; Kazuva *et al.*, 2018).

To satisfy the aforementioned drivers, anthropogenic activities known as pressures are undertaken in the coastal wetlands (Abalansa *et al.*, 2020; Federigi *et al.*, 2022; United Nations Environment Programme, 2018a). These activities include urban growth activities in and around coastal wetlands, petty trading, fishing as well as tourism-related activities (Abalansa *et al.*, 2020). These activities often result in the accumulation of plastic waste in coastal wetlands through improper disposal practices (United Nations Environment Programme, 2018b; Tang, 2023; Van Rensburg *et al.*, 2020).

The state of macroplastic and microplastic accumulation in coastal wetlands has been found to be on the rise in several studies (Chico-Ortiz *et al.*, 2020; Cozzolino *et al.*, 2020; Culligan *et al.*, 2021; Dung *et al.*, 2021; Li *et al.*, 2020; Nukpezah *et al.*, 2022). Their accumulation is often worsened by heavy rainfall and floods (Ford *et al.*, 2022; Haque & Fan, 2023). Studies on the social perceptions of individuals and institutions on issues pertaining to the plastic waste problem in such environments have also shown that there is a general perception of a high accumulation rate (Hartley *et al.*, 2018; Van Oosterhout *et al.*, 2022; Van Rensburg *et al.*, 2020). Public perceptions on the entities most responsible for tackling the plastic waste problem point to plastic producers and the government (Baechler *et al.*, 2024). Some studies have also recommended a ban on single-use plastics such as plastic bags as has been done in countries like Rwanda (Madara *et al.*, 2016; Madigele & Mogomotsi, 2017; Negussie & Mustefa, 2017; Xanthos & Walker, 2017).

2.9.2 Impacts on Aquatic Animal Species of Wetlands

Macroplastic waste in the aquatic systems of wetlands causes entanglement of animal species which reduces their food hunting capabilities and limits their movement, thereby making them more vulnerable to predators (Mattsson *et al*., 2015; Nukpezah *et al*., 2022). Again, their entanglement in macroplastics often results in suffocation and drowning (Mattsson *et al*., 2015). Microplastics and nanoplastics in wetlands are also an issue of great concern due to the harmful effects they have on aquatic species (Li *et al*., 2023). Their small sizes have been identified in several studies as the primary cause of them being easily consumed by aquatic animal species like fish (Blankson *et al*., 2022; Deng *et al*., 2020; Musah *et al*., 2021; Thompson *et al*., 2009a). This puts not only their wellbeing at risk but also, the wellbeing of other organisms in their respective food webs such as humans and birds is threatened (Kumar *et al*., 2021; Li *et al*., 2023; Musah *et al*., 2021; Reisser *et al*., 2013; Thompson *et al*., 2009a; Werner *et al*., 2016). A major factor that makes plastics harmful to aquatic species is the plasticisers they contain (Andrady & Neal, 2009; Miranda *et al*., 2019; Wagner *et al*., 2014; Werner *et al*., 2016). Plasticisers like Bisphenol A (BPA) and phthalates have been found to cause genetic alterations and development abnormalities in species such as fish and crabs respectively (Oehlmann *et al*., 2009).

Again, microplastic ingestion by aquatic species has been reported to affect their hunger detection and digestion ability, leading to malnourishment and death (Thompson *et al*., 2009a; Werner *et al*., 2016). Research has shown that subjection of fish to substantial volumes of microplastics increases the concentration of reactive oxygen species and causes histological changes in their gonads (Qiang & Cheng, 2021). These result in the damage of their reproductive function (Oehlmann *et al*., 2009; Qiang & Cheng, 2021). Consumption of microplastics by some wetland aquatic species also results in abnormalities in their DNA (Cedervall *et al*., 2012). Fish that are exposed to nanoplastics of polystyrene have been found to be unable to efficiently carry out metabolism of lipids (Cedervall *et al*., 2012). Nanoplastics also bring about brain biochemical alterations in fish which results in them exhibiting unusual behavioural patterns (Smith *et al*., 2007).

2.9.3 Impacts on Water Birds of Wetlands

Macroplastics in wetlands limit the access of native and migratory water birds to benthic aquatic species which they rely on for food (Nukpezah *et al*., 2022). Again, some water birds employ macroplastics in the construction of their nests, which increases the tendency of them becoming entangled with the plastic debris (Daudt *et al*., 2023; Luna *et al*., 2022). Water birds also have the tendency of perceiving both macroplastics and microplastics as food and consuming them (Daudt *et al*., 2023). This is evident in studies which have discovered the presence of microplastics in feathers and faecal matter of water birds (Reynolds & Ryan, 2018). However, the amount of plastic debris consumed by them depends on their feeding habits (Mattsson *et al*., 2015; Reynolds & Ryan, 2018). Plastic consumption leads to an impairment in their production of fat (Mattsson *et al*., 2015). It also puts the wellbeing of endangered species of water birds at risk, thereby worsening the possibility of them becoming extinct.

2.9.4 Impacts on Plant Species and Soil of Wetlands

Microplastics in wetland soils have been reported to have some positive impacts like improving water retention capacity and increasing permeability and porosity through the facilitation of the evaporation of soil moisture from their wide surface area (Li *et al*., 2023). However, other studies have shown that microplastics decrease the synthesis of chlorophyll and normal height and weight of some wetland plant species (Galloway *et al*., 2017; Li *et al*., 2023; Yu *et al*., 2021). The microplastics-induced decrease in the normal height and weight of wetland plants is primarily due to their adverse effects on microbial populations, structure of the soil, discharge, movement and adsorption of contaminants as well as the movement of soil nutrients (Li *et al*., 2023). Microplastics have been proven to lead to a considerable increase in the emission of carbon dioxide from soils (Gao *et al*., 2021). The carbon emitted is utilised by some microorganisms responsible for negatively affecting the normal functioning of plants (Rillig *et al*., 2017).

Additionally, microplastics – especially microplastics of polyethylene, polystyrene, polypropylene and PVC, have been found to have a detrimental effect on the composition of soil nutrients such as total nitrogen, organic matter, phosphorus and potassium as well as on the activities of enzymes in the soil (Yu *et al*., 2021). Moreover, microplastics and the additives they contain alter the manner in which wetland seeds germinate, alters the abundance and variety of some microorganisms such as algae and bacteria in the soil and also brings about oxidative stress in wetland plants (Yu *et al*., 2021). The alteration of the variety of soil microorganisms has adverse impacts on the nitrogen and carbon cycling roles of the soil (Gao *et al*., 2021; Kong *et al*., 2018; Li *et al*., 2023; Yu *et al*., 2021).

2.10 Macroplastic Accumulation in Coastal Wetlands

Macroplastic debris found in coastal wetlands usually comprise carrier bags, beverage and food packaging, fishing equipment, footwear, amongst others (Barnes *et al*., 2009; Blettler *et al*., 2017; Cozzolino *et al*., 2020; Sajorne *et al*., 2021). Macroplastic litter accumulating in these coastal environments generally originate from two main sources: land-based sources and ocean-based sources (MCS, 2009; OSPAR Commission, 2010; Veiga *et al*., 2016). Veiga *et al*. (2016) defined land-based sources as plastic litter produced in the terrestrial environment or along the coast and has the potential to eventually make its way into the ocean. Ocean-based sources on the other hand refer to plastic litter which is directly released into the marine environment through activities such as fishing and shipping (Veiga *et al*., 2016). In coastal environments, land-based sources reportedly account for greater than 80% while ocean-based sources account for the remaining amount (Miranda *et al*., 2019; Sheavly & Register, 2007; Veiga *et al*., 2016).

The monthly or seasonal undertaking of macroplastic monitoring surveys enables the exploration of long-term trends in macroplastic accumulation in coastal wetlands (Barnes *et al*., 2009; Nukpezah *et al*., 2022). The rate of macroplastic accumulation in coastal wetland areas like estuaries has been reported to increase over time and is influenced by factors like tidal and wind currents, proximity to urban settlements and anthropogenic activities (Barnes *et al*., 2009; Sajorne *et al*., 2021; Tramoy *et al*., 2021). A study conducted by Nukpezah *et al*. (2022) on litter accumulation along coastal lagoons in Ghana found that there was more macroplastic litter accumulation in urbanised coastal areas and lesser accumulation levels in less-urbanised areas. Another study by Sajorne *et al*. (2021) in Philippines also found higher accumulation in urbanised coastal areas and lesser accumulation rates in non-urban areas. Findings of coastal macroplastic monitoring studies can be used by policy makers to make informed decisions regarding plastic use and plastic waste management (Blettler *et al*., 2017).

2.11 Assessment of Microplastic Accumulation in Sediments

Unlike water and biota which are only capable of presenting relatively short-term evidence of the presence of pollutants, sediments have the ability to serve as a reservoir for the accumulation and storage of pollutants over an extended time span (Bakir *et al*., 2023; Kukkola *et al*., 2022; Willis *et al*., 2017). This enables sediments to serve as a relatively stable and resilient site conducive for the conduction of both short- and long-term assessments of microplastics (Bakir *et al*., 2023; Kukkola *et al*., 2022). The microplastics in sediments have been reported to retain their properties over long periods of time (Simon-Sánchez *et al*., 2022). The key factor facilitating their preservation in sediments is their durability and the ability of sediments to significantly shield them from water, oxygen and ultraviolet radiation from the sun, thereby reducing their susceptibility to degradation (Liu *et al*., 2019; Simon-Sánchez *et al*., 2022). The prolonged presence of microplastics in sediments paves the way for the conduction of studies on their deposition through time in a chronological manner, in order to assess the historical trend in microplastic accumulation (Simon-Sánchez *et al*., 2022).

Sediment coring is a type of sampling which involves the extraction of sediments to a specific depth while ensuring the preservation of the depositional sequence. This type of sampling is undertaken using a hollow tube-like equipment known as a sediment corer. Sediment core samples obtained from undisturbed regions are essential for the determination of the evolution of microplastic accumulation through time (Kukkola *et al*., 2022; Simon-Sánchez *et al*., 2022). This is carried out through the comparison of the microplastic abundance at various depths of the sediment cores and the determination of the ages of the depths being studied (Kukkola *et al*., 2022; Willis *et al*., 2017). The major factors responsible for the amount of microplastics found in sediment cores are human activities as well as rate of flow of water and sedimentation in aquatic systems (Dung *et al*., 2021). Sedimentation refers to the transportation, deposition and preservation of sediments at the bottom of an aquatic ecosystem (Szmytkiewicz & Zalewska, 2014). Szmytkiewicz & Zalewska (2014) indicate that the rate of sedimentation is dependent on the sediments' origin, hydrodynamic conditions present as well as the intensity of biological production in the aquatic ecosystem. In undisturbed sedimentary sequences, deeper depths represent sediments of older ages while shallower depths correspond to younger ages (Willis *et al*., 2017).

In the context of coastal wetlands, sediment core analysis provides deeper understanding of how past anthropogenic activities have impacted these environments and this in turn facilitates the recommendation of appropriate policy responses to tackle their susceptibility to the plastic waste problem. Studies conducted on microplastics in sediment cores in both marine and estuarine settings indicate that the abundance of microplastics is more in shallower depths and lesser in deeper depths (Dung *et al*., 2021; Kukkola *et al*., 2022; Willis *et al*., 2017). This has been found to correspond to the period in which plastic production, usage and disposal began to increase (Dung *et al*., 2021; Willis *et al*., 2017).

For examining the historical trend in microplastic accumulation in sediment cores, the determination of the ages of sediments can be analysed via two (2) main approaches: Lead-210 (^{210}Pb) isotope dating and sediment trap approach (Barsanti *et al*., 2020; Kukkola *et al*., 2022; Szmytkiewicz & Zalewska, 2014; Willis *et al*., 2017). Lead-210 (^{210}Pb) isotope dating can be used to measure the ages of sediments beyond a period of 100 years (Barsanti *et al*., 2020; Szmytkiewicz & Zalewska, 2014). The ^{210}Pb isotope in sediments is derived from precipitation and also from ^{226}Ra decay (Szmytkiewicz & Zalewska, 2014). Lead-210 (^{210}Pb) produced from precipitation is known as unsupported ^{210}Pb while ^{210}Pb produced from ^{226}Ra decay is referred to as supported ^{210}Pb (Szmytkiewicz & Zalewska, 2014). Unsupported ^{210}Pb becomes less active with increasing depth of sediments while supported ^{210}Pb activity occurs at a steady rate regardless of depth (Szmytkiewicz & Zalewska, 2014). Due to the trend in unsupported ^{210}Pb activity, it can be used to measure sedimentation rate and the ages of sediments at successive depths (Barsanti *et al*., 2020; Szmytkiewicz & Zalewska, 2014). Measurement of the activity of unsupported ^{210}Pb is undertaken by subtracting the measured activity of supported ^{210}Pb from that of the whole isotope $^{210}Pb_{tot}$ in the specific sediment depth being studied (Szmytkiewicz & Zalewska, 2014). The ^{210}Pb isotope dating approach employed is largely reliant on the nature of the environment and on the trend of the activity of ^{210}Pb through the various sediment depths (Barsanti *et al*., 2020; Szmytkiewicz & Zalewska, 2014). Examples of ^{210}Pb dating approaches are Constant Rate of Supply Model and Constant Flux Constant Sedimentation Rate approach (Szmytkiewicz & Zalewska, 2014).

Sediment trap is one of the most commonly used equipment for in-situ determination of rate of sedimentation and ages of sediment cores (Cieśla *et al*., 2019; Szmytkiewicz & Zalewska, 2014). Cieśla *et al*. (2019) discussed three (3) major types of sediment trap set-ups: one type is made with funnel-shaped containers, another type is made with rectangular-shaped containers and the last type is made with cylindrical-shaped tubes. Sediment trap set-ups constructed with cylindrical tubes are however considered to be the most effective type, even in aquatic ecosystems which have considerably strong water currents (Cieśla *et al*., 2019). Other factors which are implemented to further increase the effectiveness of this type of set-up are the use of an optimal height to diameter ratio which falls between three (3) and six (6) for the cylindrical tubes and also, the installation and maintenance of the set-up in a vertical position regardless of the hydrodynamic conditions present (Ceiśla *et al*., 2019).

Sediment trap set-ups with cylindrical tubes are commonly constructed with between two (2) and four (4) tubes which are all attached to a frame and installed at a specific depth in the water column, above the water bed (Ceiśla *et al*., 2019; Szmytkiewicz & Zalweska, 2014). The set-ups are left at the sampling locations for a number of months after deployment with routine retrieval of one or two tubes from each set-up at regular time intervals till all tubes on each deployed set-up are retrieved (Szmytkiewicz & Zalewska, 2014). Rate of sedimentation is typically expressed in two forms: Linear Accumulation Rate and Mass Accumulation Rate (Szmytkiewicz & Zalewska, 2014). As their names imply, the Linear Accumulation Rate is a measure of the sediment depth built up per unit time and is usually calculated in mm/year or cm/year while the Mass Accumulation Rate is a measure of the sediment mass deposited per unit area per unit time and is usually calculated in g/m^2/year or g/cm^2/year (Szmytkiewicz & Zalewska, 2014). These accumulation rates are used to calculate the relative ages of sediments at different depths. Accumulation rate determination using the sediment trap approach has been found to yield similar results to the ^{210}Pb isotope dating method (Szmytkiewicz & Zalewska, 2014). Hence, the sediment trap approach is regarded as a more direct and cost-effective method for age determination of sediment cores. Figure 2.1 shows a diagram of a sediment trap set-up constructed with cylindrical tubes.

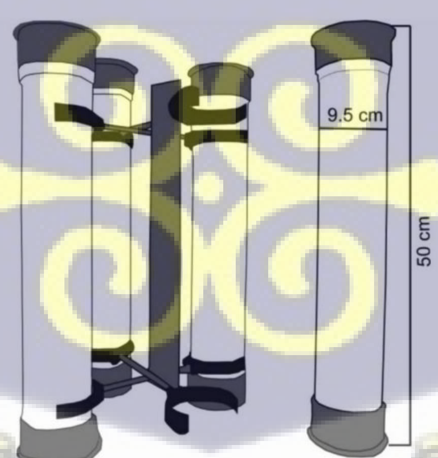


Figure 2.1: Diagram of a Sediment Trap Set-Up Constructed with Cylindrical Tubes

Source: Szmytkiewicz & Zalewska (2014)

2.12 Microplastic Accumulation in Coastal Wetlands

Coastal microplastic studies in sediment cores are essential for the determination of the historical trend in microplastic accumulation in coastal environments (Kukkola *et al*., 2022; Simon-Sánchez *et al*., 2022). Coastal wetland environments such as mangroves, lagoons and estuaries have been found to retain significant amounts of microplastics in sediment cores (Chico-Ortiz *et al*., 2020; Culligan *et al*., 2021; Dung *et al*., 2021; Mohamed *et al*., 2023; Pradit *et al*., 2022). Microplastics found in sediment cores in such environments exhibit varying trends in abundance with increasing sediment core depth. Some studies have reported a clear decrease in microplastic abundance with increasing depth while others have reported fluctuations in abundance through depth (Culligan *et al*., 2021; Dung *et al*., 2021; Fan *et al*., 2019; Kukkola *et al*., 2022; Willis *et al*., 2017).

The vertical distribution of microplastics in sediment cores is influenced by the rate of plastic production, hydrodynamic conditions and population growth in and around the coastal wetlands (Willis *et al*., 2017; Yuan *et al*., 2023). Additionally, fluctuations in microplastic abundance through sediment depth is often attributed to fishing activities, unstable sedimentation rates and disturbance of sediments through bioturbation by organisms such as worms and crabs (Boateng *et al*., 2024; Culligan *et al*., 2021; Dung *et al*., 2021; Willis *et al*., 2017; Yuan *et al*., 2023). In the case of estuarine environments, some studies have reported lesser amounts of microplastics in the top sediments and this has been attributed to the dynamic nature of estuaries caused by tidal currents and the flow of rivers through them which causes resuspension of microplastics and impedes stable microplastic accumulation in the sediments (Chico-Ortiz *et al*., 2020; Yuan *et al*., 2023).

2.13 Findings of Literature Review and Knowledge Gap

The literature review essentially demonstrated plastic ubiquity, their properties, polymer composition and mode of degradation, transportation and impacts on the environment. Nonetheless, majority of studies on plastics primarily focus on the marine environment, with terrestrial and sensitive transitional systems having insufficient research. This is similarly the case in Ghana which is predisposed to plastic waste accumulation from poor disposal practices, particularly in crucial transitional systems like the Densu Delta Ramsar Site. Hence, this requires the study of the Ramsar site's plastic waste accumulation rates, polymer composition, driving forces, impacts and appropriate regulatory measures. The identified knowledge gap necessitates the conduction of this study to facilitate sustainable and effective mitigation.

2.14 Conceptual Framework of Study

The conceptual framework to be employed in this research is the Driver-Pressure-State-Impact-Response (DPSIR) model. The DPSIR model is an approach that was formulated by the European Environment Agency (Bradley & Yee, 2015; Troian *et al.*, 2021). The development of this framework was founded on a previous version known as the Pressure-State-Response approach created by a statistician called Anthony Fried in the 1970s (Burkhard & Müller, 2008; Troian *et al.*, 2021). The DPSIR framework enables the systematic assessment of the cause-and-effect connection between human-induced socio-economic factors and environmental degradation plaguing ecosystems in order to be guided on the development of appropriate sustainable policies or measures to tackle the environmental degradation (Bradley & Yee, 2015; Burkhard & Müller, 2008; Malekmohammadi & Jahanishakib, 2017).

By standard definition, the ‘driver’ component of the DPSIR framework refers to the fundamental socio-economic factors and needs required for life sustenance that lead to the undertaking of anthropogenic activities to address those needs (Abalansa *et al*., 2020; Bradley & Yee, 2015; Troian *et al*., 2021; United Nations Environment Programme, 2018a). The ‘pressure’ component refers to the range of anthropogenic activities which are carried out to satisfy the socio-economic factors and needs, leading to alterations in ecosystems and human wellbeing (Abalansa *et al*., 2020; Bradley & Yee, 2015; Kazuva *et al*., 2018; United Nations Environment Programme, 2018a). There are often multiple ‘drivers’ and ‘pressures’ responsible for a single environmental issue (United Nations Environment Programme, 2018a). This reflects the non-linear nature of the interaction between ‘drivers’ and ‘pressures’ (United Nations Environment Programme, 2018a). ‘State’ on the other hand encompasses the changes in chemical, physical or biological conditions of the ecosystem under examination resulting from the presence of anthropogenic pressures (Malekmohammadi & Jahanishakib, 2017; Müller & Burkhard, 2012; Troian *et al*., 2021). Thus, the ‘state’ component involves the assessment of the chemical, physical or biological characteristics of the ecosystem such as the presence of contaminants, excessive concentration of nutrients, range of biodiversity, amongst others (Bradley & Yee, 2015; Malekmohammadi & Jahanishakib, 2017).

The ‘impact’ component describes the ways in which the provision of ecosystem services is affected due to changes in the ‘state’ (Bradley & Yee, 2015; Müller & Burkhard, 2012; Troian *et al*., 2021). The ecosystem services are typically classified as regulating, provisioning, supporting or cultural (Bradley & Yee, 2015). The recommended approach by United Nations Environment Programme (2018a) for assessing the ‘impact’ phase of the DPSIR framework is to assess both the socio-economic impacts to human wellbeing and the environmental impacts associated with ecosystem services relevant to the area under study. This approach is further supported by a study by Burkhard and Müller (2008) which highlighted the ability of a decrease in the quality of ecosystem services to have detrimental impacts on socio-economic conditions. The 'response' component refers to the informal and formal policies, regulations or measures that are put in place to address the environmental issue (Bradley & Yee, 2015; Müller & Burkhard, 2012). The measures principally aim at mitigating, averting or creating an adaptation system for the 'drivers', 'pressures', 'state' and 'impact' components of the DPSIR framework (Bradley & Yee, 2015).

The DPSIR model has been utilised by crucial institutions like the United Nations Environment Programme (UNEP), Organization for Economic Cooperation and Development (OECD) and United States Environmental Protection Agency (USEPA) due to its effectiveness in providing a systematic guideline for the undertaking of Integrated Environmental Assessments of environmental issues arising from the relationship between socio-economic factors and ecosystems (Bradley & Yee, 2015; Troian *et al*., 2021). The versatility of the DPSIR model enables its application in diverse environmental issues like the management of water resources, climate change, agriculture as well as biodiversity (Bradley & Yee, 2015; Troian *et al*., 2021). In Ghana, Agyemang *et al*. (2007) employed the DPSIR framework in the assessment of environmental degradation in Northern Ghana and concluded that it is an effective method of studying intricate environmental problems to enable appropriate policy formulation. Kyere-Boateng & Marek (2021) used the framework to assess the socio-ecological causes of forest degradation in the country, to develop suitable interventions. Regarding plastic waste research, a notable study by Oduro (2023) involved the use of DPSIR to examine the drivers, pressures, state and impacts of plastic waste on the livelihood of people living at Bakaano-Ola coastline in Ghana's Cape Coast, to facilitate mitigation.

For the present study on plastic waste accumulation in the Densu Delta Ramsar Site, the 'driver' component involves the determination of the socio-economic factors and needs which induce the undertaking of anthropogenic activities of which the generation and release of high volumes of plastic waste in the Ramsar site is a consequence. The main 'drivers' are population growth, urbanisation, economic growth and Maslow's Hierarchy of Needs which demonstrates the essential needs of life such as the needs for shelter, income, food and recreation (Akindele & Alimba, 2021; Kazuva *et al*., 2018; Owusu-Sekyere *et al*., 2013).

The 'pressure' component encompasses the examination of the human activities which lead to the accumulation of plastic waste in the Ramsar site, that are undertaken to satisfy the identified socio-economic factors and needs. The 'state' component comprises the determination of plastic waste (macroplastics and microplastics) accumulation in selected locations within the Ramsar site. The 'impact' component consists of the identification of the effects that plastic waste in the Ramsar site has on its ecosystem services as well as the socio-economic conditions of persons within the Ramsar site. The key types of ecosystem services which could potentially be affected by plastic waste in the Ramsar site are provisioning, supporting and regulating services (Arabi & Nahman, 2020). The 'response' component involves the recommendation of informal and formal measures that can be adopted to mitigate or avert the 'drivers', 'pressures', 'state' and 'impacts' of plastic waste in the Ramsar site. Figure 2.2 shows the conceptual framework for this study.

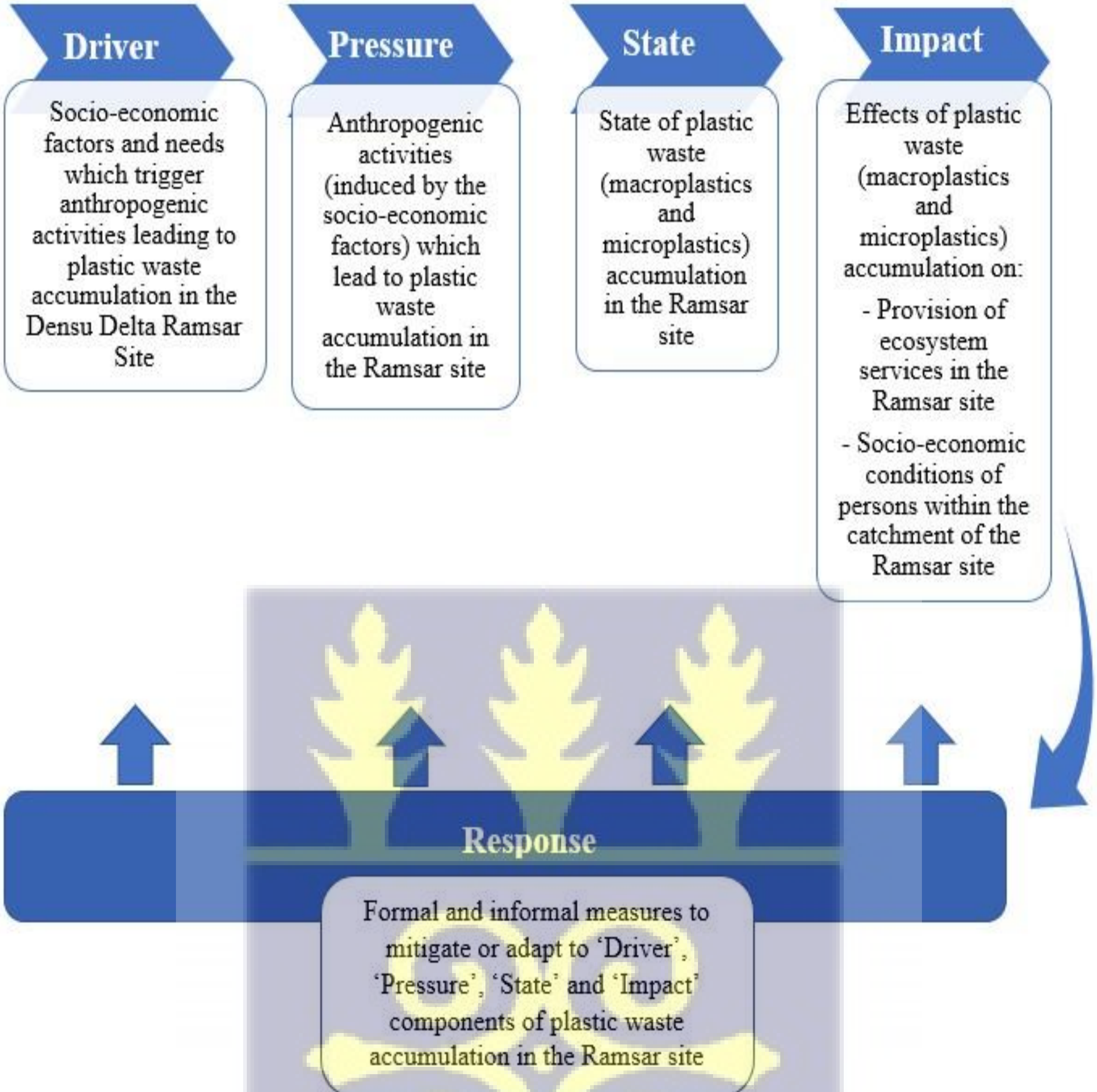


Figure 2.2: Conceptual Framework used in the Assessment of Plastic Waste Accumulation in the Densu Delta Ramsar Site in Ghana

Source: Adapted from United Nations Environment Programme (2018a)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter presents the methodological approach of this research. It gives a description of the study area, research design, the procedure used in data collection and analysis as well as the quality control measures employed to ensure accuracy of results.

3.2 Study Area

The Densu Delta Ramsar Site is a coastal wetland situated in the south-western portion of Accra – the capital city of Ghana (Denutsui *et al*., 2011; Osei *et al*., 2010) (Figure 3.1). In 1992, it became internationally recognised under the Ramsar Convention of Wetlands of which Ghana is a party to. It has an area of about 46.2 km^2 and possesses a lagoon, flood plains, sand dunes, fresh water marsh, salt pans and scrub (Blankson *et al*., 2022; Gbogbo, 2007; Kondra, 2016). The salt pans cover 18 km^2 of the total area (Gbogbo, 2007). The major communities which fall within the catchment of the Ramsar site include: Panbros, Tsokome, Bortianor, Aplaku and Tetegu. The Ramsar site performs important ecological functions such as serving as the habitat for plant species like mangroves and animal species such as native and migratory water birds, fish and crabs (Appeaning Addo *et al*., 2008; Blankson *et al*., 2022). Figure 3.1 shows a map of the study area.

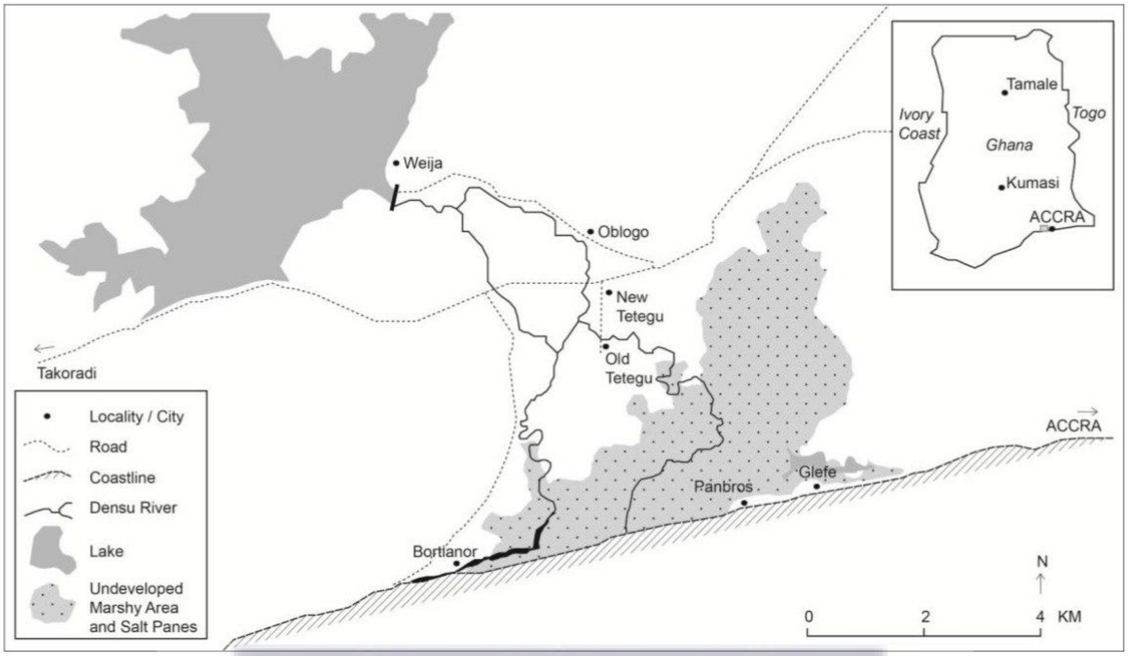


Figure 3.1: Map of Densu Delta Catchment

Source: Frick-Trzebitzky (2017)

3.2.1 Climate

The Ramsar site is located in the dry equatorial climatic region of Ghana which is controlled by three (3) air masses namely: the monsoon, equatorial and the harmattan air masses (Denutsui *et al*., 2011; Ghana Statistical Service, 2014). The Ramsar site is also regarded as falling within the coastal savanna region which is characterised by two (2) rainfall seasons which peak in the months of June and October each year (Denutsui *et al*., 2011; Ghana Statistical Service, 2014). Its average annual rainfall is 800 mm (Denutsui *et al*., 2011). The highest average monthly temperatures are in March and April (Denutsui *et al*., 2011). The minimum daily temperature is 22.8 °C while the maximum is 33.0 °C (Denutsui *et al*., 2011). The yearly mean temperature ranges between 24.2

°C and 31.0 °C (Denutsui *et al*., 2011). Relative humidity is lowest in January and highest in August (Denutsui *et al*., 2011).

3.2.2 Vegetation

Due to its location in the coastal savanna agro-ecological region, the Ramsar site is dominated by vegetation such as white and red mangroves, coconut (*Cocos nucifera*) and coastal grassland which comprises species like *Sporobolus virginicus*, *Sesuvium portulacastrum*, *Imperata cylindrica* and *Cyperus articulates* (Gbogbo, 2007; Ghana Statistical Service, 2014).

3.2.3 Geology

The Ramsar site falls within the Akwapim Range of the Togo Structural Unit which forms part of the Dahomeyide Orogenic Belt (Darko *et al*., 2019; Denutsui *et al*., 2011; Ghana Statistical Service, 2014). Hence, it is underlain by metamorphic and sedimentary rocks such as quartzite, phyllites, schist and sandstones (Darko *et al*., 2019; Denutsui *et al*., 2011; Ghana Statistical Service, 2014).

3.2.4 Drainage and Relief

The water resources of the Ramsar site are mainly derived from the Densu River which takes its source from the Atewa Range Forest Reserve in the Eastern Region of Ghana (Appeaning Addo *et al*., 2008; Osei *et al*., 2010). The flow of the Densu River into the Ramsar site is however regulated by the Weija Reservoir situated some kilometres upstream for the supply of water to a portion of Accra (Appeaning Addo *et al*., 2008; Denutsui *et al*., 2011; Osei *et al*., 2010). The relief in the Ramsar site ranges between twenty (20) and hundred (100) metres above sea level (Denutsui *et al*., 2011). As a transitional region, the Ramsar site acts as the conduit for the flow of the Densu River into the Atlantic Ocean (Appeaning Addo *et al*., 2008; Denutsui *et al*., 2011; Nukpezah *et al*., 2022; Osei *et al*., 2010). Again, it has been identified as an area susceptible to floods during heavy rainfall and the periodic spilling of the Weija Reservoir (Frick-Trzebitzky & Bruns, 2017).

3.2.5 Economic Activities

The location of the Ramsar site in the densely populated coastal city of Accra has led to the undertaking of several economic activities within its catchment (Nukpezah *et al*., 2022, Osei *et al*., 2010). These economic activities include fishing, petty trading, recreational activities, construction of residential buildings, crab hunting, small-scale farming and salt mining (Appeaning Addo *et al*., 2008; Blankson *et al*., 2022; Kondra, 2016; Osei *et al*., 2010). Plate 3.1 shows fishing activities in the Ramsar site.

Plate 3.1: Fishing Activities in the Ramsar Site

Source of Images: Author

Figure 3.2 shows a map of the study area with the sampling points.

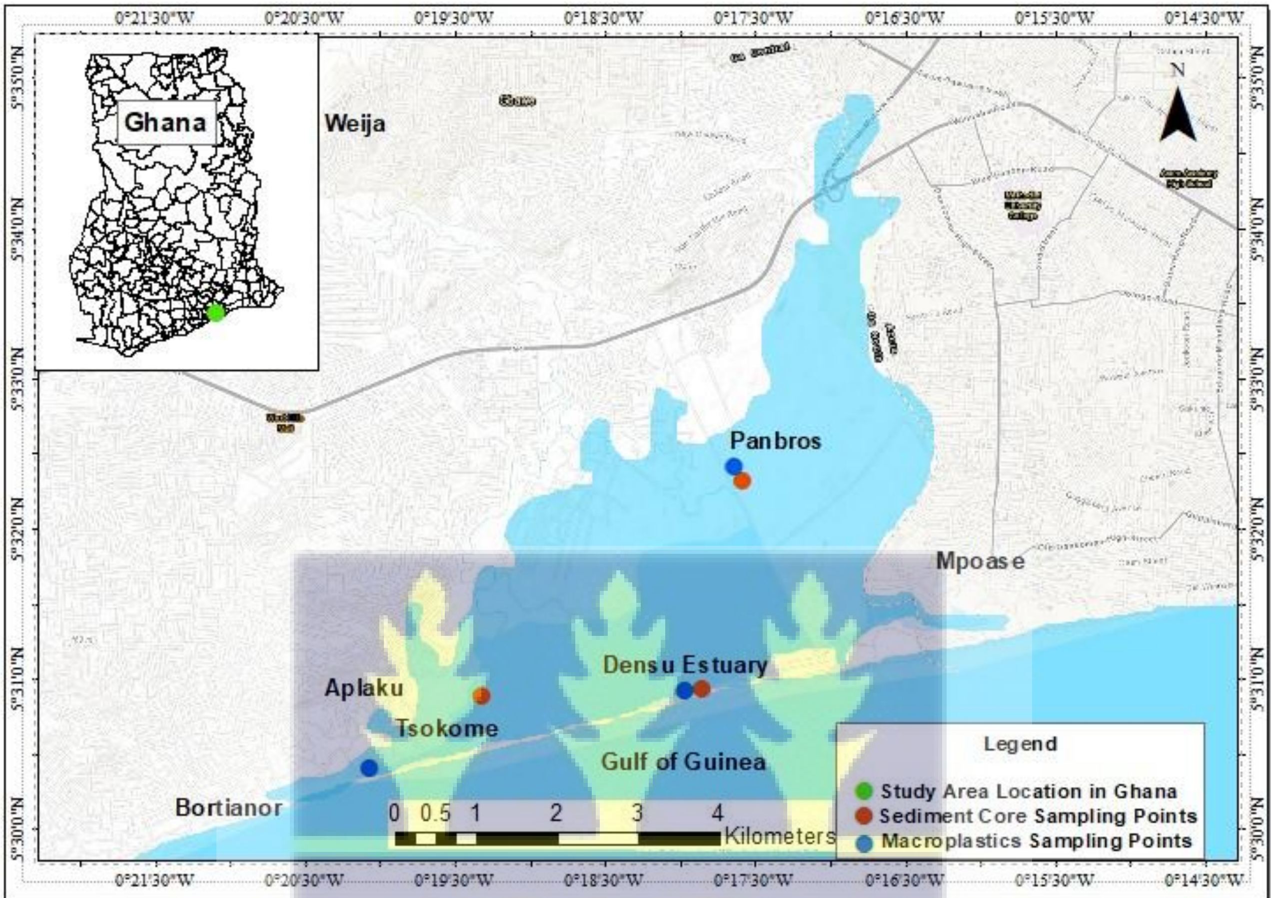


Figure 3.2: Map of the Densu Delta Ramsar Site showing Sampling Points and Some Relevant Communities

Source: Author

3.3 Research Design

The research design used is the mixed method approach which involved an integration of quantitative and qualitative approaches. The mixed method was chosen as the research design in this study to ensure that the aim and specific objectives of the study were adequately tackled and that all factors influencing the research problem were taken into account (Creswell & Plano Clark, 2007). This study is an explanatory research based on the Driver-Pressure-State-Impact-Response (DPSIR) framework. This enabled the determination of the factors (drivers and pressures) responsible for plastic waste accumulation in the Ramsar site and the resultant state and impacts. These in turn guided the recommendation of appropriate response measures to tackle the issue.

3.4 Sources of Data

The data for this research was obtained from both primary and secondary sources.

3.4.1 Primary Sources

These were obtained from the following: macroplastic litter monitoring surveys within the Ramsar site, standard laboratory assessments of microplastics in sediment core samples from the Ramsar site, deployment of sediment traps, administering of questionnaires to primary stakeholders, conduction of semi-structured interviews with secondary stakeholders as well as field observation.

3.4.2 Secondary Sources

These were obtained from published peer-reviewed articles, books and gray literature. The obtaining of the secondary data from these sources was undertaken through the conduction of a literature review.

3.5 Target Population

3.5.1 Inclusion Criteria

The inclusion criteria for this study were:

- Macroplastic litter surveys were carried out within the catchment of the Ramsar site.
- All sediment core samples for microplastics laboratory analysis were obtained from the catchment of the Ramsar site.
- Primary stakeholders encompassed persons aged 18 years and above who live and/or work within the catchment of the Ramsar site.
- Secondary stakeholders consisted of key institutions in charge of the environmental protection of the Ramsar site.

3.5.2 Exclusion Criteria

The exclusion criteria for this study were:

- For macroplastic litter and microplastic assessments, areas which do not fall within the catchment of the Ramsar site were excluded.
- Persons encountered in the Ramsar site who are aged 18 years and above but do not live and/or work in the Ramsar site.
- Persons encountered in the Ramsar site who are below the age of 18.
- Institutions which are not in charge of the environmental protection of the Ramsar site.

3.6 Reconnaissance Study

A reconnaissance visit to the study area was undertaken in June, 2023. This visit was undertaken in order to get familiar with the study area and to decide on the sampling points for both the macroplastic litter surveys and the collection of sediment core samples for laboratory assessment of microplastics. The reconnaissance visit was also undertaken to identify and get familiar with some of the primary and secondary stakeholders prior to the data collection phase of the research.

3.7 Data Collection

The data collection phase was carried out over a period of three (3) months spanning August to October, 2023. The data collected was guided by the specific objectives of this study. The methodology for data collection is discussed in the following sections.

3.8 Determination of Macroplastic Litter Accumulation

The methods employed in the determination of macroplastic litter accumulation in the Ramsar site were adapted from Blettler *et al*. (2017), Sajorne *et al*. (2021), Nukpezah *et al*. (2022), OSPAR Commission (2010) and MCS (2009). This involved the determination of the monthly abundance, diversity and sources of freshly accumulated macroplastic litter at the banks of the Densu River at the three (3) sampling locations in the Ramsar site: Panbros, Tsokome and Densu Estuary. Prior to commencement of the macroplastic litter survey, July, 2023 was dedicated to the removal of all macroplastic litter which was present at the three (3) sampling locations. This was done to ensure that solely freshly accumulated litter was collected during the months of macroplastic sampling. Sampling was carried out over three consecutive months spanning August to October, 2023. At each of the sampling locations, transects which had dimensions of 50 m by 30 m were set up parallel to the watermark of the Densu River as done by Blettler *et al*. (2017) and Sajorne *et al*. (2021).

In each month of sampling, every visible newly accumulated macroplastic litter (with a diameter greater than 2.5 cm) in the 50 m by 30 m transect were collected (Blettler *et al*., 2017; Opfer *et al*., 2012). To ensure that all macroplastic litter are collected from the established transect, a pattern for walking within the transect was adapted from Opfer *et al*. (2012). This walking pattern is presented in Figure 3.3. Waste collection sacks were used for the collection of the macroplastic litter. The collected litter were transported away from the sampling locations to prevent double counting in subsequent months of data collection. They were then sorted into plastic litter categories based on their functional origin or use (for instance: drinks/water bottles, water sachets, food containers, crisp/sweets wrappers, amongst others) as recommended by OSPAR Commission (2010). The photo guide provided by OSPAR Commission (2010) aided in the precise identification and sorting of the collected macroplastic litter into the various categories. Unidentifiable plastic litter were categorised as 'Others' (OSPAR Commission, 2010). Subsequently, the items in each litter category were manually counted to assess the abundance. All macroplastic litter were also weighed on a digital scale to determine their mass. The macroplastic data was recorded on pre-designed datasheets adapted from OSPAR Commission (2010) guideline (Appendix A). After completion of data collection for each month, it was ensured that the macroplastic litter were appropriately disposed of. The monthly macroplastic litter accumulation rate (r) at the sampling locations were calculated using Equation 4:

$$r = \frac{Total\ Amount\ of\ Macroplastics\ at\ Sampling\ Location\ per\ Month}{Transect\ Area} \qquad (4)$$

(Blettler *et al*., 2017)

The monthly accumulation rates calculated for each sampling location were expressed in items/m^2/month. MCS (2009) classification system was used to group the macroplastic litter recorded at each sampling location according to their most likely sources: 'public litter', 'fishing sources', 'sewage-related debris', 'shipping sources', 'fly tipped sources', 'medical sources' as well as 'non-sourced'. A brand audit was also carried out to identify the top brands dominating plastic litter across the three (3) sampling locations. This was done through the examination of brand details (brand name and country of production) on the macroplastic litter. Thus, the audit also aided in determining whether they are local or foreign brands. This revealed whether the macroplastic litter was generated locally or possibly underwent transportation from a different geographical region (Veiga *et al*., 2016). Figure 3.3 as well as Plates 3.2, 3.3 and 3.4 show images of some of the key processes involved in the macroplastic data collection.

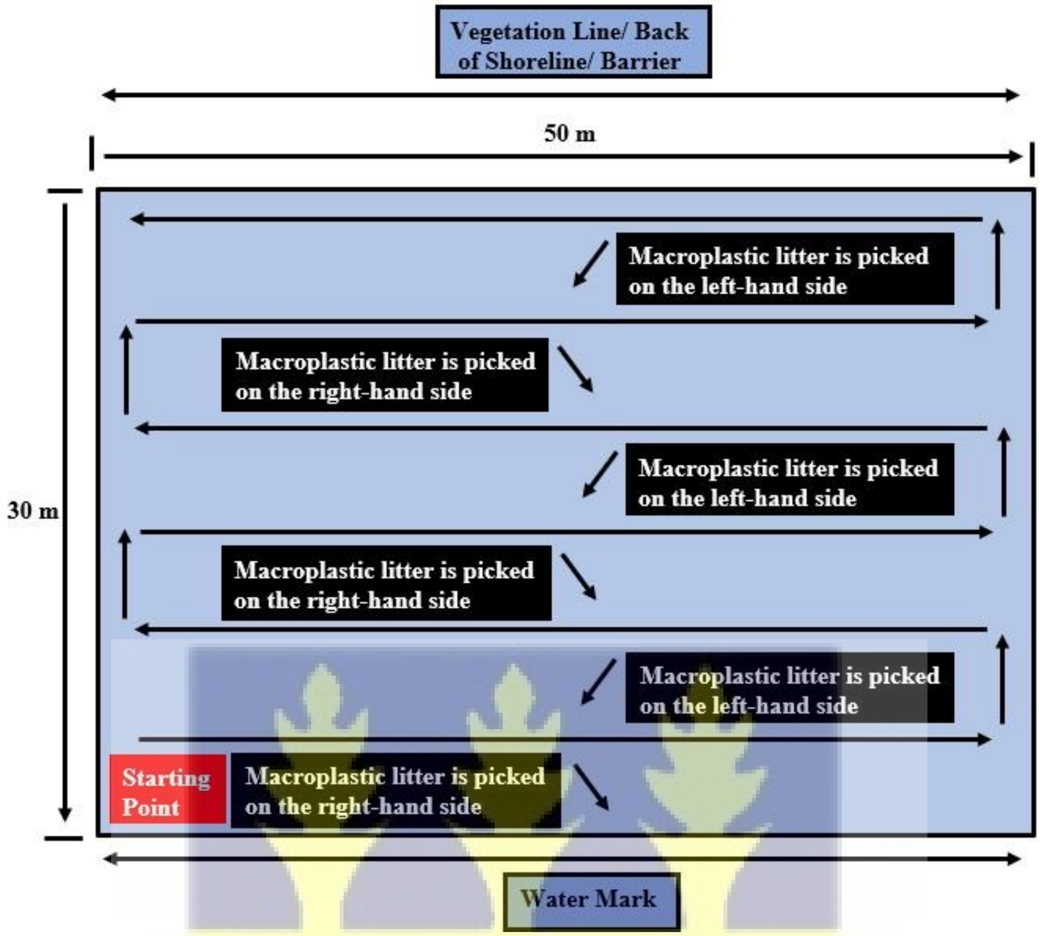


Figure 3.3: Pattern Chosen for Walking for the Collection of Macroplastic Litter at Sampling Locations

Source: Adapted from Opfer *et al*. (2012)

Plate 3.2: Transect Layout for Macroplastic Litter Sampling at Densu Estuary

Plate 3.3: Demonstration of the Collection and Handling of Macroplastic Litter at Sampling Location

Plate 3.4: Sorting of Plastic Litter Categories

Source of Images: Author

3.9 Determination of Microplastic Accumulation in Sediment Cores

3.9.1 Collection of Sediment Core Samples

Three (3) replicate sediment cores each were collected from three (3) sampling stations in the Ramsar site in September, 2023, making a total of nine (9) cores. Replicate cores were taken at each sampling location as recommended by United Nations Environment Programme (2020) for the determination of possible variation. Each core had a 30 cm length. Sediment core sampling was carried out with a corer with an 8.5 cm internal diameter and a height of 60 cm. Care was taken in sampling to maintain the depositional sequence of the sediment cores. The selection of the three (3) sampling stations was informed by studies by Dung *et al*. (2021), Chico-Ortiz *et al*. (2020) and Culligan *et al*. (2021) which revealed that mangrove regions, lagoons and estuarine regions respectively, of coastal wetlands are hotspots for microplastic accumulation in sediments. The three (3) selected sampling locations were a mangrove region in Panbros – which is located in the principal catchment of the Ramsar site, Tsokome a fishing community situated where the Densu Lagoon can be found in the Ramsar site and the Densu Estuary which represents the transition area between the Densu River and the Atlantic Ocean.

After sampling, each of the sediment cores was extruded out of the corer and cut at intervals of 5 cm along each core length, following the standard procedure used by Li *et al*. (2020) and Matsuguma *et al*. (2017). Each sediment core therefore had 6 slices (sub-samples). Each sub-sample was stored in aluminium foil, appropriately labelled, placed in an ice chest and transported to the laboratory for analysis. Aluminium foil was used to store and transport the sub-samples to minimise the possibility of microplastic contamination from sample storage bags made of plastic. In total, fifty-four (54) sediment core sub-samples were collected for laboratory analysis. Table 3.1 provides a summary of the number of sediment core samples that were collected from the study area for laboratory analysis of their microplastics content.

Table 3.1: Summary of Number of Sediment Core Samples Collected from Densu Delta Ramsar Site for Microplastic Assessment

Number of Sampling Locations	3
Number of Sediment Cores Collected per Sampling Location	3
Total Number of Sediment Cores Collected	3 x 3 = 9 sediment cores
Length of Each Sediment Core	30 cm

Interval at which each Sediment Core was sliced	5 cm
Number of Slices per Sediment Core	$\frac{30}{5}$ = 6 slices (sub-samples)
Total Number of Slices for all Sediment Cores	6 x 9 = **54 slices (sub-samples)**

3.9.2 Laboratory Analysis of Sediment Core Samples

Preliminary laboratory processes involved the oven-drying of each 5 cm core slice at 60 °C until dry constant weight was attained. Afterwards, the dried core slices were each pulverised using a mortar and pestle.

Digestion

A measured 50 grams quantity of sediments was extracted from each pulverised 5 cm slice and sieved using a 5 mm sieve in order to ensure that all plastic items larger than 5 mm were removed from the sediments to prevent them from being counted as microplastics (Duan *et al*., 2020). The sediments were subsequently transferred into beakers well-rinsed with distilled water (Duan *et al*., 2020). Hydrogen Peroxide (H_2O_2) digestion was then undertaken on them to eliminate organic matter content and biofouling as recommended by Mendoza *et al*. (2021) and Kumar *et al*. (2021), to avoid interference with microplastic analysis. The digestion process involved adding 30 ml of 30% Hydrogen Peroxide solution to each of the core sub-samples in the beakers and stirring with the aid of a metal stirrer till bubbling ceased.

Density Separation

Density separation was then carried out to facilitate the extraction of microplastics from the sediment matrix. This process was carried out using 1.2 g/ml saturated Sodium Chloride (NaCl) solution. NaCl was chosen for making the salt solution for the density separation process due to its much more environmentally-friendly nature in comparison to other salts like Zinc Chloride ($ZnCl_2$) which has been found to be toxic (Kumar *et al*., 2021). One hundred and fifty millilitres (150 ml) of saturated NaCl solution was added to each digested sub-sample in the beakers to create a system of differing densities that enabled microplastics of lower density to float; thus, facilitating their extraction from their sediment matrix. The content of each beaker was mixed for a duration of ten (10) minutes and subsequently left to stand for twelve (12) hours. After the twelve (12) hour period, the supernatant in each beaker was carefully transferred into a fresh set of smaller beakers thoroughly rinsed with distilled water, in preparation for the next step which is filtration. The supernatant in each small beaker was then filtered under vacuum using CHMLAB 1.2 µm glass filter papers. After each filtration process, the filter papers were carefully placed in clean labelled glass petri dishes and briefly oven dried at a temperature of 40°C, covered with glass lids and stored in preparation for their examination under a stereomicroscope.

Quantification of Microplastics

To quantify the microplastics retained on the filter papers for each 5 cm slice of the sediment cores, the filter papers were observed under a Leica EZ4D stereomicroscope which operates in conjunction with an in-built digital camera. Using a magnification of x40, all microplastics observed on the filter papers were counted. The standard methodology used in counting microplastics on filter papers was derived from Hidalgo-Ruz *et al*. (2012) as well as Teng *et al*. (2019). These methods involved the counting of microplastics in a ‘Z’ pattern (to prevent double counting), determination of their shapes, sizes and colours as well as the isolation of a portion of them for Fourier Transform Infrared Spectroscopy (FTIR) analysis (Teng *et al*., 2019). An item was recognised as a microplastic if it lacked organic structures, resisted breakage, maintained its form and exhibited flexibility when pressed with a metal probe (Hidalgo-Ruz *et al*., 2012). Unlike microplastics, organic matter disintegrates when subjected to the same treatment (Willis *et al*., 2017). The microplastic abundance was recorded in microplastics per 50 grams of sediments (microplastics/50g). All counted microplastics were also classified into their respective shapes (fibre, fragment and film) and analysis of sizes was carried out by measuring the length of the longest axis of the microplastic particles using an in-built measurement software. They were then recorded in the following size classes: <100 µm, 100 – 500 µm, 501 – 1000 µm, 1001 – 3000 µm and 3001 – 5000 µm. The colour categories (red, black, blue, green, yellow, white and transparent) of all counted microplastics were also recorded. Photographs of microplastics were taken with the in-built digital camera. Plate 3.5 shows images of the stereomicroscope used for microplastic quantification.

Plate 3.5: Quantification of Microplastics using Stereomicroscope

Source of Images: Author

Polymer Identification

Fourier Transform Infrared Spectroscopy (FTIR) was used for polymer identification of microplastics in the sediment core samples. This technique utilises distinct polymer properties for the identification of microplastic types (Kumar *et al*., 2021). A total of ninety (90) microplastic particles were randomly isolated across the three sampling locations and analysed using Spectrum Two Perkin Elmer FT-IR Spectrometer. Scans were undertaken with a 4 cm^{-1} resolution. OMNIC 9.0 software (Thermo Fisher Scientific) was used for the assessment of output spectra as well as their comparison with polymer libraries. In line with the process for spectral quality assessment employed by Woodall *et al*. (2014), quality indices that matched a polymer library by 70% and above were accepted.

The microplastic polymer composition identified through FTIR analysis was compared with the average polymer composition in the national macroplastic waste stream which was calculated from data reported by Miezah *et al*. (2015) - Appendix G. Miezah *et al*. (2015) reported the plastic polymer composition relative to the entire national waste stream based on: low-, middle-, and high-income household levels across all regions of Ghana. The national average composition for each polymer type calculated in the present study was done across the three (3) household income levels reported by Miezah *et al*. (2015). This calculated national average macroplastic data was normalised to sum up to 100% to enable comparison with microplastic data from the Ramsar site. For any polymer type which was present in national plastic waste stream data but absent in microplastic data from the Ramsar site, a corresponding value of 0% was assigned to the polymer in the microplastic data. This was done to provide consistency in comparison. The comparison between the two (2) sets of data was carried out to determine whether national macroplastic waste composition has a significant influence on microplastic composition in the Ramsar site.

<u>Quality Control and Assurance</u>

All laboratory procedures were carried out carefully to minimise the possibility of microplastic contamination. Quality control and assurance procedures employed in the laboratory analysis of microplastics in the sediment core samples were adopted from Dung *et al*. (2021), Li *et al*. (2020) and Munno *et al*. (2018). These procedures included the wearing of cotton lab coats and polymer-free nitrile gloves throughout the laboratory analysis (Li *et al*., 2020). Polymer-free nitrile gloves were worn instead of vinyl polymer gloves to prevent the introduction of microplastics from gloves into the samples (Li *et al*., 2020). At the beginning of the laboratory analysis, the sediment core slices were oven-dried at 60 °C to reduce the risk of loss of microplastics from heating at higher temperatures (Munno *et al*., 2018). The procedures also included the use of glass beakers to contain sediments and solutions during digestion, density separation and filtration. All beakers and other apparatus were thoroughly rinsed with distilled water prior to their usage (Li *et al*., 2020). Glass petri dishes were also used for storing filter papers. The use of plastic tools and equipment was greatly reduced in the laboratory to avoid contaminating samples with microplastics (Li *et al*., 2020).

Procedural blanks were also run in parallel with the extraction of microplastics from the sediment core samples. Air-borne microplastic contamination was also assessed by placing three (3) filter papers in three (3) glass petri dishes and putting each of them in three (3) different locations in the laboratory, leaving them uncovered for twenty-four (24) hours. These filter papers were analysed under the stereomicroscope for the possible presence of microplastics. As shown in Plate 3.6, it was also ensured that all solutions and sediment core samples in beakers and other containers were covered with aluminium foil at all times till they were ready to undergo laboratory analysis (Dung *et al*., 2021). Filter papers in glass petri dishes were also covered with their glass lids when not in use. These were done to prevent air-borne microplastic contamination.

Plate 3.6: Beakers containing Supernatant from Density Separation covered with Aluminium Foil

Source of Image: Author

3.9.3 Deployment of Sediment Traps for the Determination of Sediment Accumulation Rate

Sediment trap set-ups were deployed to each of the three (3) sampling locations where the sediment cores were collected: Panbros, Tsokome and Densu Estuary. The sediment traps were used for the in-situ determination of the sediment accumulation rate to enable the calculation of the relative ages of the sediments in the various depths of the sediment cores for the examination of the historical trend in microplastic accumulation. The three (3) sediment trap set-ups were deployed in August, 2023 and remained at the locations till October, 2023. The method used for the construction of the sediment trap set-ups was adopted from Szmytkiewicz and Zalewska (2014). Each trap set-up was made up of four (4) cylindrical tubes attached to one (1) frame. The frame acted as an anchor to maintain the set-up in a vertical position and to provide stability for the tubes.

As recommended by Szmytkiewicz and Zalewska (2014), the cylindrical tubes had a 50 cm height and a 10 cm diameter (giving a height to diameter ratio of 5). At each sampling location, the stand of the set-up was firmly installed vertically in the waterbed while ensuring that the cylindrical tubes were at an approximately 0.5 metres depth above the waterbed as done by Szmytkiewicz and Zalewska (2014) to minimise the effect of water level fluctuation and also to facilitate the effective capture of settling sediments. Plate 3.7 shows images of the sediment trap set-up before deployment and during the process of installation at the Tsokome sampling location.

During the period of deployment, two (2) tubes were retrieved from each set-up at each sampling location after one (1) month (September, 2023) and again, after two (2) months (October, 2023), until all the four (4) tubes were retrieved from the set-ups at each sampling location. After each monthly tube retrieval, the tubes were then transported to the laboratory and the sediments were extracted from the tubes and oven dried at 60°C until constant weight was attained. Afterwards, the dry sediments were weighed on a digital weighing scale to determine their masses. The determined sediment masses for the two months were employed in the calculation of the sediment accumulation rates known as Linear Accumulation Rate and Mass Accumulation Rate. The Linear Accumulation Rate was used in the construction of the age-depth profiles of the cores as done by Dung *et al*. (2021) and Li *et al*. (2020). The age-depth profiles and the mean microplastic abundance per sediment core depth interval for the three (3) sampling locations were then used to determine the historical trend in microplastic accumulation. The Linear and Mass Accumulation Rates were determined in cm/year and g/cm^2/year respectively using Equations 2 and 3. In calculating Linear Accumulation Rate, the sediment density was set at the standard value of 2.65 g/cm^3 as is often done in literature (Jilbert *et al*., 2020; Szmytkiewicz & Zalewska, 2014;

Waldschläger *et al*., 2022). This value represents the density of quartz which is the dominant mineral often found in sediments (Waldschläger *et al*., 2022).

$$Mass\ Accumulation\ Rate = \frac{m}{AT} \text{ (Szmytkiewicz \& Zalewska, 2014)} \quad (2)$$

$$Linear\ Accumulation\ Rate = \frac{Mass\ Accumulation\ Rate}{Sediment\ Density} \text{ (Jilbert et al., 2020)} \quad (3)$$

Where:

m = Mass of dry sediments from cylindrical tube (g)

A = Area of tube opening (cm^2)

T = Time of trap analysis (years)

Sediment Density = 2.65 g/cm^3 (Jilbert *et al*., 2020; Szmytkiewicz & Zalewska, 2014; Waldschläger *et al*., 2022)

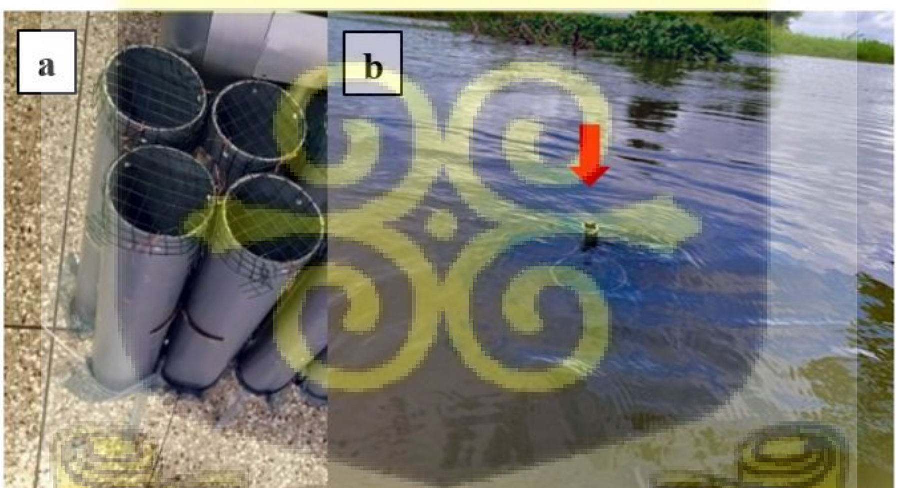


Plate 3.7: Sediment Trap Set-Up Before (a) and During (b) Process of Deployment for the Assessment of Sediment Accumulation Rate

Source: Author

3.10 Administering of Questionnaires and Semi-Structured Interviews

Questionnaires (Appendix H) were administered and semi-structured interviews (Appendix I) were conducted with primary and secondary stakeholders, respectively. The purpose was to determine their perceptions of the underlying causes (drivers and pressures) of plastic waste accumulation in the Ramsar site, its state and impacts to the Ramsar site as well as their recommendation of response measures to tackle the issue. The semi-structured interviews with secondary stakeholders (key institutions in charge of the protection of the Ramsar site) involved the asking of open-ended questions which allowed the provision of detailed information on institutional perspectives, challenges, initiatives, experiences and recommendations with regard to plastic waste in the Ramsar site.

To ensure that the specific objectives pertaining to the perceptions of relevant stakeholders on the 'Drivers', 'Pressures', 'State', 'Impacts' and 'Response' to plastic waste accumulation in the Ramsar site were properly tackled, the questionnaire and semi-structured interviews were designed to have five sections: Section A covered the demographic information and background of the primary and secondary stakeholders respectively; Section B addressed the 'Drivers' and 'Pressures' of plastic waste accumulation in the Ramsar site; Sections C and D covered the social perceptions of its state and impacts to the Ramsar site respectively and Section E focused on views on the appropriate response measures that can be put in place to tackle the issue.

For primary stakeholders, assessment of their perceptions of the 'Drivers' involved asking them about the underlying socio-economic factors and needs causing plastic waste accumulation, identified from literature which are: population growth which causes a rise in the need for shelter, economic growth which brings about a rise in the need to have a source of income, population growth which intensifies the need for food such as fish and urbanisation which generates a heightened demand for recreation (Abalansa *et al*., 2020; Kazuva *et al*., 2018; Owusu-Sekyere *et al*., 2013; United Nations Environment Programme, 2018a).

In terms of 'Pressures', they were asked about their opinion on the 'Driver'-induced anthropogenic activities causing the accumulation of plastic waste in the Ramsar site based on the findings from literature: urban growth activities – to tackle the rise in the need for shelter caused by population growth, petty trading activities (the identified major occupation) – to tackle the rise in the need for income brought about by economic growth, fishing activities – to tackle the rise in the need for food as well as income and tourism-related activities – to tackle the heightened demand for recreation (Abalansa *et al*., 2020; United Nations Environment Programme, 2018a). They were subsequently asked about the ways in which they discard their plastic waste and the possible contribution from other sources (surface runoff and river flow from upstream sources, transport by wind action and ocean-transported plastic litter). Persons to whom questionnaires were administered to were permitted to select more than one driver and pressure due to the possibility of there being multiple drivers and pressures responsible for plastic waste accumulation in the Ramsar site (United Nations Environment Programme, 2018a). Their perception of the 'State' involved asking about their view of the current and past states and the state of plastic waste accumulation after heavy rainfall or floods. It also involved assessing their knowledge on the existence of microplastics.

Primary stakeholders were again asked about their opinion on the 'Impacts' of plastic waste on the Ramsar site based on possible socio-economic and ecosystem services-related impacts identified from literature. In terms of socio-economic impacts, their perceptions of the following were determined: rise in public health concerns such as cholera and malaria due to prevalence of plastic waste in the Ramsar site, negative impact on fishing and other sources of livelihood as well as reduction in level of attractiveness of the Ramsar site leading to a decrease in tourism potential (Abalansa *et al*., 2020; Kazuva *et al*., 2018; Mugilarasan *et al*., 2021). Similarly, their perceptions of the most relevant potential ecosystem services-related impacts were assessed: fish ingesting or becoming entangled in plastics (provisioning services), destruction of habitat of biodiversity (supporting services) and reduction in water quality which falls under the regulating services category (Arabi & Nahman, 2020; Liquete *et al*., 2013).

With regard to the 'Response' step of the DPSIR framework, respondents were asked of their opinions on the appropriate measures which can be put in place by persons within the Ramsar site and also by government or relevant institutions to curb plastic waste accumulation in the Ramsar site. It was ensured that easily understandable expressions were used in the questionnaire and interviews to facilitate effective communication with primary and secondary stakeholders.

The formulated questionnaire and semi-structured interview questions were included among documents sent to the Ethics Committee for Basic and Applied Sciences (ECBAS) of the University of Ghana for ethical clearance prior to them being administered to primary and secondary stakeholders. Ethical clearance was subsequently granted by ECBAS with document reference number: ECBAS 079/22-23.

3.10.1 Sample Size

Questionnaires were administered to a total of 397 primary stakeholders within the catchment of the Ramsar site. This representative sample size was determined using the Taro Yamane sample size formula (Yamane, 1967):

$$n = \frac{N}{(1+N(e)^2)} \quad \text{(Yamane, 1967)} \qquad (1)$$

Where:

n = Sample size

N = Total population = 60,134 (obtained from Ghana Statistical Service)

e = Margin error = 5% (0.05)

n ≈ 397

With regard to secondary stakeholders, interviews were conducted with representatives of six (6) institutions in charge of the environmental protection of the Ramsar site: Weija-Gbawe Municipal Assembly, Ga South Municipal Assembly, Environmental Protection Authority (EPA), Wildlife Division of Forestry Commission, Panbros Salt Industries Limited and Water Resources Commission (WRC). To ensure confidentiality, the names of institutions were represented by labels in the results chapter.

3.11 Field Observation

To complement the views of primary and secondary stakeholders, field observations were carried out. This was done in order to enhance knowledge on the 'drivers', 'pressures', 'state', 'impacts' and appropriate 'response' measures for tackling the plastic waste issue in the Ramsar site.

3.12 Data Analysis

3.12.1 Macroplastic Litter

Shapiro-Wilk test was used to verify the normality of the macroplastic data in IBM SPSS Statistics 25 software. Descriptive Statistical Analysis was carried out in Microsoft Excel 2019 software for the determination of the monthly abundance, diversity and sources of macroplastic litter at each sampling location. One-Way Analysis of Variance (ANOVA) was used to determine if there is a statistically significant difference in macroplastic abundance and diversity across the three (3) sampling locations in the Ramsar site as well as across months. This was done in IBM SPSS Statistics 25 software. A statistical significance level of 0.05 was used for all analyses. All visual representation of data was carried out in Microsoft Excel 2019 software.

3.12.2 Microplastics

Normality and homogeneity of microplastic data were determined using the Shapiro-Wilk test and Levene's test respectively in IBM SPSS Statistics 25 software. Descriptive statistical analyses of the abundance, shape, size and colour of microplastics in the sediment cores were undertaken in Microsoft Excel 2019 software. In IBM SPSS Statistics 25 software, One-Way ANOVA was undertaken to determine if there is a significant difference in mean microplastic abundance across the three (3) sampling locations. Pearson product correlation analysis was carried out to determine the relationship between mean microplastic abundance and sediment core depth at the sampling locations. Simple linear regression was also carried out to assess the predictive relationship between the calculated national average macroplastic polymer composition adapted from Miezah *et al*. (2015) and the microplastic composition from the Ramsar site. A statistical significance level of 0.05 was used for all analyses. All visual representation of data was undertaken in Microsoft Excel 2019 software.

3.12.3 Questionnaires and Semi-Structured Interviews

Descriptive statistical analysis was carried out on the questionnaire responses of primary stakeholders in Microsoft Excel 2019 and IBM SPSS Statistics 25 software for the determination of their perceptions of the 'drivers', 'pressures', 'state', 'impacts' and appropriate 'response' to plastic waste accumulation in the Ramsar site. Thematic analysis was undertaken on the transcribed interview responses of secondary stakeholders. All visual representation of data was carried out in Microsoft Excel 2019 software.

3.13 Limitation of Study

The limitation of this study was the relatively short time frame (two months) for the sediment trap deployment. This short time frame may not fully account for sedimentary processes such as resuspension of sediments which is associated with varying hydrodynamic conditions over longer periods. Despite this limitation, the study provides reliable information on plastic waste accumulation in the Ramsar site and can also serve as a basis for the conduction of future studies which account for longer term trends in sediment deposition processes.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter presents results of data collected during this research using the methods described in Chapter Three (3). The chapter is divided into sections based on the specific objectives of this research.

4.2 Abundance, Diversity and Sources of Macroplastic Litter in the Ramsar Site

4.2.1 Abundance of Macroplastic Litter

Over the entire three (3) months sampling period (August to October, 2023), a total of 3856 individual macroplastic items were recorded across all three sampling locations. The monthly abundance of macroplastic litter recorded at each sampling location is described in the following sections.

Panbros Sampling Location

Across the three months sampling period, a total abundance of 762 macroplastic items were recorded at the Panbros sampling location with the highest being recorded in September (n = 301) while the second highest was in August (n = 253) and the lowest was in October (n = 208) as shown in Table 4.1. The monthly macroplastic litter accumulation rates were 0.17 items/m^2/month for August, 0.20 items/m^2/month for September as well as 0.14 items/m^2/month for October. The mean accumulation rate over the three (3) months period was 0.17 ± 0.03 items/m^2/month (Table

4.2). Figure 4.1 shows the monthly abundance of macroplastic litter at the Panbros sampling location.

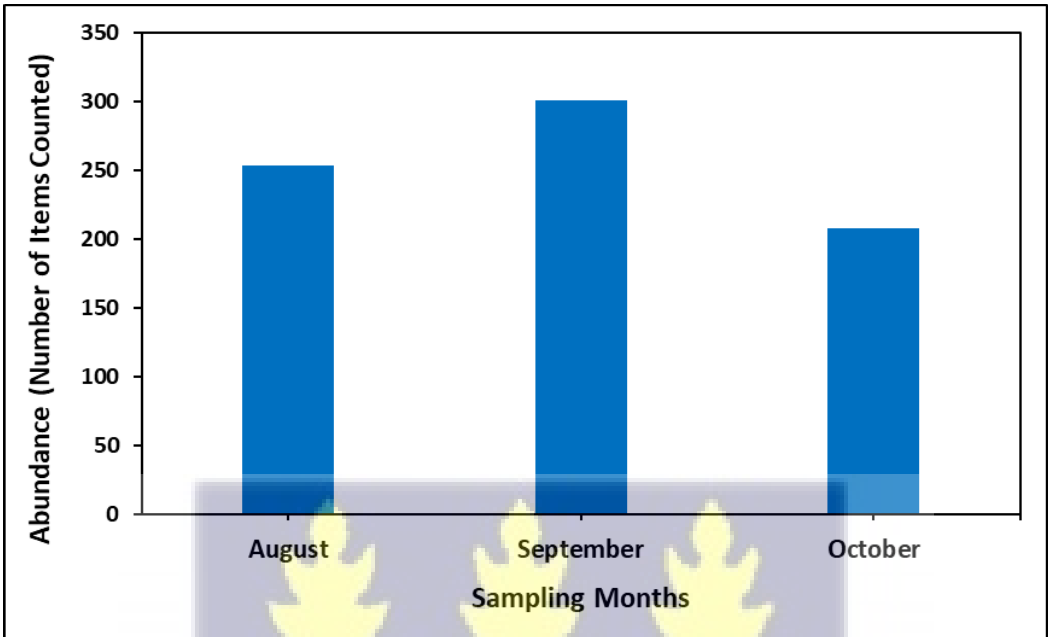


Figure 4.1: Monthly Abundance of Macroplastic Litter at Panbros Sampling Location (August – October, 2023)

Tsokome Sampling Location

A total of 1186 macroplastic items were recorded at Tsokome across the three months period. As shown in Table 4.1, the highest was recorded in August (n = 501), the second highest was recorded in September (n = 426) and the least was recorded in October (n = 259). The monthly macroplastic litter accumulation rates were 0.33 items/m^2/month for August, 0.28 items/m^2/month for September and 0.17 items/m^2/month for October while the mean accumulation rate across the three months was 0.26 ± 0.08 items/m^2/month (Table 4.2). Figure 4.2 illustrates the monthly abundance of macroplastic litter at Tsokome.

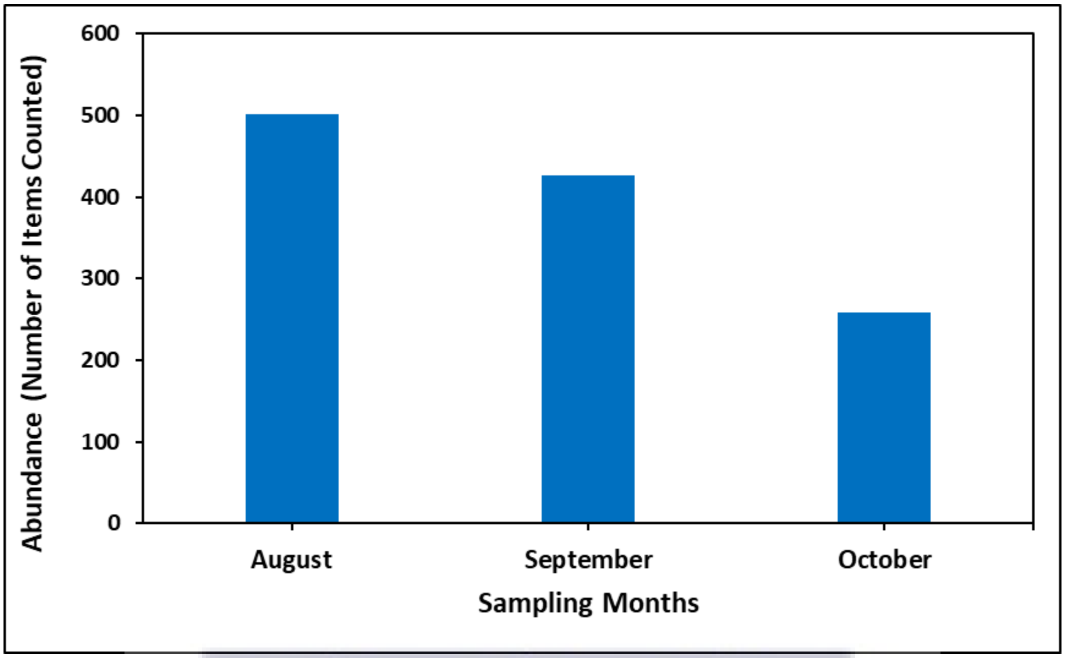


Figure 4.2: Monthly Abundance of Macroplastic Litter at Tsokome Sampling Location (August – October, 2023)

Densu Estuary Sampling Location

Across the three months of sampling, a total abundance of 1908 macroplastic items were recorded at the Densu Estuary sampling location. Six hundred and fourteen (614) items were recorded in August, 533 items were recorded in September and 761 were recorded in October which made October the month with the highest abundance (Table 4.1). August represented the month with the second highest abundance while September was the month with the lowest abundance. The monthly macroplastic litter accumulation rates were 0.41 items/m^2/month for August, 0.36 items/m^2/month for September and 0.51 items/m^2/month for October. Across the three months, the mean accumulation rate was 0.43 ± 0.08 items/m^2/month (Table 4.2). Figure 4.3 shows the monthly abundance of macroplastic litter at the Densu Estuary sampling location. Tables 4.1 and

4.2 also show summaries of the monthly abundance and rates of macroplastic litter accumulation for each sampling location respectively.

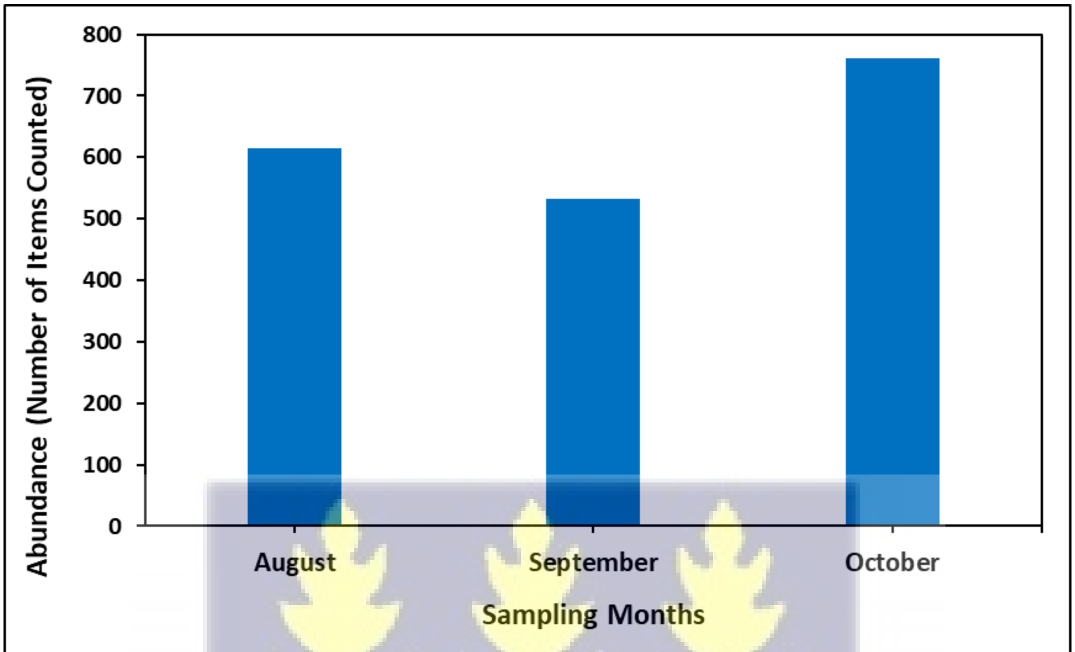


Figure 4.3: **Monthly Abundance of Macroplastic Litter at Densu Estuary Sampling Location (August – October, 2023)**

Table 4.1: Summary of the Abundance of Macroplastic Litter Across Sampling Locations and Months in the Densu Ramsar Site

Sampling Months	Panbros	Tsokome	Densu Estuary	Total Abundance Per Month
August	253	501	614	**1368**
September	301	426	533	**1260**
October	208	259	761	**1228**

Total Abundance Per Location	**762**	**1186**	**1908**	**3856**

Table 4.2: Summary of Monthly Rates of Macroplastic Litter Accumulation for each Sampling Location in the Densu Ramsar Site

Sampling Months	Panbros (items/m²/month)	Tsokome (items/m²/month)	Densu Estuary (items/m²/month)
August	0.17	0.33	0.41
September	0.20	0.28	0.36
October	0.14	0.17	0.51
Mean Macroplastic Litter Accumulation Rate Across Three Months	**0.17 ± 0.03**	**0.26 ± 0.08**	**0.43 ± 0.08**

<u>Comparison of Monthly Abundance and Accumulation Rates of Macroplastic Litter Across Locations</u>

Across the three sampling locations, the Densu Estuary recorded the highest monthly abundance of macroplastic litter. This was followed by the Tsokome sampling location while the least monthly abundance was recorded at Panbros (Table 4.1). One-Way ANOVA showed a statistically significant difference in the monthly abundance across the three locations ($p = 0.010$). Tukey HSD post hoc test showed that this difference was significant between Panbros and Densu Estuary sampling locations ($p = 0.009$). All locations together yielded a total abundance of 1368 macroplastic items in August (which represented the month with the highest abundance), 1260 items in September; representing the second highest and the least in October with 1228 items (Table 4.1). One-Way ANOVA, however, indicated that there was no statistical significance in macroplastic abundance across months ($p = 0.963$).

In relation to the monthly rates of macroplastic litter accumulation across locations, One-Way ANOVA showed a statistically significant difference ($p = 0.009$). Tukey HSD post hoc test again showed that the difference was significant between Panbros and Densu Estuary sampling locations ($p = 0.008$). Across the three months, the mean macroplastic litter accumulation rate was highest at the Densu Estuary (0.43 ± 0.08 items/m^2/month) while the second highest rate was at the Tsokome sampling location (0.26 ± 0.08 items/m^2/month) and the lowest at Panbros (0.17 ± 0.03 items/m^2/month) as shown in Table 4.2. Figures 4.4 and 4.5 show the monthly abundance and mean rates of macroplastic litter accumulation across the three (3) sampling locations and months respectively.

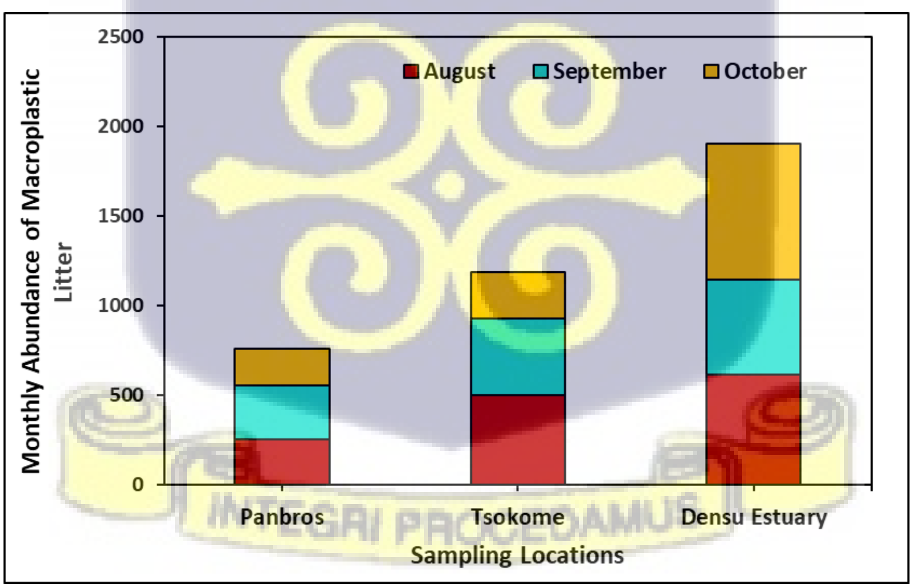


Figure 4.4: Monthly Abundance of Macroplastic Litter Across Sampling Locations of the Densu Ramsar Site

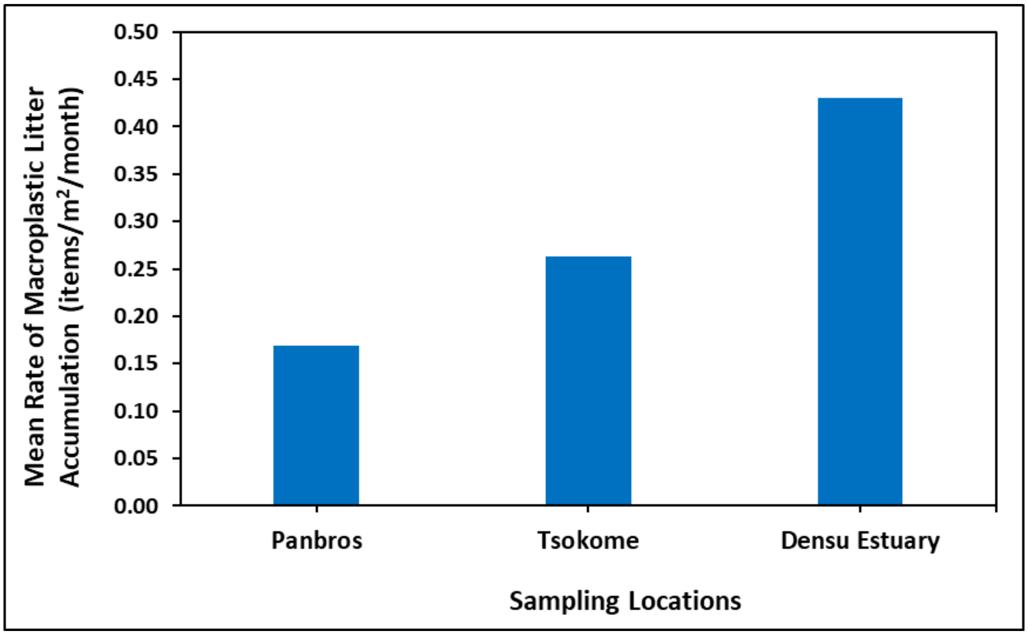


Figure 4.5: Mean Rate of Macroplastic Litter Accumulation for Each of the Three (3) Sampling Locations Across the Three (3) Months Period

4.2.2 Diversity of Macroplastic Litter

Across all three (3) sampling locations, a total of twenty-five (25) macroplastic litter categories were recorded over the entire three (3) month sampling period in accordance with OSPAR Commission (2010) classification. The four (4) highest occurring litter categories across locations were small bags (n = 748), black polythene bags (n = 631), water sachets (n = 625) and drinks/water bottles (n = 608). The number and specific types of macroplastic litter categories (diversity) identified at each sampling location is described in the following sections.

<u>**Panbros Sampling Location**</u>

Across the three (3) months period, seventeen (17) macroplastic litter categories (based on OSPAR Commission (2010) classification) were observed at the Panbros sampling location. This represents 68.0% of the total number of macroplastic litter categories recorded across all three sampling locations over the entire sampling period. The macroplastic litter categories observed comprised: drinks/water bottles, water sachets, caps/lids, black polythene bags, small bags, disposable plastic drinking cups, alcohol sachets, amongst others (Figure 4.6). Twelve (12) of the litter categories were observed in August, thirteen (13) in September and twelve (12) in October (Table 4.3).

Over the three months, water sachets were the highest recorded litter category at the Panbros sampling location (n = 193). The highest quantity of water sachets was in September (n = 78), the next highest quantity was in August (n = 63) and the lowest was in October (n = 52). Drinks/water bottles were the second highest recorded litter category across the three (3) months period (n = 147). They were highest in September (n = 62). The second highest quantity was in August (n = 54) and the least was in October (n = 31). Black polythene bags were the third highest litter category across the three months (n = 109). Its highest abundance and second highest abundance were recorded in September (n = 46) and October (n = 32) respectively while its lowest abundance was recorded in August (n = 31).

Majority of the macroplastic litter categories identified at the Panbros sampling location were consistently recorded in all three sampling months except for ‘others’, plastic medical packaging, plastic labels, plastic shoes and flip-flops, plastic cosmetic packaging, sanitary towels and diapers, food containers (takeaway packs) and nets which were inconsistent across the three months (Appendix C). Figure 4.6 shows the macroplastic litter categories recorded at the Panbros sampling location across the three months period in order of decreasing abundance.

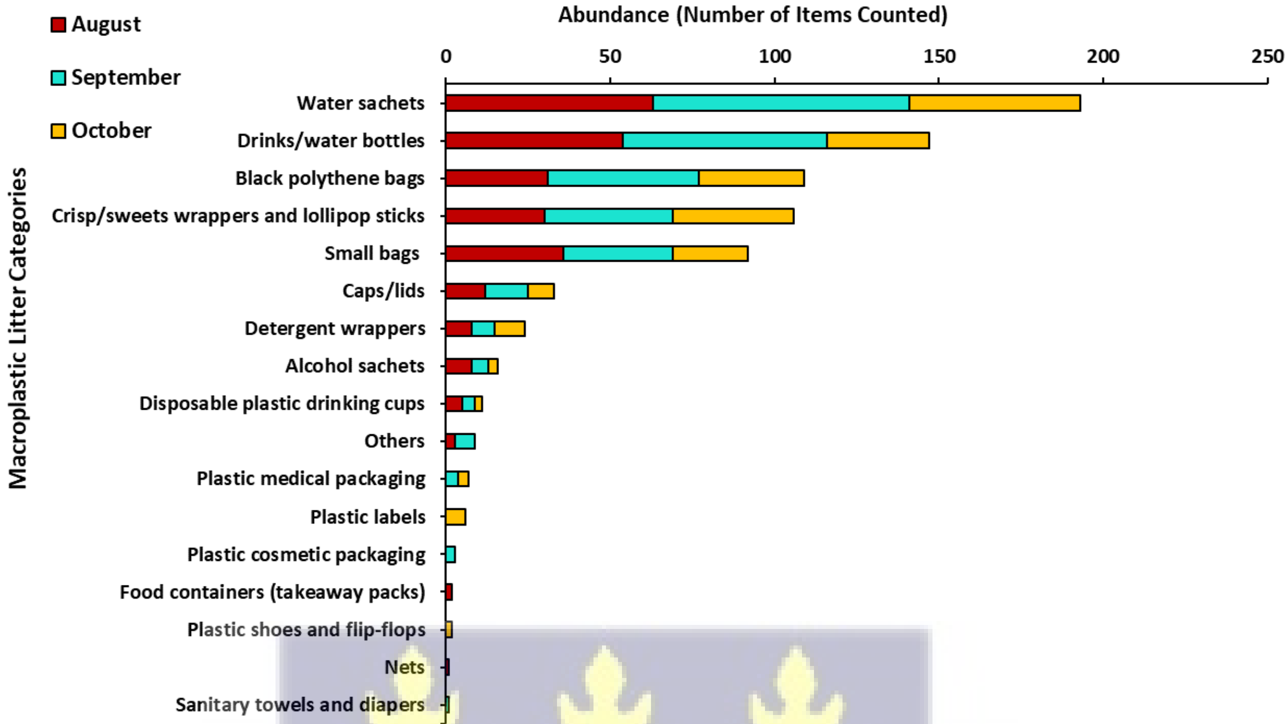


Figure 4.6: Macroplastic Litter Categories Recorded Across Three Months Period at Panbros (August – October, 2023) in the Densu Ramsar Site

<u>Tsokome Sampling Location</u>

At the Tsokome sampling location, twenty-two (22) macroplastic litter categories were identified over the three months period. This represents 88.0% of the total number of macroplastic litter categories recorded across all three sampling locations over the three months period. The categories consisted of: drinks/water bottles, caps/lids, water sachets, black polythene bags, small bags, alcohol sachets, disposable plastic drinking cups, plastic cutlery and straws, amongst others (Figure 4.7). Twenty (20), seventeen (17) and sixteen (16) categories were recorded in the months of August, September and October respectively (Table 4.3).

Across the three months period, small bags were the highest occurring macroplastic litter category at the Tsokome sampling location (n = 405). Its highest quantity was recorded in August (n = 189) while the second highest and least quantities were recorded in the months of September (n = 135) and October (n = 81) respectively. Black polythene bags represented the second highest occurring macroplastic litter category across the three months period (n = 273). They were most abundant in August (n = 118) with the second highest abundance occurring in September (n = 98) and the least occurring in October (n = 57). Water sachets were the third highest litter category (n = 146). The greatest amount of water sachets was recorded in August (n = 61), the second highest was in September (n = 50) and the lowest was in October (n = 35).

Majority of the macroplastic litter categories recorded at the Tsokome sampling location consistently occurred in all three months of sampling with the exception of plastic cutlery and straws, food containers (takeaway packs), rope, nylon sacks, plastic cosmetic packaging, sanitary towels and diapers, plastic medical packaging and foam which were absent in some months (Appendix D). Figure 4.7 shows the macroplastic litter categories recorded at the Tsokome sampling location across the three sampling months in order of decreasing abundance.

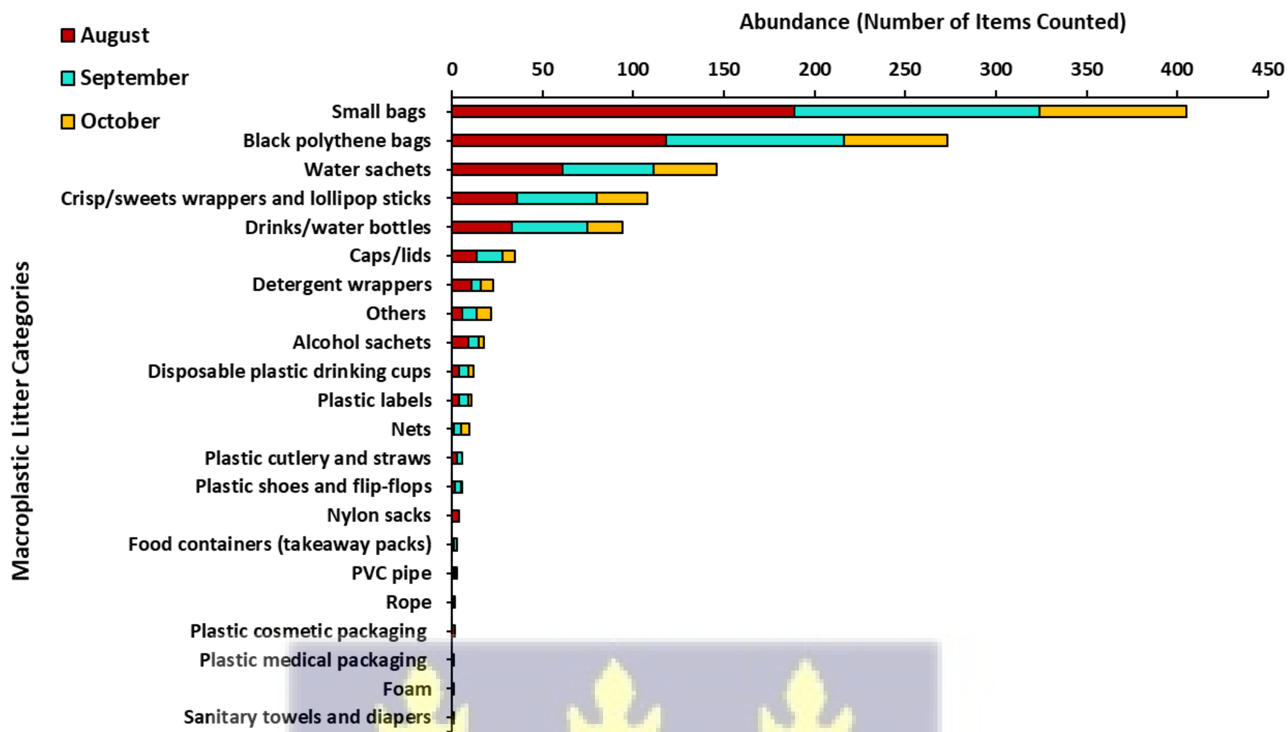


Figure 4.7: Macroplastic Litter Categories Recorded Across Three Months Period at Tsokome (August – October, 2023) in the Densu Ramsar Site

<u>Densu Estuary Sampling Location</u>

Over the three months, twenty-three (23) macroplastic litter categories were recorded at the Densu Estuary sampling location. This represents 92.0% of the total number of macroplastic litter categories recorded across all three sampling locations over the entire sampling period. The macroplastic litter categories recorded over the three months period were composed of: drinks/water bottles, caps/lids, water sachets, black polythene bags, small bags, alcohol sachets, disposable plastic drinking cups, amongst others (Figure 4.8). Seventeen (17) of these litter categories were recorded in August, nineteen (19) categories were recorded in September and nineteen (19) categories were recorded in October (Table 4.3).

Across the three months period, drinks/water bottles represented the macroplastic litter category with the greatest abundance (n = 367). The highest amount was recorded in October (n = 158) while the second highest and least were recorded in August (n = 112) and September (n = 97) respectively. Water sachets were the second highest litter category across the three months period (n = 286). Again, its highest abundance was in October (n = 135); its second highest was in August (n = 81) and the least was in September (n = 70). Small bags represented the third highest litter category identified across the three months period with a total abundance of 251. The highest quantity which was 94 was recorded in October while the second highest and least quantities were recorded in September (n = 93) and August (n = 64) respectively.

Most macroplastic litter categories encountered at the Densu Estuary sampling location were consistently recorded throughout the three sampling months except for detergent wrappers, sanitary towels and diapers, food containers (takeaway packs), foam, pens, combs/plastic hair brushes, cigarette lighters, nylon sacks and rope which exhibited inconsistency (Appendix E).

Figure 4.8 shows the macroplastic litter categories recorded at the Densu Estuary sampling location across the three months period in order of decreasing abundance. Table 4.3 shows a summary of the number of macroplastic litter categories recorded for each of the three (3) sampling locations on a monthly basis as well as the overall number of categories recorded per location and per month. Plate 4.1 also shows samples of some of the macroplastic litter categories recorded across the three (3) sampling locations over the three (3) months period.

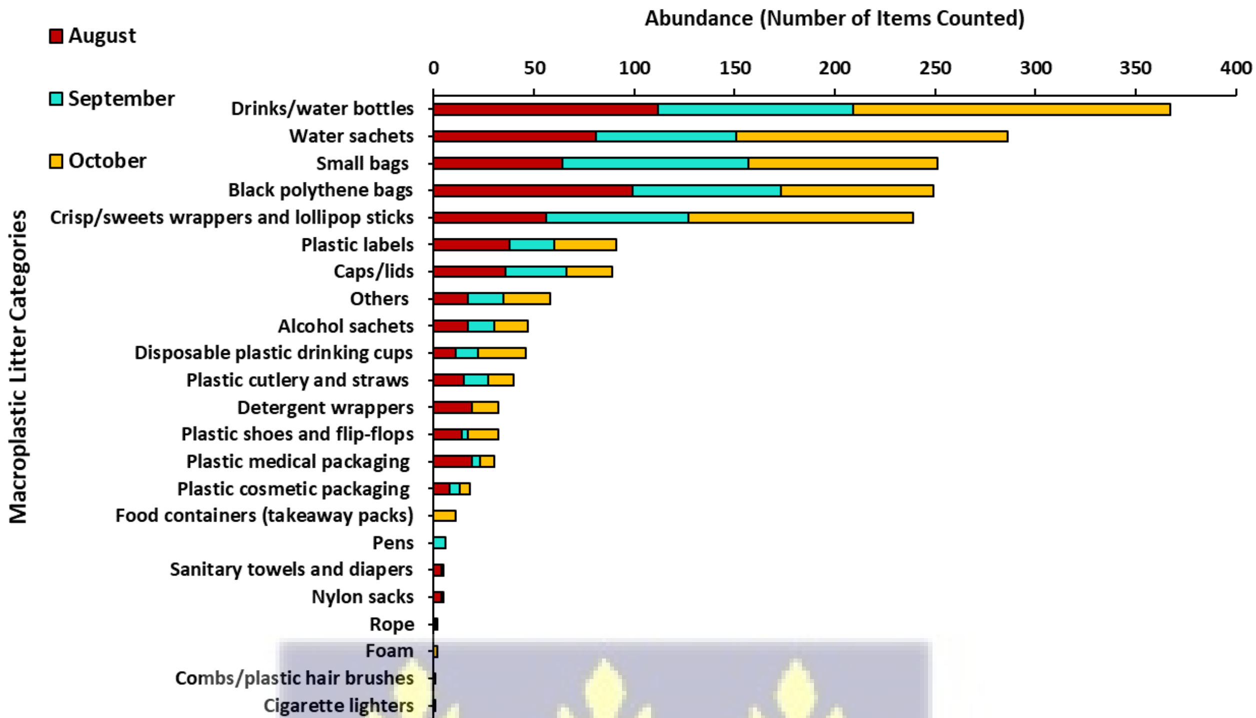


Figure 4.8: Macroplastic Litter Categories Recorded Across Three Months Period at Densu Estuary (August – October, 2023) in the Densu Ramsar Site

Table 4.3: Summary of Number of Macroplastic Litter Categories (Diversity) Recorded Across the Different Sampling Locations in the Densu Ramsar Site

Sampling Months	Panbros	Tsokome	Densu Estuary	Overall Number Per Month	Percentage (%) of Overall Number Per Month
August	12	20	17	**21**	**84.0**
September	13	17	19	**24**	**96.0**
October	12	16	19	**21**	**84.0**

Overall Number Per Site	**17**	**22**	**23**	**-**	**-**
Percentage (%) of Overall Number Per Site	**68.0**	**88.0**	**92.0**	**-**	**-**

Plate 4.1: Samples of Some of the Macroplastic Litter Categories from the Densu Ramsar Site

Source of Images: Author

Comparison of Macroplastic Litter Diversity Across Locations and Months

Overall, the Densu Estuary sampling location had the most diverse range of macroplastic litter categories (n = 23) while Tsokome sampling location had the second most diverse range (n = 22) across the three months period. The Panbros sampling location on the other hand had the least diverse range (n = 17). One-Way ANOVA showed a statistically significant difference in diversity across locations (p = 0.004). Tukey HSD post hoc test indicated that the significance was greatest between Panbros and Densu Estuary (p = 0.005). With regard to the macroplastic litter diversity across months, it is evident from Table 4.3 that diversity was highest in September (n = 24). Both August and October on the other hand recorded the same level of diversity (n = 21), making them both the second highest. One-Way ANOVA showed that there was no statistically significant difference across months (p = 0.966).

4.2.3 Sources of Macroplastic Litter

Public litter which is a land-based source was the most dominant source, constituting 95.82% of macroplastic litter recorded across all sampling locations in the Ramsar site over the three months period. Shipping and fly tipped sources on the other hand were not recorded at any of the sampling locations.

Panbros Sampling Location

Public litter was the most dominant source identified in all three (3) months of sampling at the Panbros sampling location. Public litter was consistently encountered throughout all three (3) months and accounted for 83.33% of all macroplastic litter recorded in August, 76.92% of the macroplastic litter recorded in September and 91.67% of the macroplastic litter recorded in

October. The fishing category accounted for 8.33% of litter recorded in August but was absent in September and October. Sewage-related debris represented 7.69% of the litter recorded in September but was absent in August and October. The medical category accounted for 7.69% of the litter recorded in September and 8.33% of the litter recorded in October but was absent in August. The non-sourced category represented 8.33% of the litter recorded in August and 7.69% of the litter recorded in September but was absent in October.

After public litter, the medical and non-sourced categories both represented the second most prevalent macroplastic litter source across all three sampling months. The fishing category on the other hand represented the third most dominant source while sewage-related debris accounted for the least dominant source at the Panbros sampling location. Figure 4.9 shows the sources of macroplastic litter at the Panbros sampling location.

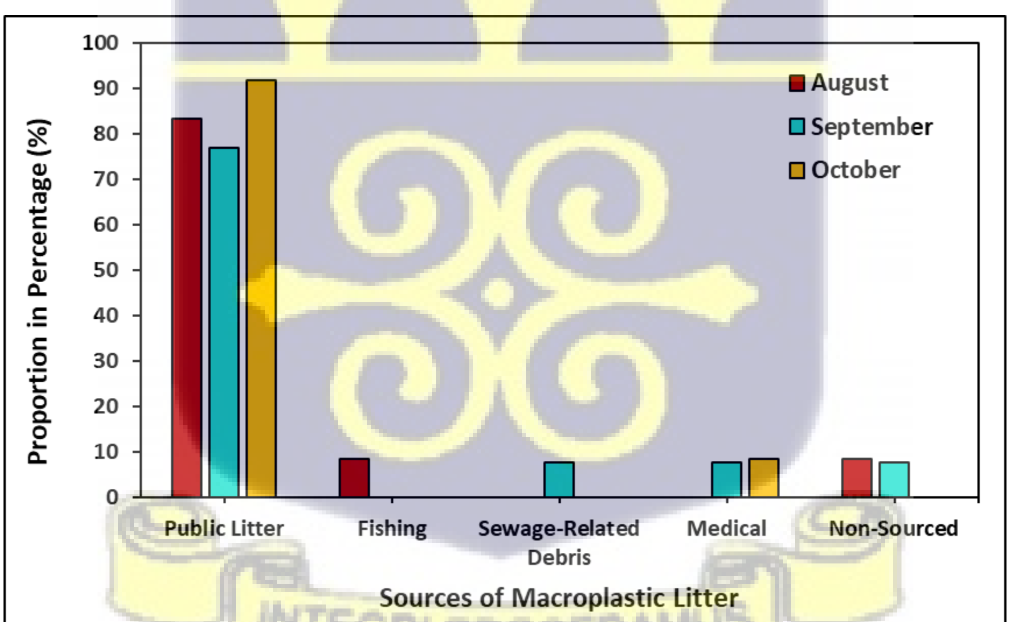


Figure 4.9: Sources of Macroplastic Litter at Panbros (August – October, 2023) in the Densu Ramsar Site

<u>Tsokome Sampling Location</u>

Public litter was the most prevalent source of macroplastic litter recorded across all three (3) months at the Tsokome sampling location. It was consistently found in all three (3) months and accounted for 75.00% each of macroplastic litter recorded in August and October as well as 82.35% of litter recorded in September. The fishing category accounted for 10.00%, 11.76% and 6.25% of litter recorded in August, September and October respectively. Sewage-related debris accounted for 5.00% of litter recorded in August but was absent in September and October. The medical category was only present in October and accounted for 6.25% of the macroplastic litter recorded while the non-sourced category represented 10.00% of litter recorded in August, 5.88% in September and 12.50% in October. Across the three sampling months, the non-sourced category represented the second most dominant source. This was followed by the fishing, medical and sewage-related debris categories in order of decreasing dominance. Figure 4.10 illustrates the sources of macroplastic litter at the Tsokome sampling location.

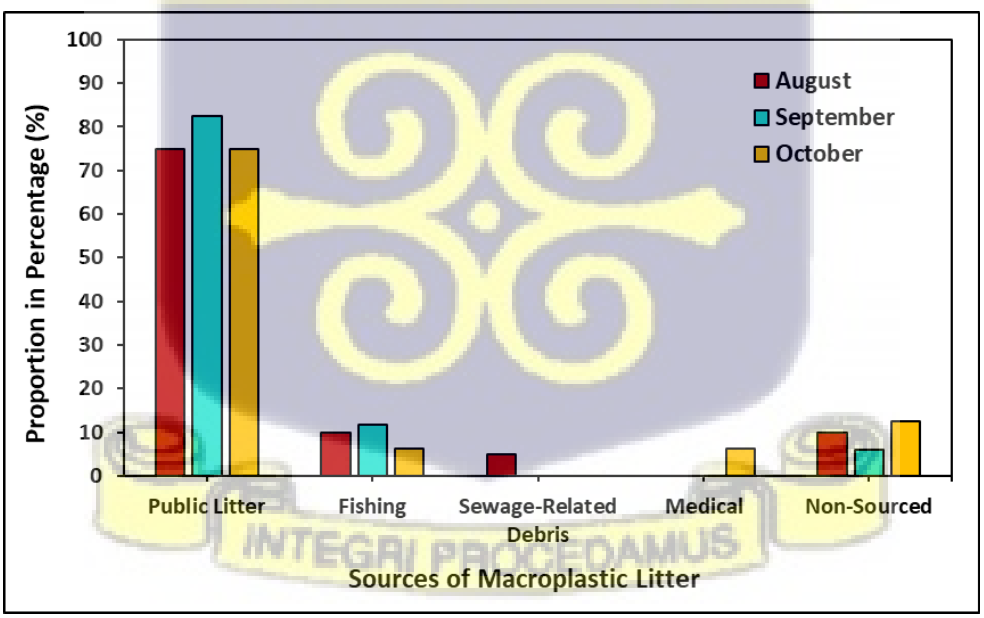


Figure 4.10: Sources of Macroplastic Litter at Tsokome (August – October, 2023) in the Densu Ramsar Site

Densu Estuary Sampling Location

At the Densu Estuary sampling location, public litter was the most dominant source of macroplastic litter across all three months. It was consistently recorded in all three months and accounted for 76.47%, 78.95% and 73.68% of macroplastic litter in August, September and October respectively. Fishing category accounted for 5.26% each in September and October but was absent in August. Sewage-related debris accounted for 5.88% in August and 5.26% in October but was absent in September. The medical category represented 5.88% of litter recorded in August while September and October recorded 5.26% each. The non-sourced category on the other hand represented 11.76% of litter recorded in August while September and October recorded 10.53% each. The non-sourced and medical categories represented the second and third most prevalent sources respectively across the three (3) months period. Again, sewage-related debris represented the fourth most prevalent source while the fishing category accounted for the least prevalent source. Figure 4.11 illustrates the sources of macroplastic litter at the Densu Estuary sampling location.

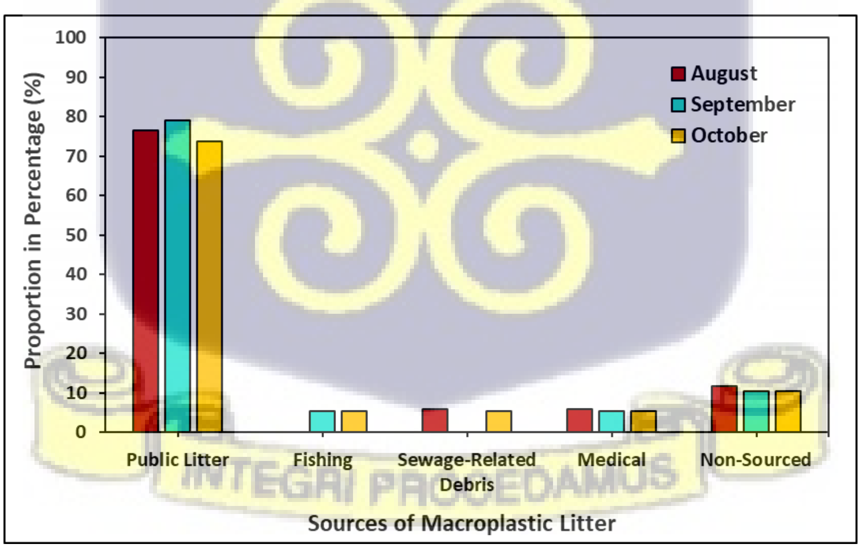


Figure 4.11: Sources of Macroplastic Litter at Densu Estuary (August – October, 2023) in the Densu Ramsar Site

Brand Audit

Of the twenty-five (25) macroplastic litter categories recorded across all sampling locations in the Ramsar site for the three months period, thirteen (13) of them, constituting 52.0% were made up of unbranded items. The unbranded items included black polythene bags, disposable plastic drinking cups, small bags, plastic cutlery and straws, foam, rope, net, among others. The remaining 48.0% (n = 12) consisted of plastic items that are typically branded. Of this percentage which is typically branded, a significant portion of the brand names were illegible as a result of subjection to adverse environmental conditions and were consequently unidentifiable. The macroplastic litter categories with the most identifiable brand names were drinks/water bottles, water sachets, alcohol sachets as well as detergent wrappers. A larger portion of the brands identified were local brands. The top brands identified over the three (3) months period under the drinks/water bottles category were 'Belcola', 'Voltic', 'Beta Malt', 'Belaqua', 'Malta Guiness', 'Aqua Splash' and 'Special Ice'. The top brands under the water sachets category were 'Sprint Ice', 'Everpure', 'Favor Ice' and 'Voltic Cool'. For the alcohol sachets category, the top brands identified were 'Kasempa', 'Adonko', 'Goal' and 'Striker' and for the detergent wrappers category, the top brands were 'Lavita', 'MOK' and 'So Klin'.

4.3 Microplastic Abundance in Sediment Cores and Historical Trend in Microplastic Accumulation in the Ramsar Site

4.3.1 Microplastic Abundance in Sediment Cores

Microplastics were found in all replicate sediment cores at the three (3) sampling locations (Panbros, Tsokome and Densu Estuary) in the Ramsar site. A total of 849 microplastics were recorded for all replicate cores across the three (3) locations.

At the Panbros sampling location, a total of 278 microplastics were recorded across all three (3) replicate sediment cores. The microplastic abundance in the various depths of the three (3) replicate cores ranged between 8 – 21 microplastics per 50 grams of sediments (microplastics/50g) with a mean abundance of 15.44 ± 3.50 microplastics/50g. At the Tsokome sampling location, a total of 267 microplastics were observed for all triplicate cores. The microplastic abundance in the various depths of the replicate cores ranged between 9 – 20 microplastics/50g with an average abundance of 14.83 ± 2.87 microplastics/50g. The total number of microplastics recorded for all replicate cores at the Densu Estuary sampling location was 304 microplastics. The microplastic abundance of the various depths in the replicate cores ranged between 11 – 26 microplastics/50g with a mean abundance of 16.89 ± 3.80 microplastics/50g.

Of all the three sampling locations, the Densu Estuary had the highest total amount of microplastics (n = 304). This was followed by the Panbros sampling location (n = 278) while Tsokome had the least amount (n = 267). However, One-Way ANOVA of the mean microplastic abundance across the three (3) sampling locations did not show a statistically significant difference ($p = 0.51$). The mean microplastic abundance through sediment core depth expressed in microplastics/50g for each location is shown in Table 4.4. It was also expressed in microplastics/kg (Appendix F).

Table 4.4: Mean Microplastic Abundance at Different Sediment Core Depths, Measured in Microplastics/50g for Each Sampling Location in the Densu Ramsar Site

Sediment Core Depth (cm)	Panbros (Mean ± Standard Deviation)	Tsokome (Mean ± Standard Deviation)	Densu Estuary (Mean ± Standard Deviation)
0 – 5	19.00 ± 1.73	13.67 ± 2.52	13.00 ± 2.00
5 – 10	17.33 ± 1.53	17.67 ± 3.21	23.33 ± 2.52
10 – 15	16.00 ± 2.00	16.67 ± 2.52	17.33 ± 2.08
15 – 20	15.67 ± 4.04	15.00 ± 1.73	17.67 ± 1.53
20 – 25	14.67 ± 2.08	14.67 ± 1.53	16.33 ± 1.15
25 – 30	10.00 ± 2.00	11.33 ± 2.08	13.67 ± 1.53

4.3.2 Relationship between Microplastic Abundance and Sediment Core Depth

From Table 4.4, the mean abundance of microplastics in the sediment cores of the Panbros sampling location showed an enrichment in the topmost layer (0 – 5 cm), and exhibited a consistent decrease to the last layer (25 – 30 cm). Conversely, at the Tsokome and Densu Estuary sampling locations, the mean microplastic abundance was relatively low at the top layer (0 – 5 cm) and showed fluctuations in the subsequent layers.

Pearson product correlation analysis showed that there was a strong negative correlation and statistically significant relationship between mean microplastic abundance and the sediment core depth at the Panbros sampling location ($r = -0.931$, $p = 0.007$). At the Tsokome sampling location, there was a moderate negative correlation between the mean microplastic abundance and sediment core depth ($r = -0.534$). However, this relationship was not statistically significant ($p = 0.275$). At the Densu Estuary sampling location, there was a weak negative correlation and the relationship was not statistically significant ($r = -0.251$, $p = 0.632$). Table 4.5 shows the Pearson correlation coefficients (r) and p-values for each sampling location.

Table 4.5: Correlation Between Mean Microplastic Abundance and Sediment Core Depth for Each Sampling Location in the Densu Ramsar Site

Sampling Location	r [a]	p-value
Panbros	-0.931	0.007
Tsokome	-0.534	0.275
Densu Estuary	-0.251	0.632

[a] r = Pearson Correlation Coefficient

Regarding the Panbros sampling location which exhibited a strong negative correlation and statistically significant relationship ($r = -0.931$, $p = 0.007$), a simple linear regression undertaken to assess the predictive relationship between sediment core depth and mean microplastic abundance revealed that sediment core depth accounted for 86.8% of the variance in mean microplastic abundance ($r^2 = 0.868$, $F (1, 4) = 26.197$, $p = 0.007$). Thus, sediment core depth significantly predicts microplastic abundance at the Panbros sampling location ($\beta = -1.523$, $t (4) = -5.118$, $p = 0.007$). The results indicate that an increase in sediment core depth leads to lower microplastic abundance at the Panbros sampling location. Table 4.6 and Figure 4.12 show a summary of the simple linear regression results.

Table 4.6: Results of Simple Linear Regression Between Sediment Core Depth and Mean Microplastic Abundance at Panbros in the Densu Ramsar Site

Regression Weights	ß [a]	r^2 [b]	F [c]	t-value	p-value
SCD [d] → MMA [e]	-1.523	0.868	26.197	-5.118	0.007

[a] ß = Beta Coefficient

[b] r^2 = Coefficient of Determination

[c] F = F-Statistic Indicating Overall Model Significance

[d] SCD = Sediment Core Depth

[e] MMA = Mean Microplastic Abundance

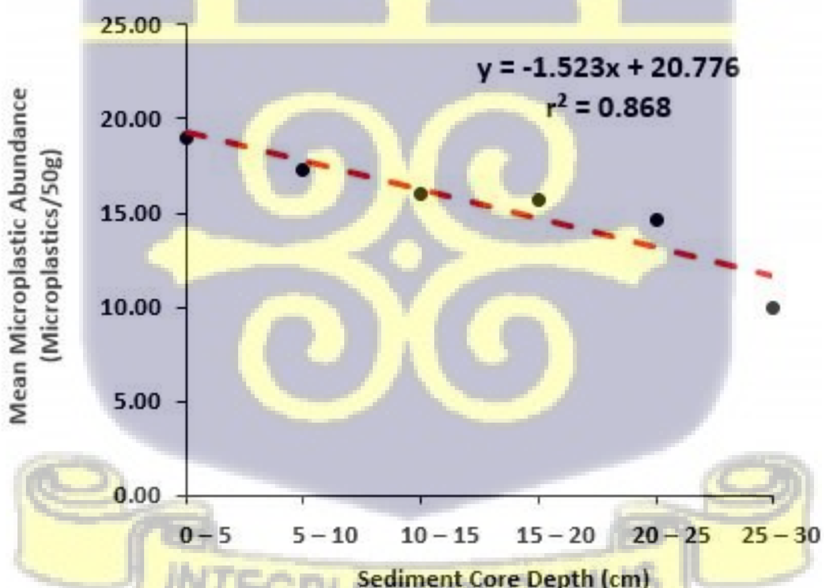


Figure 4.12: Simple Linear Regression Between Sediment Core Depth and Mean Microplastic Abundance at Panbros in the Densu Ramsar Site

4.3.3 Linear and Mass Sediment Accumulation Rates

Panbros Sampling Location

The mean mass sediment accumulation rate at the Panbros sampling location was 1.63 ± 0.23 $g/cm^2/yr$ and the mean linear sediment accumulation rate was 0.62 ± 0.09 cm/yr (Table 4.7). With this linear accumulation rate (0.62 cm/yr), each 5 cm sediment core interval was equivalent to ~8 years of sediment accumulation (Table 4.8).

Tsokome Sampling Location

The mean mass and linear accumulation rates of sediments at the Tsokome sampling location were 2.51 ± 0.20 $g/cm^2/yr$ and 0.95 ± 0.08 cm/yr respectively (Table 4.7). With a linear accumulation rate of 0.95 cm/yr, each 5 cm core interval corresponded to ~5 years of sediment accumulation (Table 4.8).

Densu Estuary Sampling Location

The mean mass sediment accumulation rate at the Densu Estuary sampling location was 5.15 ± 0.27 $g/cm^2/yr$ while the linear accumulation rate was 1.95 ± 0.11 cm/yr (Table 4.7). This linear accumulation rate (1.95 cm/yr) implied that each 5 cm core interval was equivalent to ~3 years of accumulation (Table 4.8).

Table 4.7: Mass and Linear Sediment Accumulation Rates from Sediment Traps at Each Sampling Location in the Densu Ramsar Site

Sampling Location	Trap Deployment Duration	Mass (g)	Mass Accumulation Rate ($g/cm^2/yr$)	Linear Accumulation Rate (cm/yr)
Panbros	One (1) Month	11.70 ± 0.81	1.79	0.68
	Two (2) Months	19.27 ± 1.07	1.47	0.55
	Mean	**15.49 ± 5.35**	**1.63 ± 0.23**	**0.62 ± 0.09**
Tsokome	One (1) Month	15.48 ± 1.04	2.37	0.89
	Two (2) Months	34.71 ± 5.09	2.65	1.00
	Mean	**25.10 ± 13.60**	**2.51 ± 0.20**	**0.95 ± 0.08**
Densu Estuary	One (1) Month	32.44 ± 0.49	4.96	1.87
	Two (2) Months	69.89 ± 1.80	5.34	2.02
	Mean	**51.17 ± 26.48**	**5.15 ± 0.27**	**1.95 ± 0.11**

Table 4.8: Age-Depth Profile of Sediment Cores at Sampling Locations in the Densu Ramsar Site

Sediment Core Depth (cm)	Year		
	Panbros	Tsokome	Densu Estuary
0	2023	2023	2023
5	2015	2018	2020

Sediment Core Depth (cm)	Year		
	Panbros	Tsokome	Densu Estuary
10	2007	2013	2017
15	1999	2008	2014
20	1991	2003	2011
25	1983	1998	2008
30	1975	1993	2005

4.3.4 Historical Trend in Microplastic Accumulation in the Ramsar Site

Panbros Sampling Location

The 30 cm long sediment core at the Panbros sampling location represents a deposition period extending from 1975 to 2023. The year 2023 corresponds with the surface sediments (0 cm) and 1975 corresponds with the deepest sediments (30 cm). The largest mean microplastic abundance (19.00 ± 1.73 microplastics/50g) was recorded in the uppermost layer (0 – 5 cm) that corresponds with 2023 to 2015. This was succeeded by a clear continuous decline in mean microplastic abundance to the deepest layer (25 – 30 cm) which corresponds with 1983 to 1975 where the smallest mean microplastic abundance was recorded (10.00 ± 2.00 microplastics/50g). This historical trend thus reveals a steady growth in microplastic abundance from 1975 to 2023. Figure 4.13 shows the age-depth profile of mean microplastic abundance through the sediment core from the Panbros sampling location.

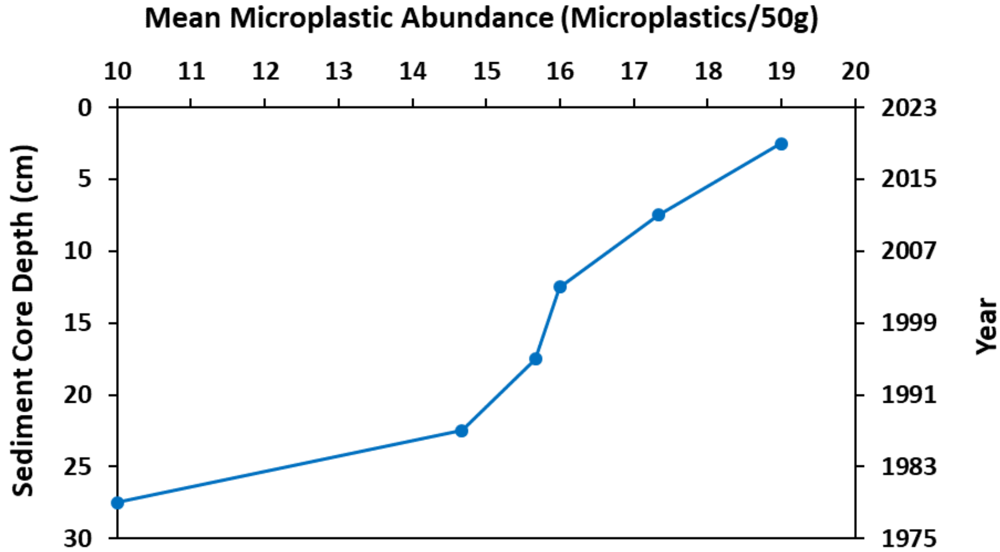


Figure 4.13: Age-Depth Profile of Mean Microplastic Abundance in Sediment Core from the Panbros Sampling Location

Tsokome Sampling Location

The sediment core at the Tsokome sampling location is equivalent to a deposition period ranging from 1993 to 2023. The year 2023 corresponds with the surface sediments (0 cm) and 1993 corresponds with the deepest sediments (30 cm). The topmost depth interval (0 – 5 cm) that corresponds with 2023 to 2018 had a mean microplastic abundance of 13.67 ± 2.52 microplastics/50g while the next depth interval (5 – 10 cm) that corresponds with 2018 to 2013 had the largest mean microplastic abundance (17.67 ± 3.21 microplastics/50g). The remaining depth intervals on the other hand showed a consistent drop in mean microplastic abundance with the lowest abundance of 11.33 ± 2.08 microplastics/50g being recorded in the deepest depth interval (25 – 30 cm) which corresponds with 1998 to 1993. The historical trend at the Tsokome sampling location revealed a largely consistent increase in microplastic abundance from 1993 to

2013, with a fluctuation in abundance between 2013 and 2023. Figure 4.14 shows the age-depth profile of the mean microplastic abundance in sediment cores from the Tsokome sampling location.

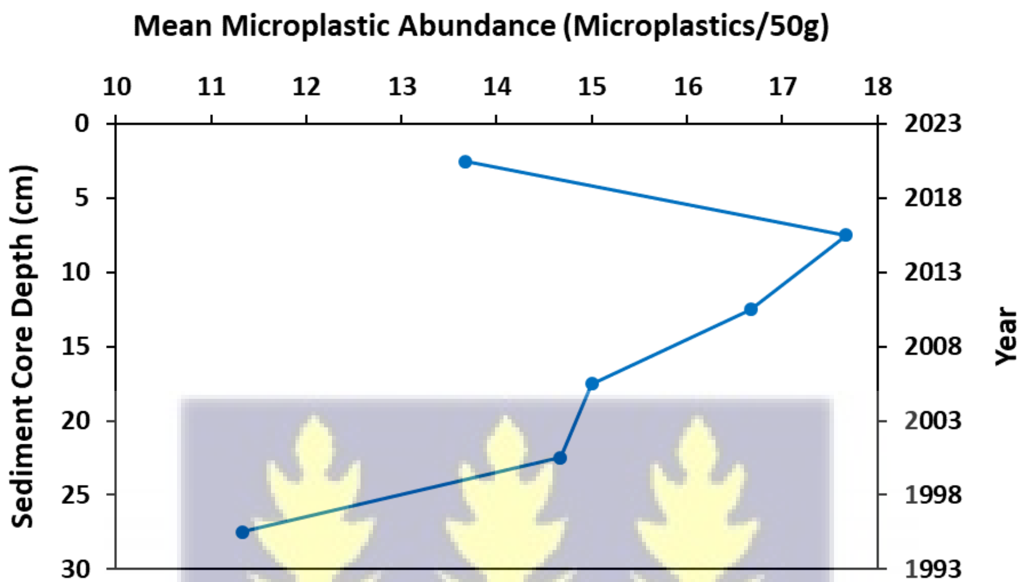


Figure 4.14: Age-Depth Profile of Mean Microplastic Abundance in Sediment Core from the Tsokome Sampling Location

Densu Estuary Sampling Location

The sediment core at the Densu Estuary sampling location represents a deposition period extending from 2005 to 2023. The year 2023 corresponds with the top sediments (0 cm) and 2005 corresponds with the deepest sediments (30 cm). The mean microplastic abundance was significantly lower in the topmost depth interval (0 – 5 cm) that corresponded with 2023 to 2020 (13.00 ± 2.00 microplastics/50g). It however increased in the 5 – 10 cm layer which corresponds with 2020 to 2017 (23.33 ± 2.52 microplastics/50g) while the remaining depth intervals showed a general decreasing trend in mean microplastic abundance, with a fluctuation in the 15 – 20 cm layer (which corresponds with 2014 to 2011) where a slight increase was observed. The historical trend at the Densu Estuary sampling location thus showed variability in microplastic accumulation from 2005 to 2023. Figure 4.15 shows the age-depth profile of mean microplastic abundance in the sediment core from the Densu Estuary sampling location. Figure 4.16 on the other hand compares the historical microplastic accumulation trend across the three locations in the Ramsar site for the 30 cm long sediment core.

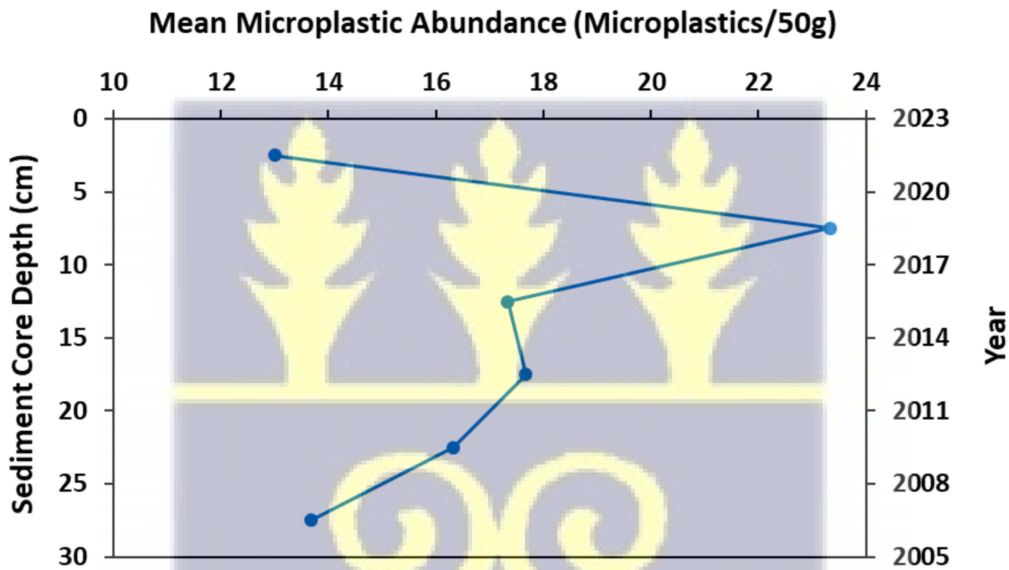


Figure 4.15: Age-Depth Profile of Mean Microplastic Abundance in Sediment Core from the Densu Estuary Sampling Location

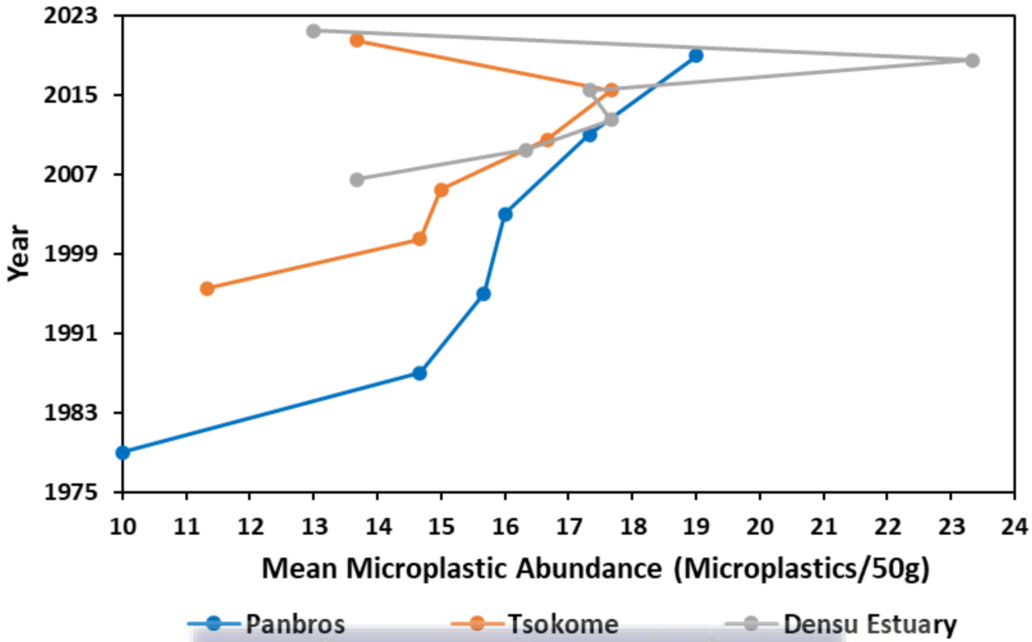


Figure 4.16: Comparison of Historical Trend in Microplastic Accumulation Across Sampling Locations in the Densu Ramsar Site

4.4 Characteristics of Microplastics in Sediments in the Ramsar Site

4.4.1 Shape, Size and Colour of Microplastics

Shape

Fibres were observed to be the most dominant shape of microplastics in sediment cores (84.34%) across all the sampling locations in the Ramsar site. Similarly, fragments (9.42%) and films (6.24%) were the second and third most dominant shapes respectively.

At the Panbros sampling location, fibres made up 84.53% of the total number of microplastics from all three (3) replicate sediment cores while fragments and films made up 9.35% and 6.12% respectively. At the Tsokome sampling location, the three (3) replicate cores altogether were composed of 89.14% fibres, 6.74% fragments and 4.12% films. Also, at the Densu Estuary sampling location, fibres made up 79.94% of the microplastics from all replicate cores, fragments constituted 11.84% while films made up 8.22%. Pellets and beads were not observed in any of the sampling locations. Figures 4.17, 4.18 and 4.19 show the overall vertical distribution of shapes of microplastics through the sediment core depth as well as the total proportion of microplastic shapes at each sampling location. Additionally, Plate 4.2 shows microscope images of microplastic shapes found in the sediment cores from the Ramsar site.

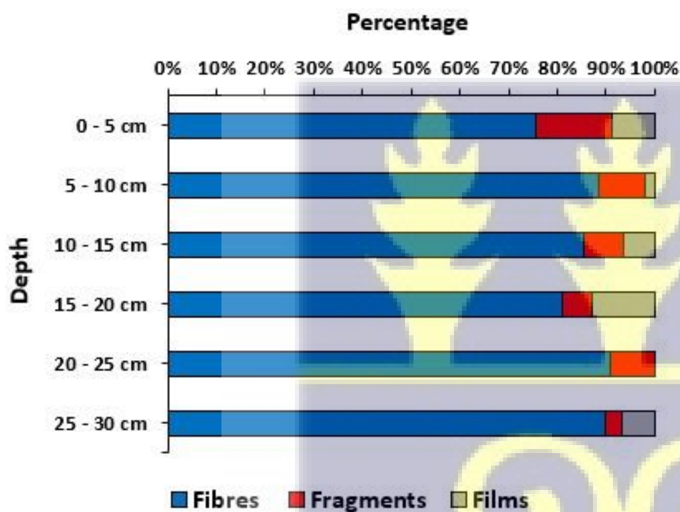


Figure 4.17a: Overall Vertical Distribution of Shapes of Microplastics through Sediment Core Depth at Panbros in the Densu Ramsar Site

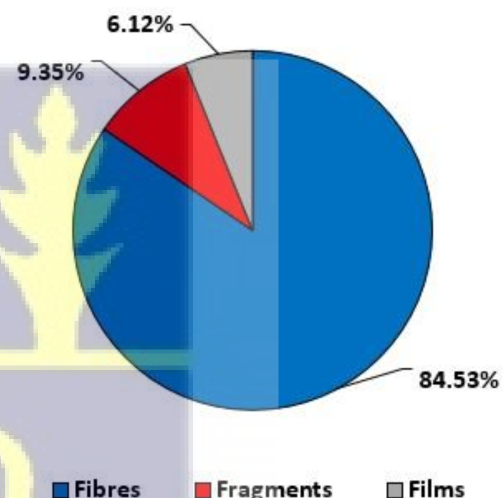


Figure 4.17b: Total Proportion of Shapes of Microplastics at Panbros in the Densu Ramsar Site

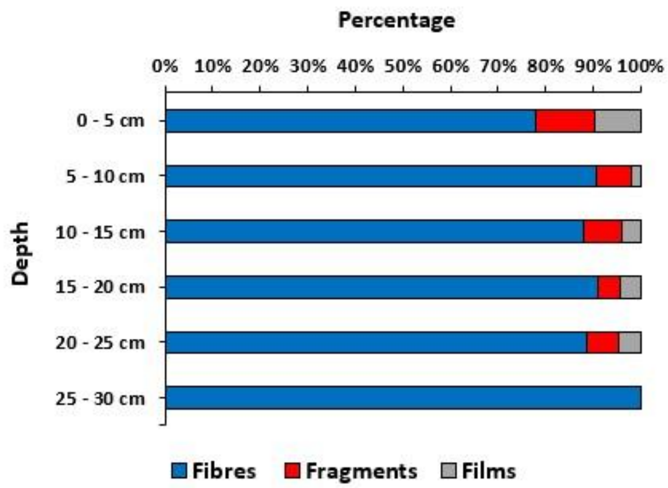


Figure 4.18a: Overall Vertical Distribution of Shapes of Microplastics through Sediment Core Depth at Tsokome in the Densu Ramsar Site

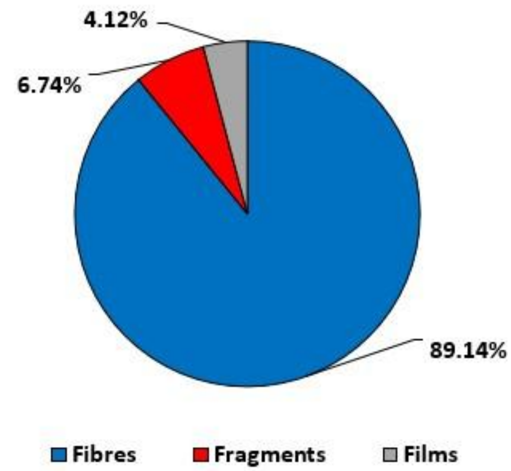


Figure 4.18b: Total Proportion of Shapes of Microplastics at Tsokome in the Densu Ramsar Site

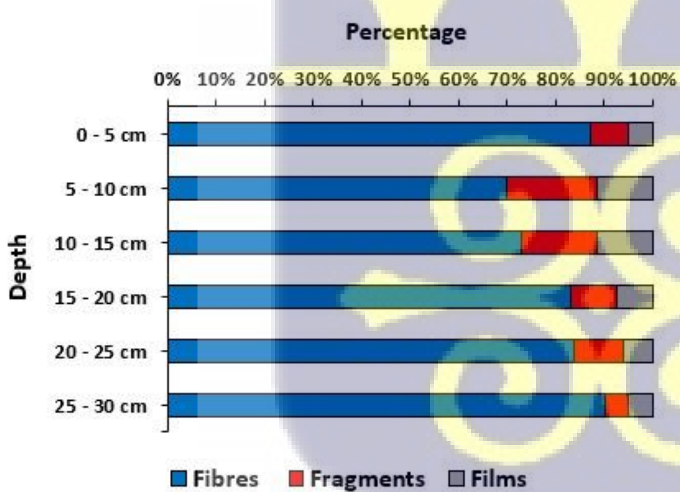


Figure 4.19a: Overall Vertical Distribution of Shapes of Microplastics through Sediment Core Depth at Densu Estuary in the Densu Ramsar Site

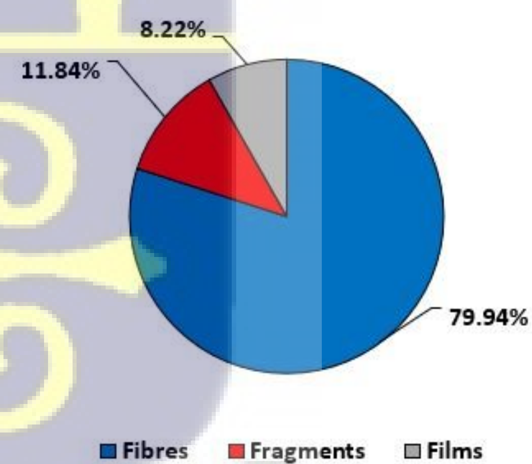


Figure 4.19b: Total Proportion of Shapes of Microplastics at Densu Estuary in the Densu Ramsar Site

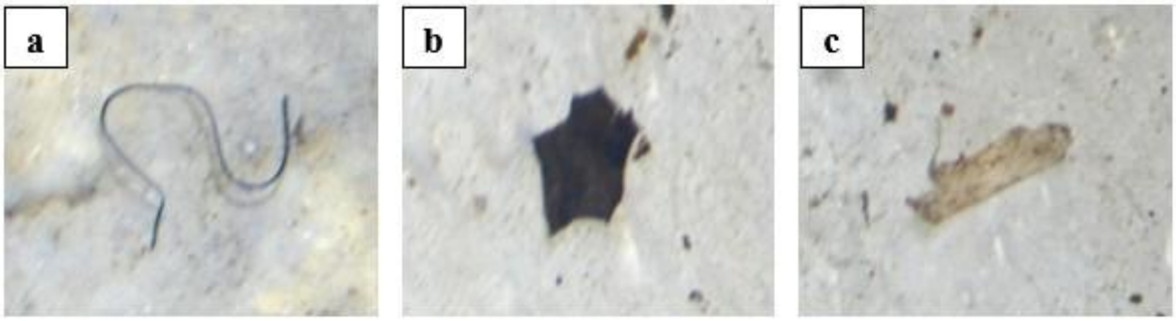


Plate 4.2: Microplastic Shapes in Sediment Cores from the Densu Ramsar Site

(a. Fibre b. Fragment c. Film)

Source: Author

(Microscope images taken during laboratory analysis of sediment core samples from the Ramsar site)

Size

The dominant size range across all sampling locations was 501 – 1000 µm (31.68%). This was followed by 1001 – 3000 µm (31.10%), 100 – 500 µm (18.96%), 3001 – 5000 µm (11.31%) and <100 µm (6.95%). At the Panbros sampling location, 9.35% of the total number of microplastics fell within the < 100 µm size class, 17.27% were within 100 – 500 µm, 35.61% were in 501 – 1000 µm, 30.58% were in 1001 – 3000 µm and 7.19% were in 3001 – 5000 µm. At the Tsokome sampling location, 4.12% were in < 100 µm, 16.10% fell within the 100 – 500 µm range, 31.84% fell in 501 – 1000 µm, 32.58% fell in 1001 – 3000 µm and 15.36% were in the 3001 – 5000 µm size range. At the Densu Estuary sampling location, 7.24% of the total number of microplastics belonged to the < 100 µm size range, 23.03% were in 100 – 500 µm, 27.96% fell in 501 – 1000 µm, 30.26% were in 1001 – 3000 µm and 11.51% were in the 3001 – 5000 µm size range. Figures

4.20, 4.21 and 4.22 show the overall vertical distribution of sizes of microplastics through the sediment core depth as well as the total proportion of microplastic sizes at each sampling location.

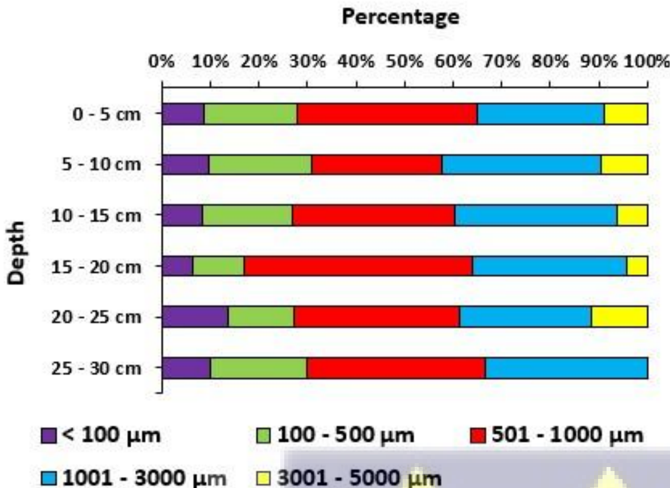


Figure 4.20a: Overall Vertical Distribution of Sizes of Microplastics through Sediment Core Depth at Panbros in the Densu Ramsar Site

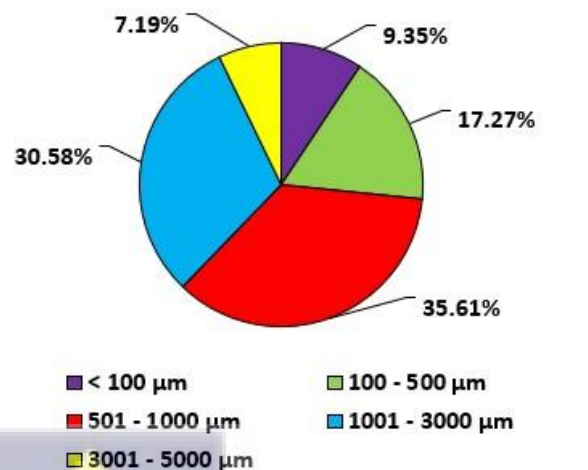


Figure 4.20b: Total Proportion of Sizes of Microplastics at Panbros in the Densu Ramsar Site

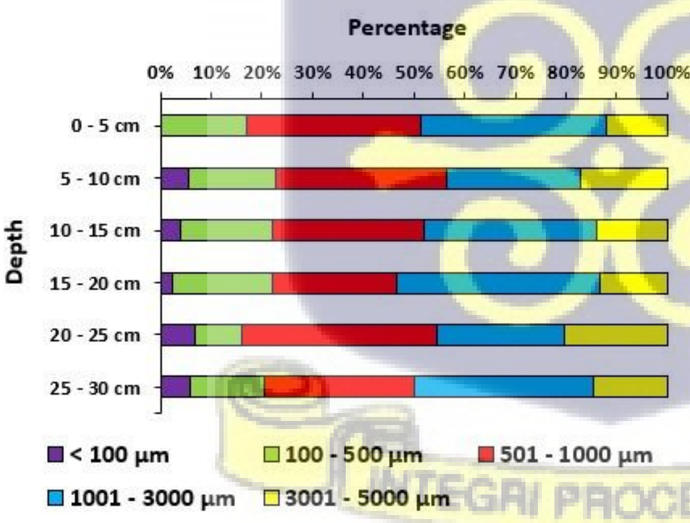


Figure 4.21a: Overall Vertical Distribution of Sizes of Microplastics through Sediment Core Depth at Tsokome in the Densu Ramsar Site

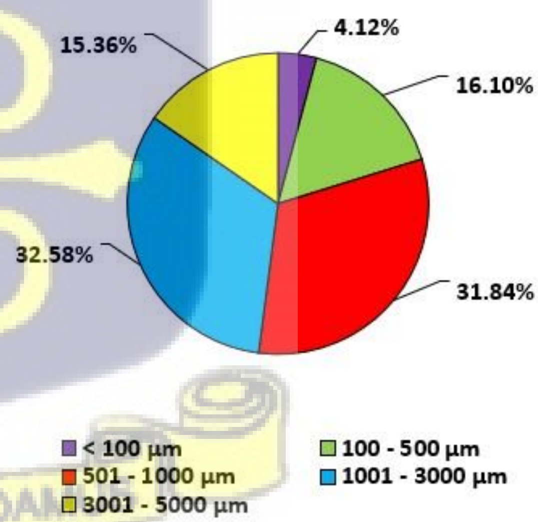


Figure 4.21b: Total Proportion of Sizes of Microplastics at Tsokome in the Densu Ramsar Site

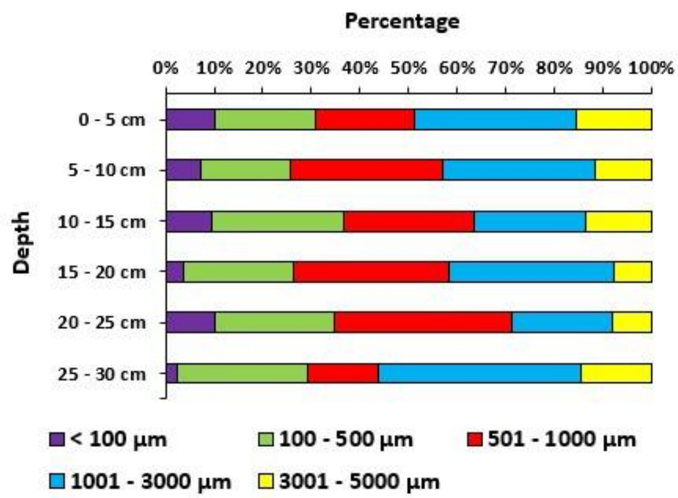


Figure 4.22a: Overall Vertical Distribution of Sizes of Microplastics through Sediment Core Depth at Densu Estuary in the Densu Ramsar Site

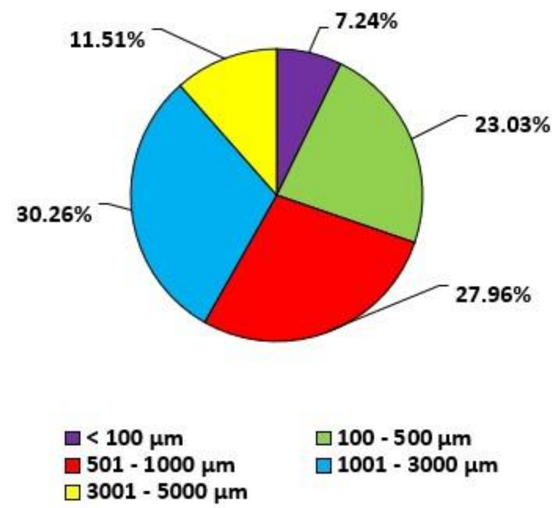


Figure 4.22b: Total Proportion of Sizes of Microplastics at Densu Estuary in the Densu Ramsar Site

<u>Colour</u>

In terms of colours of microplastics observed, black (47.70%) was the main colour across all sampling locations, followed by blue (15.78%), red (12.02%), transparent (9.42%), yellow (6.60%), green (5.42%) and white (3.06%).

At Panbros sampling location, black (43.88%) was the most dominant microplastic colour. This was followed by blue (17.27%) as well as red microplastics (12.59%). Other colours of microplastics which were found in lesser amounts at the Panbros sampling location are green (8.63%), yellow (7.55%), transparent (5.76%) and white (4.32%). At the Tsokome sampling location, black microplastics represented 52.06%, making it the main colour observed in the replicate cores. In order of decreasing amounts, the other microplastic colours at the Tsokome sampling location were red (14.23%), blue (11.61%), transparent (10.86%), green (5.99%), yellow (3.00%) and white (2.25%).

Again, at the Densu Estuary sampling location, black (47.37%) was the most dominant colour observed in the replicate cores. This was followed by lesser amounts of blue (18.09%), transparent (11.52%), red (9.54%), yellow (8.88%), white (2.63%) and green (1.97%). Figures 4.23, 4.24 and 4.25 show the overall colour distribution of microplastics in the various depths of the replicate sediment cores as well as the total proportion of microplastic colours at each sampling location. Plate 4.3 shows microscope images of fibres of different colours found in the sediment core samples from the Ramsar site.

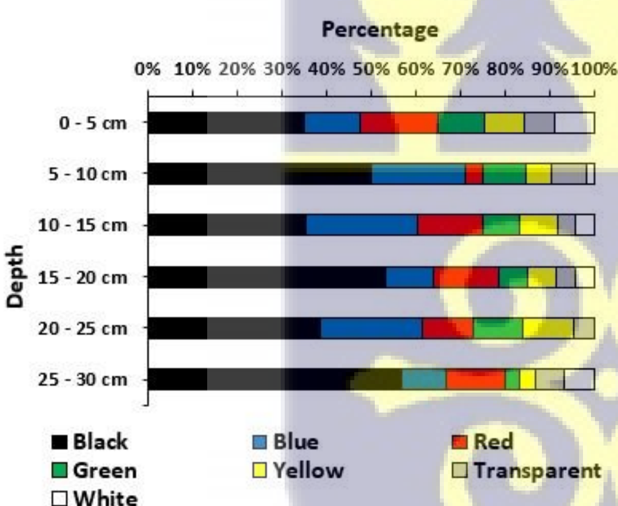


Figure 4.23a: Overall Colour Distribution of Microplastics through Sediment Core Depth at Panbros in the Densu Ramsar Site

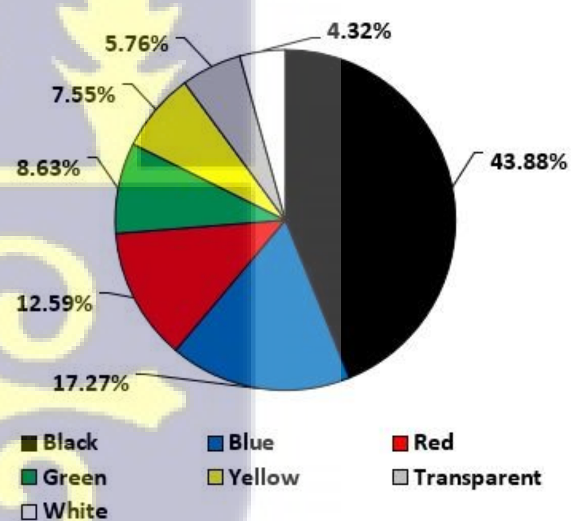


Figure 4.23b: Total Proportion of Colours of Microplastics at Panbros in the Densu Ramsar Site

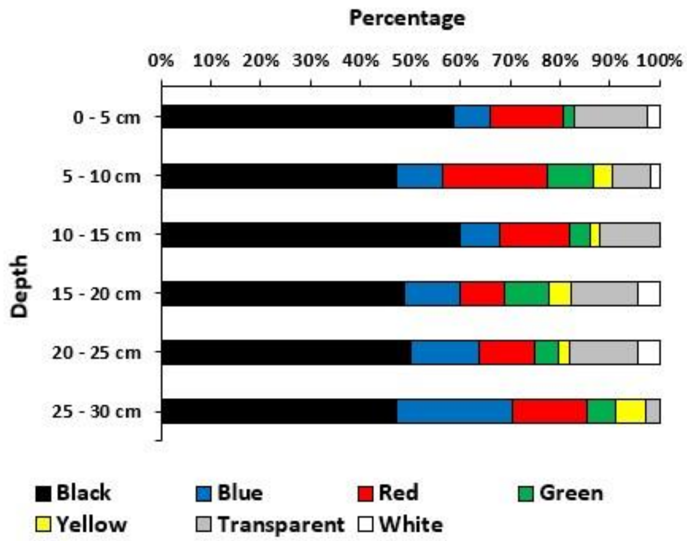


Figure 4.24a: Overall Colour Distribution of Microplastics through Sediment Core Depth at Tsokome in the Densu Ramsar Site

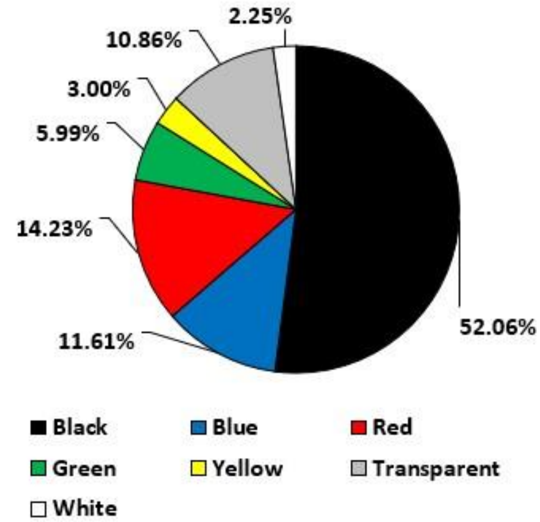


Figure 4.24b: Total Proportion of Colours of Microplastics at Tsokome in the Densu Ramsar Site

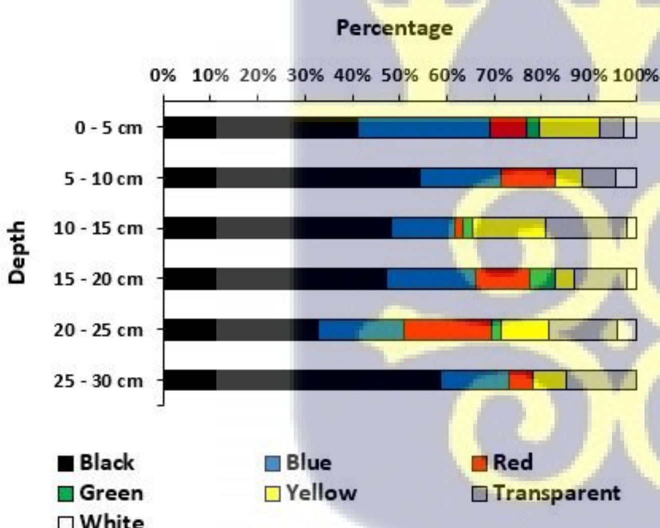


Figure 4.25a: Overall Colour Distribution of Microplastics through Sediment Core Depth at Densu Estuary in the Densu Ramsar Site

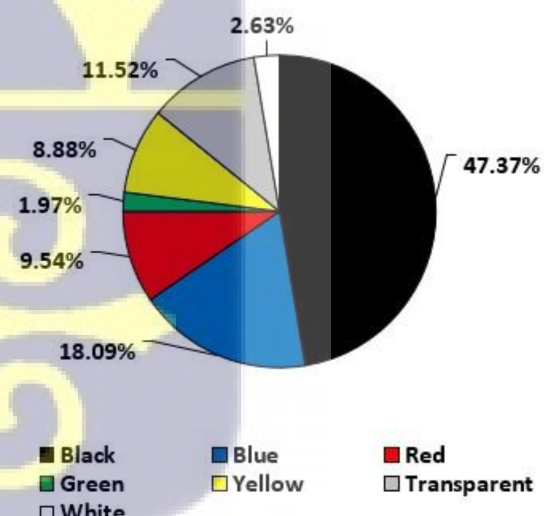


Figure 4.25b: Total Proportion of Colours of Microplastics at Densu Estuary in the Densu Ramsar Site

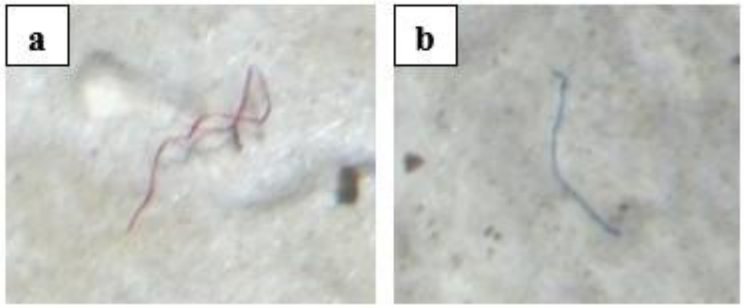


Plate 4.3: Fibres of Different Colours in Sediment Cores from the Densu Ramsar Site

(a. Red Fibre b. Blue Fibre)

Source: Author

(Microscope images taken during laboratory analysis of sediment core samples from the Ramsar site)

4.4.2 Polymer Composition of Microplastics

From the ninety (90) microplastic particles subjected to Fourier Transform Infrared Spectroscopy (FTIR) analysis, 84 particles which represent 93.33% were confirmed to be synthetic polymers and the 6 remaining particles which represent 6.67% were non-plastic particles of natural origin. The synthetic polymer types identified in the microplastic samples were polyethylene, polypropylene, polystyrene, polyester, cellophane and polyvinyl acetate. Of these six (6) confirmed polymer types, polyethylene constituted 39.29%, polypropylene represented 20.24%, polystyrene made up 15.48%, polyester represented 13.09%, cellophane was 7.14% while polyvinyl acetate constituted 4.76%. Figure 4.26 illustrates the proportion of the polymer types. Figure 4.27 also shows Fourier Transform Infrared (FTIR) spectra of the three (3) most dominant polymer types.

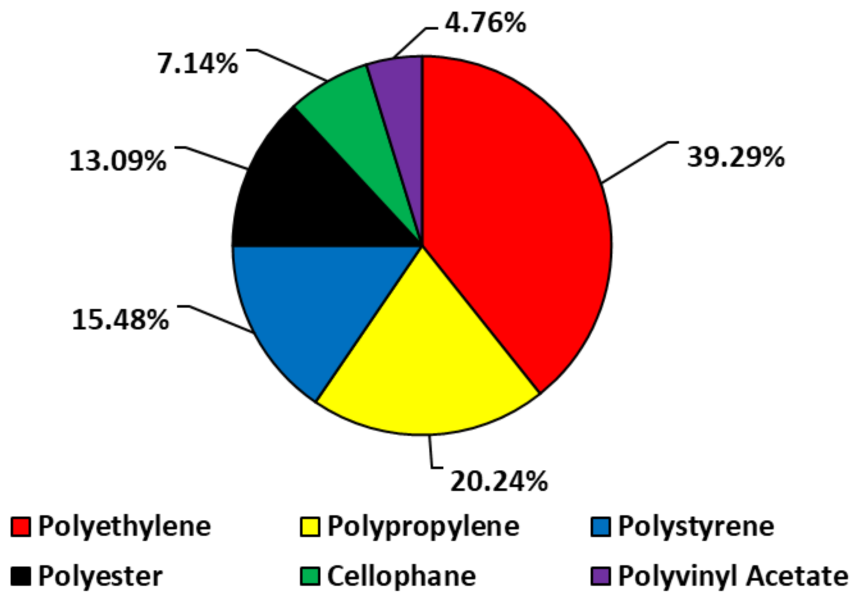
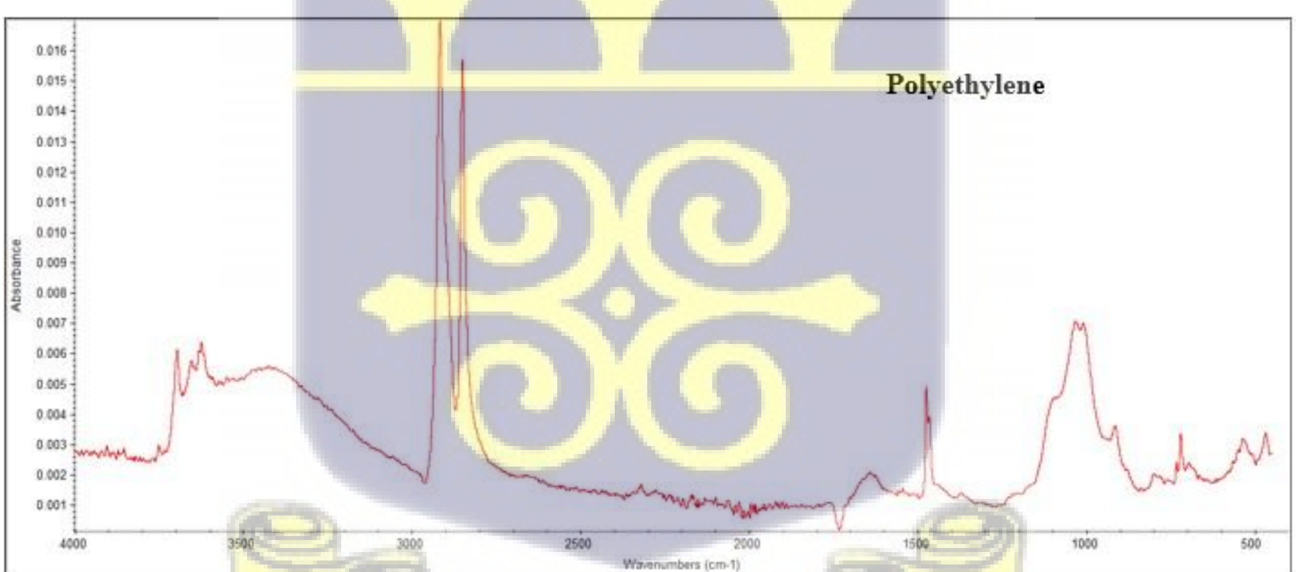


Figure 4.26: Proportion of Polymer Types Identified in the Densu Ramsar Site



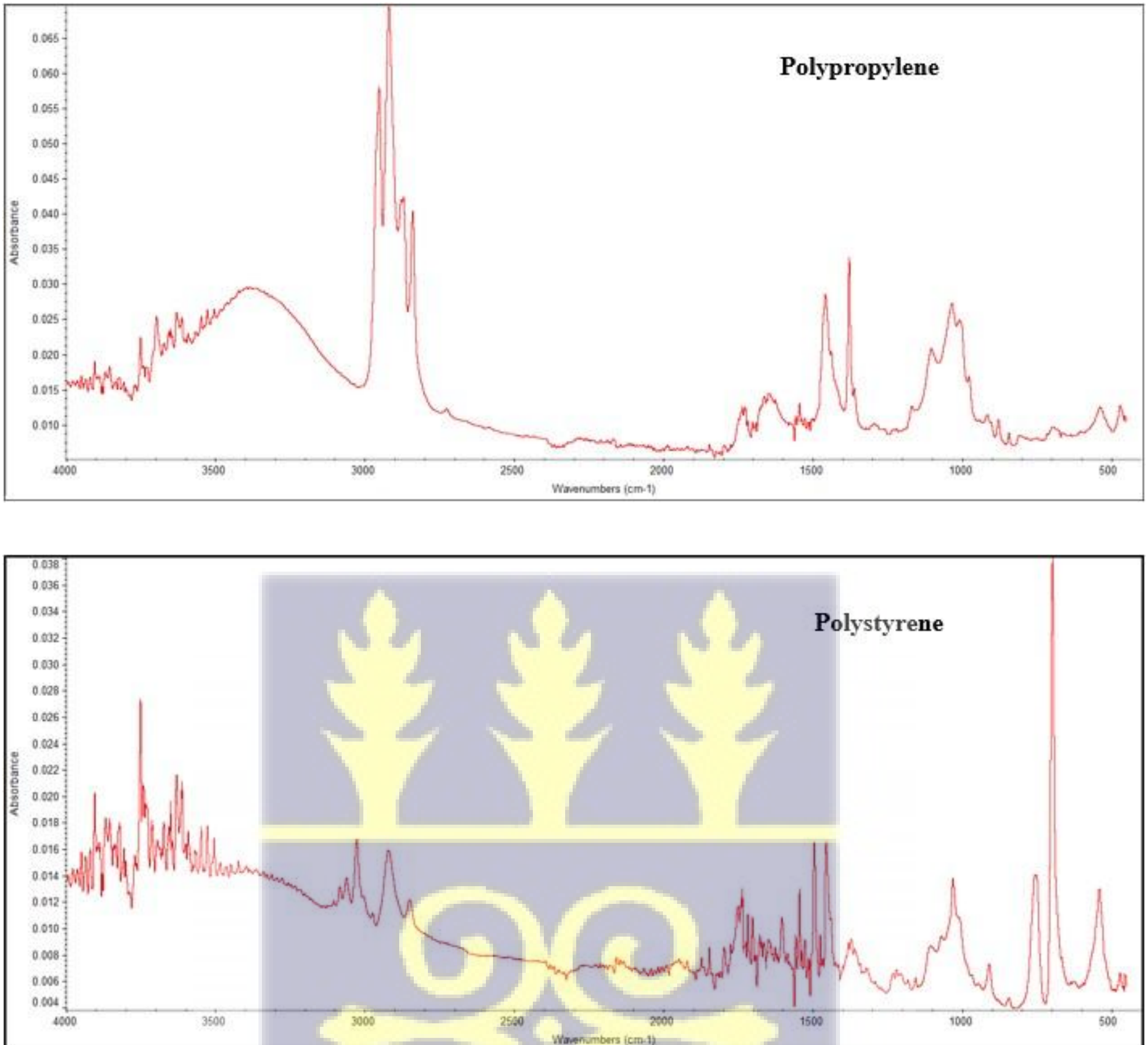


Figure 4.27: Fourier Transform Infrared Spectra of the Three (3) Most Dominant Polymer Types in the Densu Ramsar Site

4.4.3 Relationship Between Microplastic Polymer Composition from Ramsar Site and National Macroplastic Waste Stream

Table 4.9 shows the polymer composition of microplastic samples from the Ramsar site identified through FTIR analysis and the average polymer composition in the national macroplastic waste stream calculated from data reported by Miezah *et al*. (2015).

Table 4.9: Comparison Between Microplastic Polymer Composition from the Densu Ramsar Site and National Macroplastic Waste Stream

Polymer Type	National Macroplastic Waste Stream (%) [a]	Microplastics from Ramsar Site (%)
Polyethylene	47.38	39.29
Polypropylene	9.78	20.24
Polystyrene	4.05	15.48
Polyethylene Terephthalate	20.27	13.09
Polyvinyl Chloride	3.28	0.00
Others	15.24	11.90
Total	**100%**	**100%**

[a] Adapted from Miezah *et al*. (2015)

Polyethylene was the highest polymer type recorded in both the national macroplastic waste stream and microplastics from the Ramsar site. Polypropylene was the fourth highest in the national macroplastic data while it was the second highest in the microplastics from the Ramsar site. Polystyrene was however one of the lowest recorded polymer types in the national macroplastic waste stream but was the third highest in microplastics from the Ramsar site. The composition of

Polyethylene Terephthalate was similar in both sets of data but was higher in the national macroplastic waste stream. Polyvinyl Chloride was the lowest polymer type recorded in both the national macroplastic data and the microplastics from the Ramsar site and the composition of lesser known polymer types collectively recorded as 'Others' were similar in both sets of data.

The results of a simple linear regression showed that there was a strong positive correlation and statistically significant relationship between the average polymer composition in the national macroplastic waste stream and microplastic polymer composition in the Ramsar site ($r = 0.849$, $p = 0.032$). Again, the results showed that the national macroplastic waste stream accounts for 72.2% of the variance in microplastic polymer composition from the Ramsar site ($r^2 = 0.722$, $F(1, 4) = 10.366$, $p = 0.032$). These results indicate that an increase in a given polymer type in the national macroplastic waste stream would lead to an increase in the composition of the polymer in microplastics in the Ramsar site. Thus, national macroplastic polymer composition significantly predicts microplastic composition in the Ramsar site ($ß = 0.671$, $t = 3.220$, $p = 0.032$). Table 4.10 shows the results of the simple linear regression.

Table 4.10: Results of Simple Linear Regression Between Polymer Composition in National Macroplastic Waste Stream and Microplastics from the Densu Ramsar Site

Regression Weights	r	r^2	ß	F	t-value	p-value
National Macroplastic Waste Stream [a] ↓ Microplastics from Ramsar Site	0.849	0.722	0.671	10.366	3.220	0.032

[a] Adapted from Miezah *et al*. (2015)

4.5 Perceptions of Stakeholders on the Drivers, Pressures, State, Impacts and Appropriate Response to Plastic Waste Accumulation in the Ramsar Site

4.5.1 Demographic Characteristics of Primary Stakeholders

Table 4.11 shows the demographic characteristics of the primary stakeholders. Three hundred and ninety-seven (397) primary stakeholders responded to the 397 questionnaires administered, thereby constituting a 100% response rate. There were more male respondents (52.6%) than female respondents (47.4%). The largest percentage of respondents were between the ages of 40 and 49 while the least percentage were aged 60 years and above. Majority of the respondents (48.9%) had basic level of education and the respondents who had tertiary education (7.1%) were the least in number. A greater percentage (55.4%) indicated that they both live and work within the catchment of the Ramsar site. The results also show that majority of the respondents have been living and/or working in the Ramsar site for a duration ranging between 5 to 10 years. The primary stakeholders had a wide range of occupations. These included fishing and fish mongering, petty trading, salt mining, informal waste picking, tailoring, amongst others. Other respondents also indicated that they were unemployed.

Table 4.11: Demographic Characteristics of Primary Stakeholders (n = 397) associated with the Densu Ramsar Site

Variable	Frequency (F)	Percentage (%)
Gender		
Male	209	52.6
Female	188	47.4
Age		
18 – 29	90	22.7
30 – 39	83	20.9

Variable	Frequency (F)	Percentage (%)
40 – 49	102	25.7
50 – 59	82	20.7
60 and above	40	10.1
Level of Education		
None	51	12.8
Basic Level	194	48.9
Secondary Level	124	31.2
Tertiary Level	28	7.1
Link Between Respondents and the Ramsar Site		
Living in Ramsar site	131	33.0
Working in Ramsar site	46	11.6
Both	220	55.4
Number of Years of Living and/or Working in the Ramsar Site		
Less than 5 years	70	17.6
5 – 10 years	98	24.7
11 – 15 years	89	22.4
16 – 20 years	54	13.6
21 – 25 years	31	7.8
25 years and above	55	13.9

4.5.2 Demographic Profile of Secondary Stakeholders

Table 4.12 shows the demographic profile of the six (6) representatives of institutions (secondary stakeholders) who were interviewed. Appendix J also provides an overview of the mandate of the institutions labelled as Institutions A to F.

Table 4.12: Demographic Profile of Secondary Stakeholders (n = 6)

Position	Frequency (F)
Environmental Health Officers	2
Wetlands and Wildlife Officer	1
Waste Management Officer	1
River Basin Officer	1
Quality Assurance Manager	1

Table 4.13 shows the themes and sub-themes which emerged from the thematic analysis of the interview responses of secondary stakeholders.

Table 4.13: Organisation of Themes for Secondary Stakeholders

Themes	Sub-Themes
Drivers	- Population growth leading to a rise in the needs for shelter and income
Pressures	- Urban growth activities - Use and improper disposal of single-use plastics within the Ramsar site and upstream - Fishing activities

Themes	Sub-Themes
State	- Increasing rate of plastic waste accumulation - Susceptibility to receiving microplastics and macroplastics from upstream sources
Impacts	- Human health risks - Reduction in income of fishermen due to low fish catch - Reduction in tourism - Reduction in water quality - Plastic consumption by fish and water birds - Entanglement of fish and other organisms by plastic debris - Destruction of habitat of biodiversity
Response	- Attitudinal change - Clean-up exercises - Effective institutional collaboration - Public education - Segregation of plastic waste at source - Phasing out of single-use plastics - Use of environmentally-friendly alternatives to plastics - Extended Producer Responsibility - Promotion of reuse and recycling of plastics

4.5.3 Drivers

Primary Stakeholders

With regard to the drivers of plastic waste accumulation in the Ramsar site, the data collated from primary stakeholders revealed that 38.4% of the responses pointed to population growth causing a rise in the need for shelter as a driver, 30.1% of the responses indicated that economic growth bringing about a rise in the need to have a source of income is a driver, 15.4% pointed to population growth intensifying the need for food such as fish as a driver and 16.1% pointed to urbanisation generating a heightened demand for recreation as a driver. Of the responses received, it is evident that population growth causing a rise in the need for shelter and economic growth bringing about a rise in the need for income are perceived as the main drivers by primary stakeholders. Figure 4.28 is a pie chart showing the responses of primary stakeholders on the drivers.

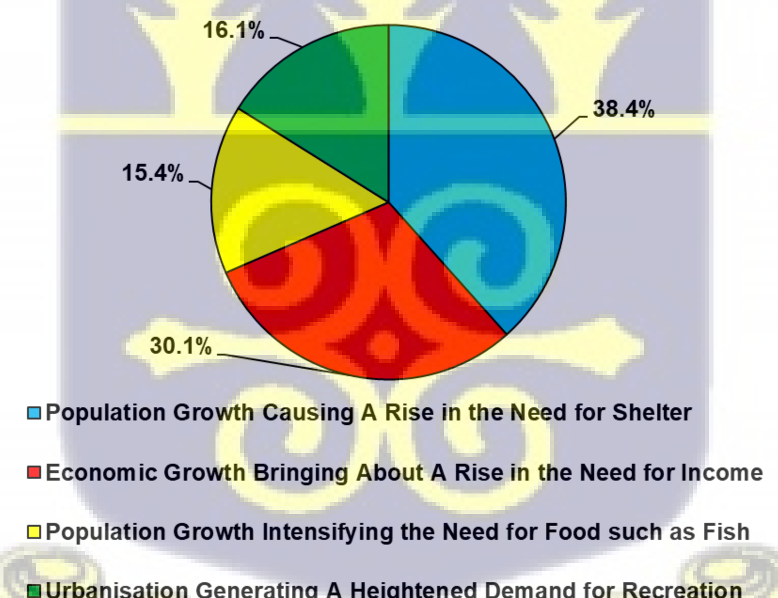


Figure 4.28: Perceptions of Primary Stakeholders on the Drivers of Plastic Waste Accumulation in the Densu Ramsar Site

Secondary Stakeholders

Some of the institutions (B, C, D and F) also alluded that population growth leading to a surge in the needs for shelter and income are the most significant drivers of plastic waste (macroplastics and microplastics) accumulation in the Ramsar site. One of them remarked:

'Unfortunately for us, everyone is coming to Accra. And because everyone is coming to Accra, everybody is looking for a place to live. Once there is a high demand for housing or land, there needs to be a supply. Almost the whole of Accra has been sold and so unfortunately for us, we have individuals who target areas like the Densu wetland area. People don't know the implications of these actions. Lack of employment is also another driving force. Wherever there are people, they would definitely generate plastic waste which would lead to pollution of the wetland.'

Institution B

4.5.4 Pressures

Primary Stakeholders

In terms of pressures responsible for plastic waste accumulation in the Ramsar site, it was found that urban growth activities accounted for 41.9% of the responses, 29.7% pointed to petty trading activities, 13.1% of the responses indicate fishing activities as a pressure and 15.3% pointed to tourism-related activities. From the responses, it is clear that primary stakeholders perceive urban growth activities as well as petty trading as the main pressures. Some added that factors accounting for how the pressures result in plastic waste production and accumulation within the Ramsar site include the packaging of most products in single-use plastics, indiscipline on the part of individuals after usage of such products as well as the lack of adequate avenues for the proper disposal of plastic waste. When asked of the ways by which they discard their plastic waste, some primary stakeholders mentioned open dumpsites, indiscriminate littering, burning and large community bins provided by government for waste disposal. Other ways mentioned were the giving of their plastic waste to informal waste collection vehicles and plastic waste pickers for recycling. Plates 4.4a and 4.4b show some of the open dumpsites which were encountered during field observation.

Regarding their perceptions on the possible contribution from other sources, 39.5% of the responses were of the opinion that surface runoff and the flow of the Densu River from upstream which greatly increases during the spilling of the Weija Reservoir, contributes to plastic waste accumulation in the Ramsar site. Again, 28.3% indicated that the ocean transports plastic waste to the Ramsar site. About one-third of responses (32.2%) also indicated that wind action transports plastic litter to the Ramsar site. This shows that the respondents perceive surface runoff and flow of the Densu River from upstream as the main contributor to plastic waste accumulation in the Ramsar site from other areas. Transportation of plastic litter by wind action is also regarded as the second main contributor. Figures 4.29a and 4.29b illustrate the perceptions of primary stakeholders on the pressures and contribution from other sources.

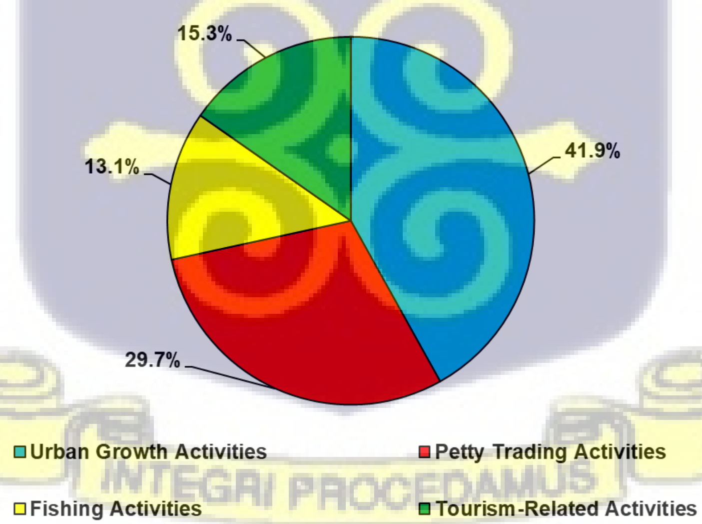


Figure 4.29a: Perceptions of Primary Stakeholders on the Pressures of Plastic Waste Accumulation in the Densu Ramsar Site

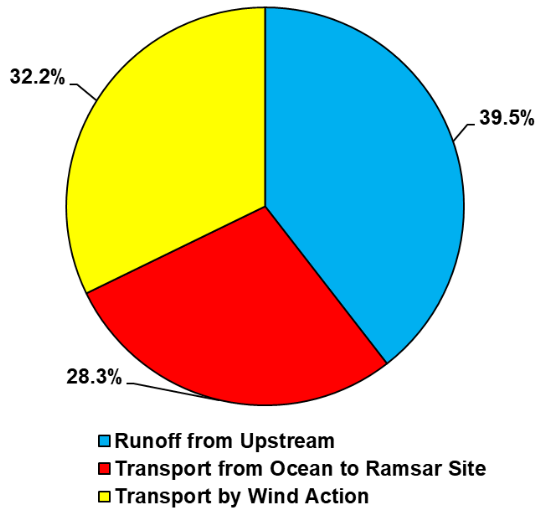


Figure 4.29b: Perceptions of Primary Stakeholders on the Contribution to Plastic Waste Accumulation in the Densu Ramsar Site from Other Sources

Plate 4.4a: Open Dumpsite Within the Densu Ramsar Site Dominated by Plastic Waste

Plate 4.4b: Open Dumpsite at the Bank of Densu Lagoon within the Densu Ramsar Site

Source of Images: Author

Secondary Stakeholders

Institutions A, B, C, D and F also stated that an increase in urban growth activities is a major pressure which results in plastic waste accumulation in the Ramsar site. Institutions B, D and F added that, the use of single-use plastics in the Ramsar site, its environs and upstream as well as their improper disposal by end users play a huge role in plastic waste accumulation in the Ramsar site. Institutions B, C and D also said that the fishing sector contributes to the accumulation through the abandoning of fishing gear such as ropes, fishing nets and net floats within the Ramsar site. In relation to the possible contribution from other sources, Institutions B, D and F were emphatic that majority of macroplastics and microplastics accumulating in the Ramsar site is transported from upstream sources and the ocean while a much lesser proportion is generated by persons within the Ramsar site. Two of these institutions explained that:

'Most of the plastics at the wetland…that is both microplastics and the large plastics. Most of it migrated from elsewhere. Surface runoff from rain and floods transports plastic waste from upstream into the wetland and it gets accumulated there. The opening of the Weija Dam would also contribute to the accumulation. The wetland also gets its plastic feed from the ocean. It is brought to the wetland during high tide. The direct feed of plastic waste into the wetland is not as much. Yes, there are a few inhabitants of the wetland who might engage in illegal dumping of plastic waste but if you should quantify them, their contribution is not much.'

Institution D

'The Ramsar site is located downstream. Runoff from upstream communities carries plastic waste to the area when it rains.'

Institution F

4.5.5 State

Primary Stakeholders

Concerning the knowledge of primary stakeholders on the existence of microplastics, it was found that 38.0% knew of the existence of microplastics, 44.9% did not know of its existence while 17.1% were unsure. Since a greater percentage (44.9%) did not know of the existence of microplastics, most responses they gave were in relation to their perceptions of issues pertaining solely to macroplastic litter. Of the responses received from primary stakeholders on the current state of plastic waste accumulation in the Ramsar site, 31 respondents representing 7.8% said that there is currently a low level of plastic waste accumulation in the Ramsar site, 135 respondents representing 34.0% stated that there is currently a moderate level and 231 respondents representing 58.2% indicated that there is a high level of accumulation.

With respect to their perceptions of the past state of plastic waste accumulation in the Ramsar site, 267 respondents representing 67.3% stated that in comparison with the current state, there was less plastic waste in the Ramsar site in the past. This shows that they perceive an increase in the accumulation of plastic waste over time. On the other hand, 29 respondents which constitute 7.3% were of the view that there was relatively more plastic waste in the Ramsar site in the past; indicating that they perceive a decrease over time. Over 100 (101) respondents representing 25.4% also said that the state of plastic waste in the Ramsar site in the past is the same as the current state. In terms of the state after heavy rainfall or floods, 8 respondents representing 2.0% were of the view that there is less plastic waste in the Ramsar site after heavy rainfall or floods, 272 respondents representing 68.5% stated that there is more plastic waste after heavy rainfall or floods while 117 respondents making up 29.5% said that the state remains the same before and after heavy rainfall or floods. Figures 4.30, 4.31, 4.32 and 4.33 show the knowledge of primary stakeholders on the existence of microplastics and their perceptions of the state of plastic waste accumulation in the Ramsar site currently, in the past and after heavy rainfall or floods respectively.

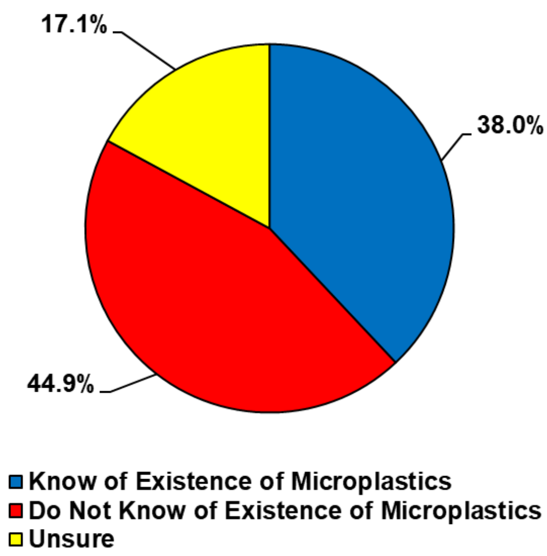


Figure 4.30: Knowledge of Primary Stakeholders on the Existence of Microplastics

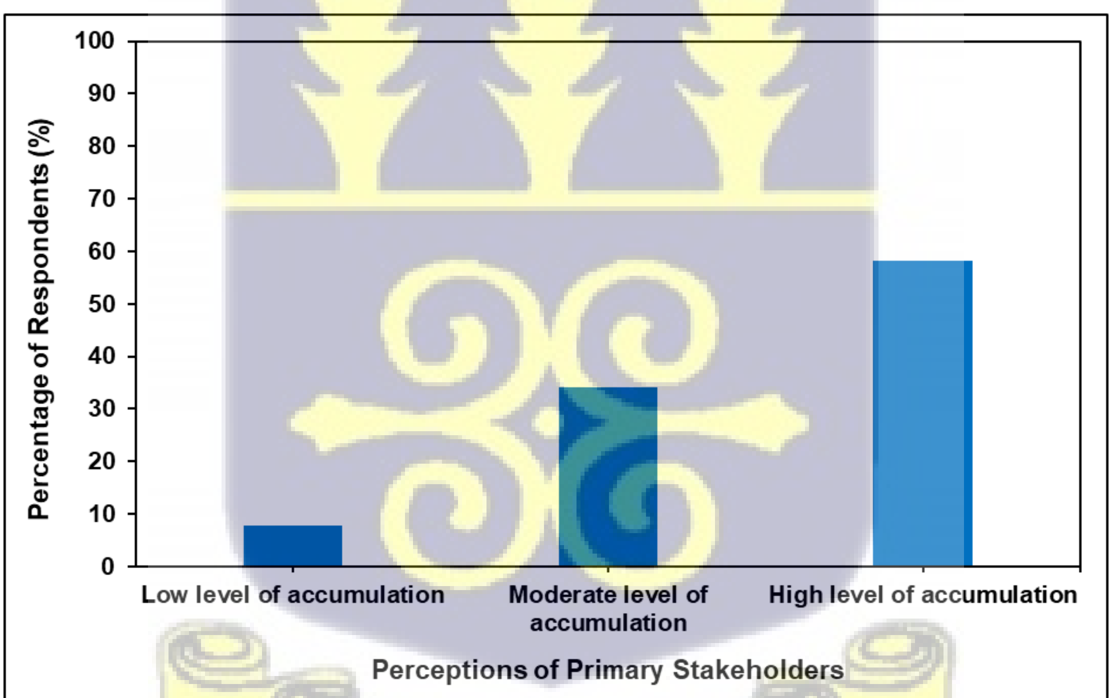


Figure 4.31: Perceptions of Primary Stakeholders on the Current State of Plastic Waste Accumulation in the Densu Ramsar Site

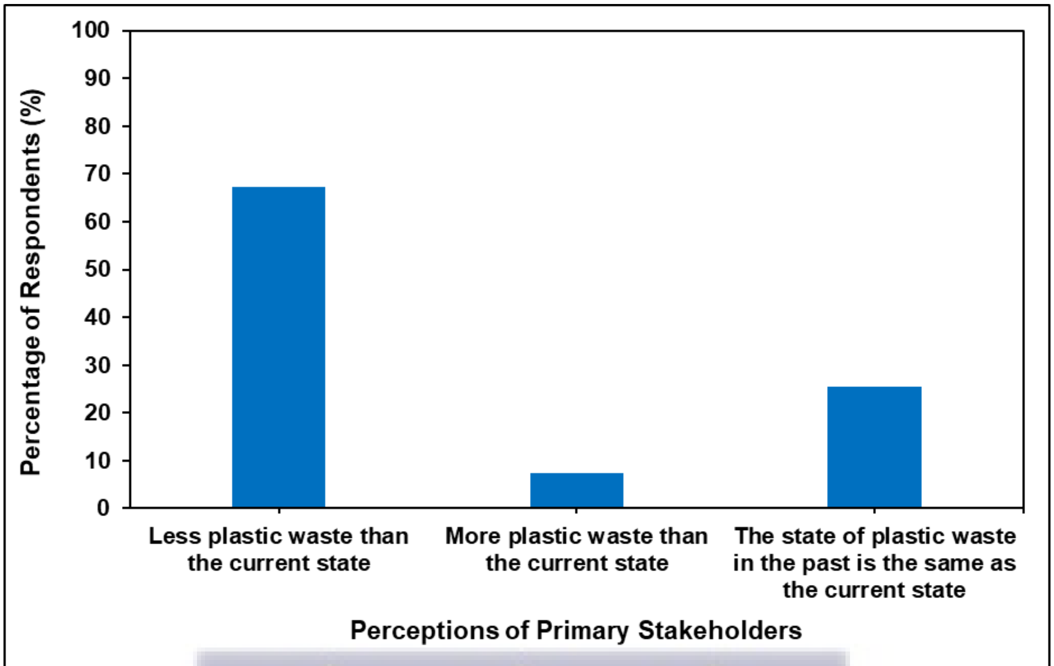


Figure 4.32: Perceptions of Primary Stakeholders on the Past State of Plastic Waste Accumulation in the Densu Ramsar Site

Figure 4.33: Perceptions of Primary Stakeholders on the State of Plastic Waste Accumulation in the Densu Ramsar Site after Heavy Rainfall or Floods

Secondary Stakeholders

Institutions B, D, E and F said that the state of plastic waste accumulation within the Ramsar site is currently bad while Institutions A and C stated that there was a moderate level. In comparison to the current state, Institutions B, D, E and F were of the view that there was less plastic waste in the Ramsar site in the past as explained by one of them:

'Of course, it was not as much as it is now and the situation would continue to worsen if something is not done about it.'

Institution B

Again, Institutions B, D and F mentioned that since the Ramsar site is located downstream, it is susceptible to receiving plastic waste from upstream sources during heavy rainfall or floods.

4.5.6 Impacts

Primary Stakeholders

On the views of primary stakeholders on socio-economic impacts of plastic waste accumulation in the Ramsar site, 26.1% of the responses pointed to the rise in public health concerns such as cholera and malaria as a socio-economic impact. More than one-third (36.4%) indicated that there are negative impacts on fishing and other sources of livelihood. Again, 33.7% pointed to a reduction in the level of attractiveness (aesthetics value) of the Ramsar site leading to a decrease in its tourism potential as a socio-economic impact while 3.8% exhibited a lack of any perceived socio-economic impact. The results show that negative impacts on fishing and other sources of livelihood as well as a reduction in the level of attractiveness of the Ramsar site are the main perceived socio-economic impacts by primary stakeholders. Figure 4.34 is a pie chart showing the perceptions of primary stakeholders on the socio-economic impacts.

Pertaining to the environmental (ecosystem services related) impacts, a greater proportion of responses from primary stakeholders (42.0%) pointed to reduction in water quality as an environmental impact. Again, 26.6% were of the view that fish ingesting or becoming entangled in plastics is an environmental impact while 25.6% pointed to the destruction of the habitat of biodiversity. On the other hand, 5.8% were not aware of any environmental impacts. Figure 4.35 illustrates the perceptions of primary stakeholders on the environmental impacts.

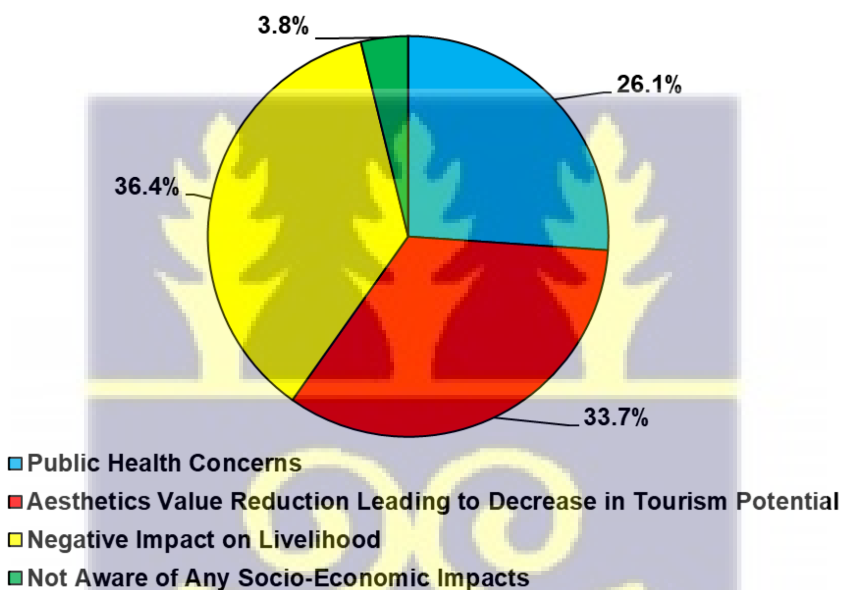


Figure 4.34: Perceptions of Primary Stakeholders on the Socio-Economic Impacts of Plastic Waste Accumulation in the Densu Ramsar Site

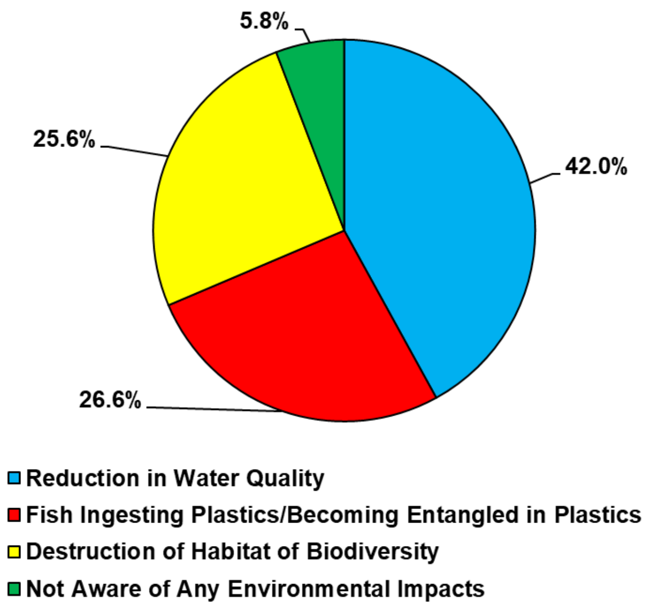


Figure 4.35: Perceptions of Primary Stakeholders on the Environmental Impacts of Plastic Waste Accumulation in the Densu Ramsar Site

Secondary Stakeholders

Regarding the impacts of plastic waste accumulation in the Ramsar site, all secondary stakeholders said that both macroplastics and microplastics have significant detrimental socio-economic and environmental impacts on the Ramsar site. Among the socio-economic impacts which were mentioned by Institutions D, E and F are reduction in sanitary conditions and increased health concerns such as cholera. Institutions A and B also spoke about additional human health risks posed by consuming fish which has ingested microplastics as explained by one of them:

'Microplastics can easily be absorbed into the food chain so when we eat fish which has taken in microplastics, it can have effects on us.'

Institution A

Institutions B, D and F also mentioned the reduction in fish catch leading to a reduction in the income of fishermen and the destruction of the aesthetic beauty of the Ramsar site leading to a reduction in tourism as other socio-economic impacts. One of these institutions stated that:

'Plastics in the environment are not visually pleasant. If the Ramsar site can serve as a tourist site, then economically, the country would lose because people would not like to visit the place.'

Institution D

The environmental impacts of macroplastics and microplastics on the Ramsar site which were mentioned by Institutions D, E and F included the reduction in water quality of the Densu River. Another impact mentioned was the consumption of plastic debris by fish and other organisms leading to bioaccumulation in the food web as explained by one institution:

'Plastic is a petroleum-based product. They contain toxins so when they find their way into the food chain for fish or any other living organism, it would affect them.'

Institution F

Other environmental impacts stated were the entanglement of fish and other animal species due to the presence of macroplastics, reduction in fish stock and spawning ability of fish and the destruction of the habitat of biodiversity. An additional environmental impact mentioned was the consumption of plastic waste by water birds as stated by one institution:

'The Ramsar site is supposed to be a protected area especially for migrant birds. These plastics, sometimes, the birds even take them as food and this can eventually cause them to die.'

Institution B

4.5.7 Response

<u>Primary Stakeholders</u>

Concerning the response measures which can be put in place by persons within the Ramsar site, 37.0% of the primary stakeholders were of the view that persons within the Ramsar site should contribute to the acquiring of waste bins, which should be placed at vantage points in order to reduce the occurrence of plastic littering. Nearly one-third (29.1%) were of the opinion that clean-up exercises should be carried out regularly. The results also showed that 14.2% pointed to the separation of plastic waste for reuse and recycling as a suitable response measure. Again, 10.0% of the primary stakeholders suggested other response measures such as the burning and burying of plastic waste as well as encouraging more persons within the Ramsar site to venture into the informal plastic waste picking business. On the other hand, 9.7% said that it was not the responsibility of persons within the Ramsar site to put in place response measures. Some of these respondents stated that it was rather the responsibility of persons upstream to stop engaging in plastic littering to reduce the transport of plastic waste downstream to the Ramsar site while others were of the view that it was rather the sole responsibility of government to ban the use of plastics. Figure 4.36 illustrates the perceptions of primary stakeholders on the appropriate response measures which can be put in place by persons within the Ramsar site.

In terms of measures which can be put in place by the government or relevant institutions, 33.5% of primary stakeholders' responses were of the view that the government or relevant institutions should provide waste bins at vantage points within the Ramsar site and upstream to reduce the occurrence of plastic littering. Close to a quarter (24.2%) of primary stakeholders said that persons within the Ramsar site and in upstream areas should be educated on responsible ways of managing plastic waste and the impacts of their improper disposal. The results also revealed that 17.8%

pointed to the strict enforcement of laws against littering as a suitable measure. Again, 15.7% indicated the implementation of policies on the significant reduction of the reliance on single-use plastics as a suitable response measure. On the other hand, 8.8% suggested other alternative response measures such as providing communities within the Ramsar site with tools for undertaking regular clean up exercises as well as the construction of recycling facilities within the vicinity of the Ramsar site. Figure 4.37 is a pie chart showing the perceptions of primary stakeholders on the suitable response measures which can be put in place by government or relevant institutions.

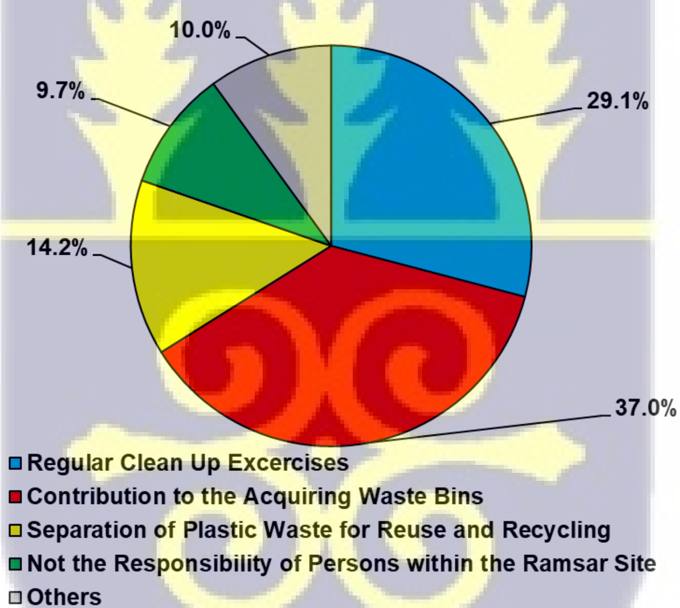


Figure 4.36: Perceptions of Primary Stakeholders on the Appropriate Response Measures Which Can Be Put in Place by Persons within the Densu Ramsar Site to Mitigate Plastic Waste Accumulation

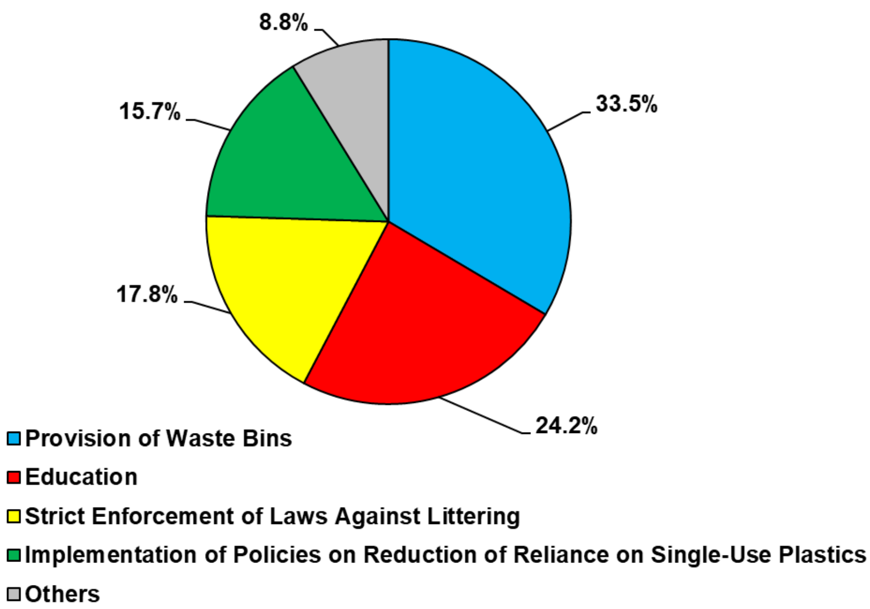


Figure 4.37: Perceptions of Primary Stakeholders on the Appropriate Response Measures Which Can Be Put in Place by Government or Relevant Institutions to Mitigate Plastic Waste Accumulation in the Densu Ramsar Site

Secondary Stakeholders

With respect to what can be done by persons within the Ramsar site and in upstream areas, all secondary stakeholders recommended attitudinal change on the part of the citizenry through the practice of proper plastic waste management such as the avoidance of plastic littering. Institutions A, C and D also recommended that persons organise and partake in regular cleanup exercises within and around the Ramsar site.

In relation to the suitable measures which can be put in place by government and other relevant institutions, Institution D said that policies such as National Plastics Management Policy of 2020 and Environmental Sanitation Policy of 2010 had already been formulated by government to curb the plastic waste accumulation problem in Ghana as a whole. Institutions A and C spoke about 'Operation Clean Your Frontage' initiative which was being carried out by district assemblies in the Greater Accra Region. Institution B also spoke about the Wetlands (Ramsar Sites) Management Regulations (L. I. 1659) which was established to ensure the protection of Ramsar sites in Ghana. They, however, added that there were issues of poor enforcement and a lack of adequate financial support which have rendered these policies ineffective. Measures recommended by secondary stakeholders include effective institutional collaboration, education of the public on the adverse impacts of improperly discarded plastic waste and the proper methods of managing plastic waste as well as strict enforcement of existing legislation on plastic waste management. Other recommended institutional measures were the promotion of segregation of plastic waste at source, phasing out of single-use plastics, implementation of Extended Producer Responsibility regulations, promotion of the use of more environmentally-friendly alternatives like paper bags and jute bags, incorporation of the circular economy into plastic waste management through measures like plastic reuse and recycling and the provision of legislative support for such initiatives as explained by one of the institutions:

'There are several strategies we have to put in place if we want to manage plastics in the Ramsar site and in Ghana as a whole. Segregation at source is key to solving this problem. We have to avoid the use of single-use plastics. Single-use plastics are difficult to recycle. Extended Producer Responsibility is also necessary for handling plastics which are difficult to recycle. We need to gradually replace plastic bags with alternatives such as paper bags and jute bags. We need to include the circular economy in the management of plastics through reuse and recycling. We need to upscale our recycling facilities. We need the support of legislation for these initiatives. A lot of the solutions are not supported by legislation.'

Institution D

It was, however, stated by Institutions A, B, D and F that plastic waste accumulation in the Ramsar site cannot be handled by government alone but rather requires the collective effort of government, other relevant institutions and the citizenry. One of them remarked:

'It is a global issue. We cannot handle it alone. It is a difficult issue to manage alone. Everyone, including government, the various institutions and individuals must come on board to solve this issue.'

Institution A

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter presents a discussion of the results obtained from this research. In line with the specific objectives, it encompasses a discussion of the abundance, diversity and sources of macroplastic litter in the Densu Delta Ramsar Site, the abundance and characteristics of microplastics in sediment cores from the Ramsar site, the historical trend in microplastic accumulation as well as the perceptions of key stakeholders on the drivers, pressures, state, impacts and appropriate response to plastic waste accumulation in the Ramsar site.

5.2 Abundance, Diversity and Sources of Macroplastic Litter in the Ramsar Site

5.2.1 Abundance of Macroplastic Litter

The highest monthly abundance and accumulation rate of macroplastic litter was recorded at the Densu Estuary sampling location. This could be because of the location of the Densu Estuary in the transition region between the Densu River and the Atlantic Ocean, which facilitates the deposition of macroplastic litter from the ocean, the Densu River and from surface runoff at this location (Kumar *et al*., 2021; Li *et al*., 2023; Mattsson *et al*., 2015; Zhou *et al*., 2015). Tramoy *et al*. (2021) in their study on macroplastic deposition and transportation in Seine Estuary in France, similarly found that estuaries are hotspots for the accumulation of macroplastic litter. Additionally, tidal and wind currents, proximity to urban settlements and anthropogenic activities greatly influence the rate of macroplastic litter accumulation in estuarine environments (Barnes *et al*., 2009; Sajorne *et al*., 2021; Tramoy *et al*., 2021).

The second highest monthly macroplastic litter abundance which was recorded at the Tsokome sampling location could be due to its proximity to the Tsokome Community (Nukpezah *et al*., 2022; Sajorne *et al*., 2021). The Panbros sampling location on the other hand which had the lowest monthly abundance and rate of accumulation, has a lesser degree of human settlements within its surroundings. Studies by Nukpezah *et al*. (2022) and Sajorne *et al*. (2021) which compared plastic litter accumulation in urbanised and less-urbanised coastal areas in Ghana and Philippines respectively, also indicate that urbanised coastal areas tend to have higher levels of litter accumulation.

At the Densu Estuary, the highest macroplastic litter abundance was recorded in October. Conversely, at Tsokome, the highest abundance was recorded in August while Panbros recorded the highest abundance in September. These results suggest that there was no direct influence of the sampling months on the abundance of macroplastic litter recorded in the Ramsar site. This was supported by One-Way ANOVA which indicated no statistical significance for macroplastic abundance across months ($p = 0.963$).

When compared to other macroplastic studies in Ghana, the total macroplastic litter abundance in the present study was found to be higher than that reported by Adu-Boahen (2024) from Biriwa and Abandze coastal areas in the Central Region but lower than that reported by Nukpezah *et al*. (2022) from the banks of Mukwei and Kpeshie Lagoons and from Keta Ramsar Site. In the global context, the present study recorded higher macroplastic abundance than that reported by Blettler *et al*. (2017) from the banks of the Setúbal Lake in Argentina but was lower than that reported by Mugilarasan *et al*. (2021) from the Digha and Sagar coastal areas in India. The occurrence of higher macroplastic litter abundance in some areas in comparison to others is attributable to greater human population and activities.

5.2.2 Diversity of Macroplastic Litter

The highest occurring macroplastic litter categories in the Ramsar site which were small bags, black polythene bags, water sachets and drinks/water bottles are consistent with the common types of plastic products used in Ghana (Fobil & Hogarh, 2006). The most diverse range of macroplastic litter was observed at the Densu Estuary sampling location which recorded a total of 23 macroplastic litter categories across the three (3) months sampling period based on OSPAR Commission (2010) classification, while Tsokome (n = 22) and Panbros (n = 17) had the second most diverse and least diverse range, respectively. One-Way ANOVA showed a statistically significant difference in diversity across locations (p = 0.004) while Tukey HSD post hoc test indicated that the significance was greatest between Panbros and Densu Estuary (p = 0.005). The high diversity of macroplastics at the Densu Estuary can again be attributed to its location in the area of transition between the Densu River and the Atlantic Ocean, which enables it to receive a wide range of macroplastic litter categories from both the ocean and upstream sources (Kumar *et al*., 2021; Li *et al*., 2023; Mattsson *et al*., 2015; Zhou *et al*., 2015).

The macroplastic litter recorded in the Densu Ramsar Site which included drinks/water bottles, black polythene bags, takeaway food containers, nets and plastic shoes/flip-flops are similar to litter types found in studies by Blettler *et al*. (2017), Cozzolino *et al*. (2020) and Sajorne *et al*. (2021) which examined the accumulation of plastic litter at the banks of a lake in Argentina, lagoon banks in Portugal and a coastal region in Philippines, respectively. The prevalence of litter categories such as black polythene bags underscores the need to phase them out as has been done in countries like Rwanda, and to replace them with environmentally-friendly alternatives such as jute bags (Madigele & Mogomotsi, 2017; Xanthos & Walker, 2017).

5.2.3 Sources of Macroplastic Litter

Unlike microplastics, the relatively large sizes of macroplastic litter enables easier identification of the purpose for which the plastic material was used for before being discarded (Napper & Thompson, 2020). As explained in Chapter Two (2), macroplastic litter accumulating in coastal environments is generally attributed to two (2) main sources: land-based sources and ocean-based sources (MCS, 2009; OSPAR Commission, 2010, Veiga *et al*., 2016). The land-based and ocean-based sources can be more specifically grouped according to MCS (2009) guidelines into: 'public litter', 'fishing sources', 'sewage-related debris', 'shipping sources', 'fly tipped sources', 'medical sources' and 'non-sourced' as was done in this study.

Public litter was the most dominant source of macroplastic litter identified in the Densu Ramsar Site, accounting for 95.82% of litter recorded over the three (3) months sampling period. Public litter belongs to the land-based source category. This indicates that land-based source was the most dominant source of macroplastic litter in the Ramsar site. Miranda *et al*. (2019) as well as Sheavly and Register (2007) in their review studies of plastic pollution in the environment, also found that land-based sources represent more than 80% of plastic litter in coastal as well as marine ecosystems. The findings again suggest that indiscriminate discarding of plastic litter by the public is mainly responsible for macroplastic litter accumulation in the Ramsar site.

The modes of release of macroplastic litter in the Ramsar site are most likely the direct generation within the Ramsar site, transportation from the ocean and transportation from upstream areas by surface runoff, the flow of the Densu River and by wind to the Ramsar site (Ford *et al*., 2022; Haque & Fan, 2023; Kumar *et al*., 2021; Li *et al*., 2023; Zhou *et al*., 2015). It is worth noting that the Weija Reservoir, which is located a few kilometres upstream, could significantly contribute to the transportation of macroplastic litter from upstream areas via the Densu River to the Ramsar site, especially during dam spillages which are often characterised by an increase in river flow velocity (Kumar *et al*., 2021). Again, macroplastic litter of land-based origin can also be transported by the ocean from one geographical location to another (Kumar *et al*., 2021; Li *et al*., 2023; Veiga *et al*., 2016; Zhou *et al*., 2015).

After the public litter category, the remaining macroplastic litter sources identified at the Panbros sampling location over the three (3) months period were medical sources, non-sourced category, fishing sources and sewage-related debris. At Tsokome, the remaining sources identified were non-sourced category, fishing sources, medical sources and sewage-related debris and at the Densu Estuary sampling location, the remaining sources were non-sourced category, medical sources, sewage-related debris and fishing sources. This reveals the similarity in macroplastic litter sources identified in all three (3) sampling locations. The aforementioned sources however occurred in insignificant amounts in comparison to public litter. The fishing sources category was most likely generated directly within the Ramsar site. This is due to the fact that the Ramsar site is a coastal area hence fishing activities usually take place within its catchment.

Most brand names of macroplastic litter identified in the Ramsar site were brands based in Ghana. This again suggests that most of the macroplastic litter were most likely either generated within the catchment of the Ramsar site or transported from upstream areas to the Ramsar site (Veiga *et al*., 2016). This implies that cross-border transportation of macroplastic litter from a different geographical location via the ocean to the Ramsar site is probably an insignificant contributor to the macroplastic litter accumulation (Veiga *et al*., 2016).

5.3 Microplastic Abundance in Sediment Cores and Historical Trend in Microplastic Accumulation in the Ramsar Site

5.3.1 Microplastic Abundance in Sediment Cores

Microplastics were found in all sediment cores from the three (3) sampling locations in the Ramsar site: Panbros, Tsokome and Densu Estuary. The highest total microplastic abundance was however observed at the Densu Estuary sampling location (n = 304). A study by Culligan *et al*. (2021) on microplastic abundance in sediment cores at estuaries in Louisiana in the United States of America, has also indicated that estuaries are hotspots for the accumulation of microplastics in sediments. The relatively higher microplastic abundance at the Densu Estuary is again attributable to the fact that estuaries are located in the transitional region between the terrestrial ecosystem and the marine ecosystem (Mattsson *et al*., 2015; Zhou *et al*., 2015). Hence, they receive microplastics from both the ocean and from rivers and surface runoff originating from terrestrial areas (Kumar *et al*., 2021; Li *et al*., 2023; Mattsson *et al*., 2015; Zhou *et al*., 2015).

The Panbros sampling location which is relatively farther away from the coast exhibited an enrichment in mean microplastic abundance in the surface layer (0 – 5 cm) and showed a clear decrease to the last layer (25 – 30 cm) and a significantly predictable relationship was found to exist between mean microplastic abundance and sediment core depth ($r = -0.931$, $r^2 = 0.868$, $p = 0.007$). Dung *et al*. (2021), Kukkola *et al*. (2022) and Willis *et al*. (2017) also reported a reduction in microplastic abundance with increasing sediment core depth, in their studies on sedimentary records of microplastics in a Vietnamese mangrove forest, United Kingdom continental shelf and an Australian estuary respectively. Conversely, the Densu Estuary and Tsokome sampling locations had relatively low mean microplastic abundance in the surface layer (0 – 5 cm) and showed some fluctuations in microplastic abundance through sediment core depth. The Pearson product correlation analysis also exhibited weak and moderate negative correlations for Densu Estuary and Tsokome respectively, both of which were found to be statistically insignificant. The fluctuations in the vertical distribution of microplastics in sediment cores at these two (2) locations which are located relatively closer to the coast is attributable to the more dynamic nature of the coast which is characterised by the influence of tidal currents, varying hydrodynamic conditions of the Densu River, unstable sedimentation rates, fishing and other anthropogenic activities along the coast and bioturbation by organisms (Chico-Ortiz *et al*., 2020; Culligan *et al*., 2021; Dung *et al*., 2021; Willis *et al*., 2017; Yuan *et al*., 2023). These possibly led to the disturbance of the sediment profile and caused the resuspension of microplastics (Chico-Ortiz *et al*., 2020; Culligan *et al*., 2021; Dung *et al*., 2021; Willis *et al*., 2017; Yuan *et al*., 2023). The clearer trend in microplastic accumulation at the Panbros sampling location could be due to the absence of some of these factors. It is likely that microplastics accumulating in sediments in the Ramsar site is also influenced by the Weija Reservoir, especially when there is higher water flow during spillages (Kumar *et al*., 2021).

In comparison to a previous study by Blankson *et al*. (2022) on microplastics in surface sediments in the Densu Delta Ramsar Site, similar microplastic abundance was recorded in the topmost sediment core depth intervals (0 – 5 cm) in the present study. When compared to other microplastic studies in Ghana, the present study recorded higher microplastic abundance than that reported by Boateng *et al*. (2024) from Lake Volta but lower than those reported by Chico-Ortiz *et al*. (2020) in sediment cores from Kpeshie and Mukwei Lagoons and by Amekugbe (2023) from the Odaw River. In the global context, the present study observed higher abundance than that reported by Willis *et al*. (2017) from Derwent Estuary in Australia. Conversely, the present study had lower abundance than that reported by Pradit *et al*. (2022) from mangrove areas in Songkhla and Pattani in Thailand. The higher microplastic abundance recorded in the present study compared to sediments in Lake Volta and Derwent in Australia is attributable to greater unregulated human activities as well as the location of the Ramsar site downstream which enables it to receive microplastics from upstream areas and also from the ocean. Similarly, the relatively lower abundance recorded in the present study in comparison to those reported from Kpeshie and Mukwei Lagoons, Odaw River and from Thailand is also attributable to the higher anthropogenic activities in these areas compared to the Ramsar site. This underscores the significant role that drivers like population growth and its resultant anthropogenic pressures play in greatly increasing microplastic abundance in various environments.

5.3.2 Historical Trend in Microplastic Accumulation in the Ramsar Site

The steady growth in microplastic abundance in sediment cores at the Panbros sampling location from 1975 to date is attributable to the consistent increase in plastic consumption and release of plastic waste in Ghana from the 1970s to date (Fobil & Hogarh, 2006; Owusu-Sekyere *et al*., 2013). Plastic composition in Ghana's waste stream was 1.4% in the 1970s, rose to 8% by the year 2000 and currently stands at approximately 14% (Miezah *et al*., 2015; Owusu-Sekyere *et al*., 2013; World Bank Group, 2020). Similar relationships between plastic waste generation and microplastic abundance were observed in sediment cores from other regions of the world (Dung *et al*., 2021; Willis *et al*., 2017). It is likely that microplastic accumulation in sediments in future years at the Panbros sampling location would continuously experience an increase, except there is a major change in plastic consumption trends and plastic waste management approaches.

In comparison to the Panbros sampling location, faster rates of sedimentation were observed at the Tsokome and Densu Estuary sampling locations. This is attributable to the transportation of sediments from both the marine environment and upstream sources to the two locations (Kumar *et al*., 2021; Li *et al*., 2023; Mattsson *et al*., 2015; Zhou *et al*., 2015). The faster rates of sedimentation at the Tsokome sampling location (0.95 cm/yr) and Densu Estuary sampling location (1.95 cm/yr) most likely resulted in rapid deposition of sediments within a short time period and this accounts for the shorter time frame of their 30 cm long sediment cores. This explains why the Tsokome sampling location represents a deposition period spanning 1993 to 2023 while the Densu Estuary sampling location represents a deposition period spanning 2005 to 2023. Again, the simultaneous transportation of sediments from both marine and terrestrial sources could have also resulted in unstable sedimentation rates leading to fluctuations in microplastic abundance in the sediment cores at the Tsokome and Densu Estuary sampling locations. These explain why the fluctuation in microplastic abundance was highest at the Densu Estuary sampling location which is characterised by a direct connection between the marine environment and the flow of the Densu River from upstream sources. The notably low microplastic abundance at the topmost sediment core layer at the Densu Estuary which corresponds with more recent times, may also be attributed to the lockdown during the COVID-19 pandemic which was associated with a sharp decline in merry-making activities at the coastal area in the Ramsar site. This decline possibly led to a reduction in the direct release of plastic waste at the Estuary.

Despite the fluctuations in microplastic abundance in the sediment cores at the Densu Estuary and Tsokome sampling locations, the trend in microplastic accumulation has generally been on the rise from 1993 to 2023 for Tsokome and from 2005 to 2023 for the Densu Estuary. This may again be attributable to the growth in plastic consumption in Ghana as well as the transportation of microplastics from other sources via the marine environment to the two sampling locations (Dung *et al*., 2021; Fobil & Hogarh, 2006; Musah *et al*., 2021).

The contribution of upstream and marine sources to the generally increasing trend in microplastic accumulation in the Ramsar site over the years highlights the interdependency between various ecosystems. This interdependency also limits the ability of the Ramsar Convention and the Wetlands (Ramsar Sites) Management Regulations (L. I. 1659) of Ghana to ensure the protection of the Ramsar site from plastic waste accumulation. These issues underscore the need to employ an integrated approach to effectively protect wetlands to limit the impact of other environments on their wellbeing.

5.4 Characteristics of Microplastics in Sediments in the Ramsar Site

5.4.1 Shape, Size and Colour of Microplastics

Similar to the study by Culligan *et al*. (2021) in estuaries in the United States, the three (3) shapes of microplastics which were found in the sediment cores from the Ramsar site were fibres, fragments and films. Fibres were the most dominant shape (84.34%) across all sampling locations in the Ramsar site. Several studies such as Dung *et al*. (2021), Li *et al*. (2020), Mohamed *et al*. (2023), Pradit *et al*. (2022) and Willis *et al*. (2017) on microplastics in sediments from mangrove forests, salt marshes and estuaries, also reported higher amounts of fibres as compared to other microplastic shapes. The high abundance of fibres at all sampling locations in the Ramsar site suggests that they have similar sources. The extensive use of fibre-based equipment such as fishing nets and ropes in coastal activities like fishing is likely to be a significant contributor to fibres in sediments in the Ramsar site (Boateng *et al*., 2024; Kukkola *et al*., 2022; Li *et al*., 2020; Pradit *et al*., 2022). The Ramsar site as a densely populated coastal area also faces other anthropogenic pressures such as aquaculture operations, building construction, industrial operations as well as the possible release of wastewater from the washing of synthetic clothing in surrounding communities, all of which can produce and lead to the release of high amounts of microplastic fibres (Kukkola *et al*., 2022; Li *et al*., 2020; Mohamed *et al*., 2023; Pradit *et al*., 2022). Atmospheric deposition of fibres is also another probable contributor to their high abundance in the Ramsar site (Kukkola *et al*., 2022).

With respect to microplastic sizes, the most dominant size ranges in the Ramsar site were 501 – 1000 µm (31.68%) and 1001 – 3000 µm (31.10%). These results are similar to studies by Boateng *et al*. (2024) and Mohamed *et al*. (2023) which also reported a significant amount of microplastics in sediments which fell within the 501 – 1000 µm and >1000 µm size ranges, in Ghana's Lake Volta and Malaysia's Kuala Gula Mangrove Region respectively. The small size of microplastics facilitates their consumption by aquatic organisms like fish which puts their wellbeing as well as the wellbeing of other organisms in their food webs like humans at risk (Blankson *et al*., 2022; Deng *et al*., 2020; Li *et al*., 2023; Musah *et al*., 2021; Thompson *et al*., 2009a). Microplastic consumption by fish and water birds also limit their hunger detection, digestion and reproductive abilities and has also been noted for causing DNA abnormalities and death (Cedervall *et al*., 2012; Nukpezah *et al*., 2022; Thompson *et al*., 2009a; Werner *et al*., 2016). Again, their small size makes them possess large surface area that permits Persistent Organic Pollutants (POPs), pathogens and heavy metals to become attached to their surface before their ingestion by aquatic species; thus worsening their toxicity (Mattsson *et al*., 2015; Miranda *et al*., 2019; Wagner *et al*., 2014; Werner *et al*., 2016).

Seven (7) microplastic colours were observed in the sediment cores across the three (3) sampling locations in the Ramsar site namely: black, blue, red, green, yellow, transparent and white, with black (47.70%) being the most dominant. The variety of microplastic colours in the Ramsar site can be attributed to a wide range of potential sources. These potential sources include packaging and fishing (Mohamed *et al*., 2023). Microplastic colours which resemble the colour of food for aquatic organisms can cause these organisms to consume such microplastics (Mohamed *et al*., 2023). This suggests that microplastic colour may be a significant factor influencing bioaccumulation in organisms (Mohamed *et al*., 2023).

5.4.2 Polymer Composition of Microplastics

Of the six (6) polymer types identified from FTIR analysis, polyethylene was the most dominant (39.29%). This was followed by polypropylene (20.24%), polystyrene (15.48%), polyester (13.09%), cellophane (7.14%) and polyvinyl acetate (4.76%). The dominance of polyethylene, polypropylene, polystyrene and polyester (PET) reflects their extensive use in Ghana (Fobil & Hogarh, 2006; Miezah *et al*., 2015). Polyethylene is commonly employed in the production of water sachets, plastic food packaging and carrier bags that are prevalent in the country (Andrady & Neal, 2009; Fobil & Hogarh, 2006; Pradit *et al*., 2022). Polypropylene is highly used for the making of plastic bottles, bowls and textile fibre (Andrady, 2015; Andrady & Neal, 2009). Polystyrene is widely used for the manufacture of disposable styrofoam food containers (Li *et al*., 2020). Polyester (in the form of PET) is commonly used in the manufacture of single-use water and beverage bottles and clothing fibre (Andrady & Neal, 2009; Benyathiar *et al*., 2022; Geyer *et al*., 2017; Olam, 2021; Panowicz *et al*., 2021). The highest occurring litter categories from the macroplastic litter assessment (small bags, black polythene bags, water sachets and drinks/water bottles) are also typically manufactured from some of these main polymers identified in microplastics from the sediment core analysis, as stated. This indicates that there is a relationship between macroplastic litter and microplastic generation in the Ramsar site. For the less dominant microplastic polymers from the Ramsar site, cellophane is used in the production of food packaging and polyvinyl acetate is employed in the manufacture of adhesives and paint (Li *et al*., 2020).

The simple linear regression results revealed that the national macroplastic waste stream (Miezah *et al*., 2015) significantly predicts microplastic polymer composition in the Ramsar site. This underscores the impact that the use of various polymer types in Ghana has on microplastic composition in the Ramsar site. For instance, polyethylene had the highest composition and polyvinyl chloride had the lowest composition in both the national macroplastic waste stream and in microplastics from the Ramsar site. The notably high composition of polyethylene in macroplastic litter on a national scale and in microplastics from the Ramsar site highlights its extensive use in Ghana. The similarities in polymer composition on a national scale and in the Ramsar site also suggests that macroplastic litter released in upstream areas, within the Ramsar site or into the ocean indeed degrades over time to form microplastics, thereby facilitating microplastic accumulation in the Ramsar site. It was however observed that polystyrene was much higher in microplastics in the Ramsar site than in the national macroplastic waste stream. This is attributable to the high use of styrofoam food containers (takeaway packs) by persons who visit a beach resort located within the Ramsar site. Overall, the significant influence which national macroplastic polymer composition has on microplastic composition in the Ramsar site suggests that, macroplastic waste management on the national level through proactive measures like the curtailment of plastic importation and the replacement of prevalent polymer types like polyethylene carrier bags with paper bags and jute bags in Ghana, could significantly reduce the composition of such polymers in microplastics in the Ramsar site.

5.5 Perceptions on Drivers, Pressures, State, Impacts and Appropriate Response to Plastic Waste Accumulation in the Ramsar Site

Appropriately tackling plastic waste accumulation in the Ramsar site requires paying attention to the perceptions of consumers, the originators of plastic waste generation (United Nations Environment Programme, 2018b; Van Rensburg *et al*., 2020). It is important that their perceptions of the drivers, pressures, state and impacts of plastic waste accumulation in the Ramsar site as well as their readiness to modify their consumption behaviour is taken into account (Van Rensburg *et al*., 2020).

5.5.1 Drivers

The primary stakeholders (persons living and/or working within the catchment of the Ramsar site) and secondary stakeholders (institutions in charge of the protection of the Ramsar site) pointed to population growth, which causes a rise in the need for shelter, as the main driver of plastic waste accumulation in the Densu Delta. Akindele and Alimba (2021), in their study on the drivers, present state and ecosystem services implications of plastic pollution in Africa's aquatic areas, determined population growth as one of the main drivers of plastic pollution. They added that coastal cities in several African countries are often characterised by the greatest population densities and are therefore more prone to plastic pollution, which is the case for Accra in Ghana, where the Ramsar site is located (Akindele & Alimba, 2021; United Nations Department of Economic and Social Affairs, 2018). Similarly, Abalansa *et al*. (2020), who conducted a review study of plastic pollution in the global coastal environment using the DPSIR framework, also found that the need for shelter is a key driving force.

Economic growth, bringing about a rise in the need for income, was the next most significant driver perceived by both primary and secondary stakeholders. A study by Fobil (2000) on municipal solid waste management in Accra, Ghana, for example, indicated that economic growth is a major driver of plastic waste generation. Economic growth is often associated with an increase in the price of goods and services. The quest to maintain an optimum living standard leads to a rise in the need to have a reliable source of income. This leads to persons moving into places such as the catchment of the Ramsar site for livelihood purposes. The third most prominent driver that emerged from the responses of primary stakeholders is urbanisation which generates a heightened demand for recreation (tourism). Akindele and Alimba (2021) in their study on plastic pollution in Africa's aquatic regions, also determined urbanisation as a significant driver of plastic pollution. Studies by Abalansa *et al*. (2020) and Federigi *et al*. (2022) on coastal plastic pollution on a global scale and in Italy respectively, also indicated that beach tourism is one of the major drivers of plastic waste accumulation in coastal areas.

5.5.2 Pressures

Urban growth activities are the main pressure of plastic waste accumulation in the Ramsar site, based on perceptions of primary (41.9%) and secondary stakeholders. Nukpezah *et al*. (2022) and Sajorne *et al*. (2021) determined in their studies on plastic litter accumulation in highly urbanised and less urbanised coastal areas in Ghana and Philippines respectively that, highly urbanised coastal areas experience higher levels of plastic waste accumulation.

Other perceived pressures included petty trading activities where single-use plastics such as plastic bags are highly used. Improper disposal of such plastic waste and the lack of adequate structures for plastic waste disposal, eventually lead to the occurrence of high volumes of plastic waste in the Ramsar site. Some of the primary stakeholders admitted to engaging in indiscriminate littering and the discarding of their plastic waste at open dumpsites. This disclosure is supported by the observance of open dumpsites during the research. Musah *et al*. (2021) in his review study on coastal plastic pollution in Ghana also indicated that open dumpsites, streets and drainage systems are common means of disposal. Additionally, improper discarding of plastic waste from fishing activities leads to abandoned fishing gear such as ropes and fishing nets, as was observed during the macroplastic litter survey in the Ramsar site. Abalansa *et al*. (2020) also observed that inappropriately discarded or lost plastic fishing equipment contributes to plastic waste accumulation in coastal areas.

Conversely, some stakeholders perceived a larger proportion of plastic waste in the Ramsar site to be transported from other sources and not locally generated. The transport of plastic waste was attributed to upstream areas, carried by surface runoff and the Densu River, as well as transport by wind action and from the ocean to the Ramsar site. During spillage events of the Weija Reservoir when it reaches its capacity, the flow of the Densu River downstream towards the Ramsar site greatly increases, leading to occasional flooding. This facilitates increased transportation of macroplastics and microplastics from upstream areas to the Ramsar site. Kumar *et al*. (2021), Li *et al*. (2023) and Zhou *et al*. (2015), in their studies of plastic pollution in coastal wetlands, also found that high water flow velocity in freshwater systems, the wind and the ocean contribute to the transport of plastic waste to such wetlands.

5.5.3 State

Almost half of primary stakeholders (44.9%) did not know of the existence of microplastics while 17.1% were uncertain of its existence. GESAMP (2016) similarly found that the general public has low knowledge on the existence of microplastics, in their assessment of public perceptions of microplastics in marine regions.

Almost two-thirds (58.2%) of primary stakeholders were of the opinion that there is currently a high level of plastic waste accumulation in the Ramsar site. Studies by Hartley *et al*. (2018) and Van Rensburg *et al*. (2020) on public perceptions of plastic litter in coastal areas in Europe and South Africa respectively, have also revealed that people within coastal areas especially in densely populated coastal areas, generally perceive the state of plastic waste to be bad. After heavy rainfall or floods, majority of primary stakeholders (68.5%) were of the view that there is usually more plastic waste in the Ramsar site. Some secondary stakeholders also stated that the location of the Ramsar site downstream makes it susceptible to receiving both macroplastics and microplastics from upstream sources during heavy rainfall or floods. Ford *et al*. (2022) as well as Haque and Fan (2023) in their studies on the connection between climate change and plastic pollution, also indicated that there is an increase in the transportation of macroplastic litter and microplastics to coastal areas during heavy rainfall and floods.

5.5.4 Impacts

Over a third (36.4%) of primary stakeholders and some secondary stakeholders highlighted the negative socio-economic impacts of plastic waste accumulation on sources of livelihood such as fishing in the Ramsar site, due to low fish catch. This is similar to the findings of Abalansa *et al*. (2020) on marine plastic pollution, which revealed that plastic waste accumulation in coastal as well as marine ecosystems is associated with low fish catch which eventually leads to a drop in the income of fishermen. Low fish catch also has repercussions on the provisioning service (food) of the Ramsar site (Abalansa *et al*., 2020). About one-third (33.7%) of primary stakeholders and some secondary stakeholders were also of the opinion that plastic waste has led to a reduction in the level of attractiveness of the Ramsar site which has resulted in a drop in its tourism potential. Mugilarasan *et al*. (2021) and Musah *et al*. (2021) also indicated that there is a link between high amounts of plastic litter in coastal areas and a drop in tourists' patronage of such areas, in their studies on the spatiotemporal distribution of litter on beaches in India and on coastal plastic pollution in Ghana respectively. Plastic waste in the Ramsar site thus has an adverse impact on its cultural services delivery - tourism (Abalansa *et al*., 2020). Again, some primary and secondary stakeholders pointed to a rise in diseases such as cholera and malaria as another socio-economic impact. This is similar to studies which indicate that plastic waste in the environment is connected to the occurrence of sanitation related diseases like cholera and malaria (Debrah *et al*., 2021; Musah *et al*., 2021; World Bank Group, 2020).

A reduction in water quality was the most perceived environmental impact among primary stakeholders (42.0%) while a lesser proportion viewed fish ingesting or becoming entangled in plastics as well as destruction of habitat of biodiversity as environmental impacts. Some secondary stakeholders similarly spoke about the negative impact of both macroplastics and microplastics on water quality in the Ramsar site. Van Oosterhout *et al*. (2022) in their study on perceptions of the public on plastic pollution in the European coastal environment, also indicated that a large proportion of the public reported a perceived decrease in water quality in the coastal environment, due to the presence of plastic waste in the water. This perception is attributable to how noticeable floating plastic debris is in water bodies. Such floating plastic debris are often seen as an indicator of pollution thereby creating the perception of a reduction in water quality.

The high awareness of most primary stakeholders on the socio-economic and environmental impacts of plastic waste accumulation in the Ramsar site, is similar to studies by Madara *et al*.

(2016) as well as Negussie and Mustefa (2017) on level of awareness of communities on plastic litter impacts in Kenya and Ethiopia respectively, which indicated that individuals are highly aware of the impacts of plastic waste within their communities. The high awareness can be explained by the influence which geographical proximity and direct exposure to an environmental issue has on individuals' perception of the issue (Van Rensburg *et al*., 2020).

5.5.5 Response

About one-third of the primary stakeholders (33.5%) recommended that government should provide waste collection bins at vantage points within the Ramsar site and in upstream areas while 17.8% suggested strict enforcement of laws against littering. This reveals that primary stakeholders are largely aware that improper ways of discarding plastic waste such as indiscriminate littering within the Ramsar site and in upstream areas are major factors accounting for the plastic waste accumulation. However, a change from widely accepted negative plastic waste management practices to responsible practices would require the conscious effort of individuals (Tang, 2023). Again, some primary stakeholders recommended the separation of plastic waste for recycling as well as education of persons on responsible ways of managing plastic waste and impacts of improper plastic waste management. Secondary stakeholders also recommended response measures such as public education and the incorporation of the circular economy into plastic waste management through measures like reuse and recycling. Similarly, in a study on ways to reduce single-use plastic in the environment, United Nations Environment Programme (2018b) recommended education of consumers on proper plastic waste management practices and implementation of policies which enable the inclusion of the circular economy into plastic production, use and waste management.

Secondary stakeholders collectively emphasised the importance of attitudinal change on the part of individuals both within the Ramsar site and in upstream areas who engage in indiscriminate littering. Attitudinal change in this regard could lead to a significant reduction in plastic waste accumulation in the Ramsar site (Van Rensburg *et al*., 2020). Some primary stakeholders recommended the banning of the use of single-use plastics by government as another appropriate response measure. Similarly, some secondary stakeholders recommended the phasing out of single-use plastics such as plastic bags and the adoption of more environmentally-friendly alternatives such as paper bags and jute bags. There are also increasing calls to ban the use of single-use plastics in other African countries like Kenya and Ethiopia (Madara *et al*., 2016; Negussie & Mustefa 2017). There is indeed evidence of the effectiveness of banning single-use plastics such as plastic bags in countries like Rwanda which is currently regarded as one of the cleanest countries in Africa after its ban on plastic bags (Madigele & Mogomotsi, 2017; Xanthos & Walker, 2017). The recommendation to phase out single-use plastics was suggested as a response measure to facilitate attitudinal change among consumers. A change in the attitude of persons in the Ramsar site and in upstream areas would however be difficult to achieve if alternatives to plastic packaging and products are not available or are inadequately available in Ghana (Tang, 2023; United Nations Environment Programme, 2018b).

Additional response measures stated by primary stakeholders included the undertaking of frequent clean-up exercises and the encouraging of more persons within the Ramsar site to venture into the informal plastic waste picking business. Secondary stakeholders on the other hand recommended additional measures such as effective institutional collaboration, implementation of Extended Producer Responsibility regulations and the upscaling of recycling facilities. These indicate that both primary and secondary stakeholders had considerable knowledge on measures which can be put in place to tackle the issue of plastic waste accumulation in the Ramsar site. The challenge however lies in the translation of the recommended response measures into actions for mitigating plastic waste accumulation in the Ramsar site. The complex and interconnected nature of issues pertaining to plastic waste accumulation in the Ramsar site would require a collaboration between all key stakeholders to tackle the problem holistically and sustainably (Abalansa *et al*., 2020).

The findings of this study have highlighted the interplay between macroplastic and microplastic accumulation, its socio-economic drivers and the potential impacts in the Densu Delta Ramsar Site. These findings can be used by policy makers to make informed decisions regarding plastic use and plastic waste management (Blettler *et al*., 2017).

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter presents a summary of the key findings of this study, the conclusions as well as recommendations for mitigating plastic waste accumulation in the Densu Delta Ramsar Site, based on the research findings. The recommendations could serve as a basis for relevant institutions to make informed decisions regarding the appropriate response measures which can be put in place to tackle plastic waste accumulation in the Ramsar site.

6.2 Summary

Four (4) specific objectives were addressed in this study. With regard to Objective One (1) targeted at assessing the state of the abundance, diversity and sources of macroplastic litter in the Ramsar site, total macroplastic litter abundance over the three (3) months sampling period ranged between 762 to 1908 macroplastic items while total monthly diversity varied between 17 to 23 litter categories, at different locations in the Ramsar site, with the Densu Estuary recording the highest abundance and diversity. The main source identified over the three (3) months period was public litter – a land-based source, accounting for 95.82% of all litter recorded and a brand audit revealed that most of the identifiable brands of macroplastic litter in the Ramsar site were brands based in Ghana.

Concerning Objective Two (2) which was centered on determining microplastic abundance in sediment cores and the historical trend in microplastic accumulation in the Ramsar site, total microplastic abundance ranged between 267 to 304 microplastics at different locations in the

Ramsar site, with the Densu Estuary notably recording the highest, indicating that it is a hotspot for microplastic accumulation. For the historical trend in microplastic accumulation in the Ramsar site, there was a steady growth in microplastic accumulation (10.00 ± 2.00 microplastics/50g to 19.00 ± 1.73 microplastics/50g) from 1975 till 2023 at the Panbros sampling location while a generally increasing but fluctuating microplastic accumulation was observed at the Tsokome sampling location (11.33 ± 2.08 microplastics/50g to 13.67 ± 2.52 microplastics/50g) from 1993 to 2023 and from 2005 to 2023 at the Densu Estuary sampling location (13.67 ± 1.53 microplastics/50g to 13.00 ± 2.00 microplastics/50g). The fluctuations at the latter two sites is attributable to their location closer to the coast which is associated with the greater impact of tidal currents, anthropogenic activities and periodic changes in hydrodynamic conditions.

In relation to Objective Three (3) which sought to characterize microplastics in sediments in the Ramsar site in terms of shape, size, colour and polymer composition, the microplastic shapes observed in order of decreasing abundance were fibres (84.34%), fragments (9.42%) and films (6.24%). On the other hand, the dominant size ranges were 501 – 1000 µm (31.68%) and 1001 – 3000 µm (31.10%) and the most common colour was black (47.70%). In terms of polymer composition, the three (3) main polymers identified were polyethylene (39.29%), polypropylene (20.24%) and polystyrene (15.48%) which are extensively used polymer types in Ghana.

In line with Objective Four (4) which aimed to evaluate the perceptions of relevant stakeholders on the drivers, pressures, state, impacts and appropriate response to plastic waste accumulation in the Ramsar site, it was found that population growth which causes a rise in the need for shelter and economic growth which brings about a rise in the need for income, were perceived as the main drivers by both primary and secondary stakeholders. The main pressures perceived by stakeholders were urban growth activities and petty trading. Some stakeholders were however emphatic that majority of the plastic waste accumulating in the Ramsar site is not generated by persons within the Ramsar site but is rather mainly transported through surface runoff, wind, the ocean and the flow of the Densu River from upstream to the Ramsar site. Most stakeholders perceive the state of plastic waste accumulation in the Ramsar site to be bad and still on the rise. The main perceived socio-economic impacts were the adverse effects on livelihoods such as fishing and a reduction in the level of attractiveness of the Ramsar site as a tourist destination. The main perceived environmental impacts on the other hand included a reduction in water quality, organisms such as fish and water birds ingesting or becoming entangled in plastics and the destruction of the habitat of biodiversity. Key among the recommended response measures were attitudinal change towards plastic waste management, public education on the impacts of plastic waste accumulation in the Ramsar site, provision of waste bins, enforcement of Extended Producer Responsibility regulations as well as the phasing out of prevalent plastic packaging such as plastic carrier bags and replacing them with alternatives like paper bags and jute bags in Ghana.

6.3 Conclusions

In conclusion, this study revealed that:

- Macroplastic litter abundance and diversity in the Ramsar site differed depending on location, with the Densu Estuary representing the greatest repository. Public litter was the main macroplastic source and the dominance of local brands observed from the brand audit indicates the land-based and Ghanaian origin of macroplastic accumulation. This emphasises the link between national regulation of macroplastic waste generation and the mitigation of plastic waste accumulation in the Ramsar site.

- Depending on location in the Ramsar site, microplastic abundance in sediment cores also differed and the Densu Estuary was observed to be the greatest sink. Again, there is a largely increasing trend in microplastic accumulation in the Ramsar site from at least 1975 to 2023, reflecting the growth in plastic consumption in Ghana from the 1970s to date.
- For the characteristics of microplastics from the Ramsar site, the most dominant shape was fibres, the main size range was 501 – 1000 µm and the main colour was black. The most common polymer on the other hand was polyethylene, which is one of the major polymers used in Ghana, indicating that the plastic types extensively used in the country influences microplastic accumulation in the Ramsar site.
- The perceptions of the drivers of plastic waste accumulation in the Ramsar site mainly point to population growth associated with a rise in the need for shelter while urban growth activities are viewed as the main pressure and there is a perceived worsening state of plastic waste accumulation in the Ramsar site. The most common perceptions of the impacts of plastic waste accumulation in the Ramsar site are the disruption of occupations such as fishing, decrease in tourism potential and water quality reduction. Furthermore, stakeholders mainly recommended attitudinal change, ban of plastics like plastic carrier bags and the provision of bins at vantage points as response measures.

On the whole, this study reinforced the importance of employing a multi-disciplinary approach such as the DPSIR framework in tackling complex environmental issues such as plastic waste accumulation in crucial ecosystems like Ramsar sites for the development of sustainable solutions. The astronomical rise in plastic waste accumulation in several important ecosystems worldwide underscores the need to change the linear approach of plastic waste management to a circular economy approach and also stresses the need for the gradual replacement of plastic products such as plastic packaging with suitable alternatives. In the quest to search for substitute materials to offset the global overdependence on plastics, it is however imperative that the other available options are well examined to ensure that they do not also have devastating consequences on the environment.

6.4 Recommendations

Based on the findings of this research, the following response measures are recommended:

- The government of Ghana should phase out specific single-use plastics such as plastic carrier bags as stated in the National Plastics Management Policy of 2020. Such a ban should however be supported with the adequate provision of environmentally-friendly alternatives such as paper bags and jute bags.
- Plastic importation into the country should be curtailed by the Ghanaian government, as another national measure to reduce plastic waste accumulation in the Ramsar site.
- Investments should be made by the Ghanaian government and private organisations to improve recycling facilities and to establish an adequate number of plastic buy-back centres within the catchment of the Ramsar site and in upstream areas with the purpose of providing financial incentives for individuals and informal plastic waste pickers in exchange for their recyclable plastic waste.
- The waste management provisions in the Wetlands (Ramsar Sites) Management Regulations (L.I. 1659) of Ghana should be strictly enforced by the government.
- There should be attitudinal change on the part of individuals within the Ramsar site and in upstream areas. The first step to this, should be the undertaking of awareness creation

campaigns by government and non-governmental institutions through avenues such as community durbars to educate individuals in the Ramsar site and in upstream areas on the impacts of plastic waste accumulation and the responsible ways of managing plastic waste.

Recommendation for Further Study

- Further historical microplastic studies should be conducted to deploy sediment traps for at least a year to account for long-term variations in sediment deposition.

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APPENDICES

APPENDIX A: MACROPLASTIC LITTER MONITORING DATA SHEET (ADAPTED FROM OSPAR COMMISSION, 2010)

Name of Sampling Location:……………………………………..

Date:………………………………………………………….

GPS Coordinates:………………………………………...

Observations about Sampling Location:

…………………………………………………………………………………………………

………………………………………………………………………………………………....

Plastic Item	Count	Mass (g)
Drinks/water bottles		
Caps/lids		
Water sachets		
Black polythene bags		
Small bags		
Alcohol sachets		
Disposable plastic drinking cups		
Plastic cutlery and straws		
Food containers (takeaway packs)		
Crisp/Sweets wrappers and lollipop sticks		

Plastic Item	Count	Mass (g)
Plastic labels		
Rope		
Nets		
Foam		
Plastic shoes and flip-flops		
Pens		
Combs/plastic hair brushes		
Cigarette lighters		
Detergent wrappers		
Plastic cosmetic packaging (such as plastic deodorant, lotion and perfume containers and toothpaste containers)		
Plastic medical packaging (such as syrup/tonic containers, tubes and packaging for pills)		
Sanitary towels and diapers		
Nylon sacks		
PVC pipe		
Others (unidentifiable plastic items)		
Total		

APPENDIX B: OVERALL MACROPLASTIC LITTER COUNT WITH CORRESPONDING MASS FOR EACH SAMPLING LOCATION FOR THE THREE MONTHS SAMPLING PERIOD

	August		September		October	
Sampling Location	**Total Count**	**Total Mass (g)**	**Total Count**	**Total Mass (g)**	**Total Count**	**Total Mass (g)**
Panbros	253	2117.27	301	2314.36	208	1571.35
Tsokome	501	3227.50	426	2561.18	259	1613.83
Densu Estuary	614	5986.94	533	3931.78	761	6811.26

APPENDIX C: MACROPLASTIC LITTER CATEGORIES RECORDED AT PANBROS SAMPLING LOCATION ACROSS THREE MONTHS SAMPLING PERIOD IN ORDER OF DECREASING ABUNDANCE

Plastic Item	August	September	October	Total Count
Water sachets	63	78	52	**193**
Drinks/water bottles	54	62	31	**147**
Black polythene bags	31	46	32	**109**
Crisp/sweets wrappers and lollipop sticks	30	39	37	**106**
Small bags	36	33	23	**92**
Caps/lids	12	13	8	**33**
Detergent wrappers	8	7	9	**24**
Alcohol sachets	8	5	3	**16**
Disposable plastic drinking cups	5	4	2	**11**
Others	3	6	0	**9**
Plastic medical packaging	0	4	3	**7**
Plastic labels	0	0	6	**6**
Plastic cosmetic packaging	0	3	0	**3**
Food containers (takeaway packs)	2	0	0	**2**
Plastic shoes and flip-flops	0	0	2	**2**
Nets	1	0	0	**1**
Sanitary towels and diapers	0	1	0	**1**
Total Count	**253**	**301**	**208**	**762**

APPENDIX D: MACROPLASTIC LITTER CATEGORIES RECORDED AT TSOKOME SAMPLING LOCATION ACROSS THREE MONTHS SAMPLING PERIOD IN ORDER OF DECREASING ABUNDANCE

Plastic Item	August	September	October	Total Count
Small bags	189	135	81	**405**
Black polythene bags	118	98	57	**273**
Water sachets	61	50	35	**146**
Crisp/sweets wrappers and lollipop sticks	36	44	28	**108**
Drinks/water bottles	33	42	19	**94**
Caps/lids	14	14	7	**35**
Detergent wrappers	11	5	7	**23**
Others	6	8	8	**22**
Alcohol sachets	9	6	3	**18**
Disposable plastic drinking cups	4	5	3	**12**
Plastic labels	4	5	2	**11**
Nets	1	4	5	**10**
Plastic cutlery and straws	3	3	0	**6**
Plastic shoes and flip-flops	2	3	1	**6**
Nylon sacks	4	0	0	**4**
Food containers (takeaway packs)	1	2	0	**3**
PVC pipe	1	1	1	**3**

Plastic Item	August	September	October	Total Count
Rope	1	1	0	**2**
Plastic cosmetic packaging	2	0	0	**2**
Plastic medical packaging	0	0	1	**1**
Foam	0	0	1	**1**
Sanitary towels and diapers	1	0	0	**1**
Total Count	**501**	**426**	**259**	**1186**

APPENDIX E: MACROPLASTIC LITTER CATEGORIES RECORDED AT DENSU ESTUARY SAMPLING LOCATION ACROSS THREE MONTHS SAMPLING PERIOD IN ORDER OF DECREASING ABUNDANCE

Plastic Item	August	September	October	Total Count
Drinks/water bottles	112	97	158	**367**
Water sachets	81	70	135	**286**
Small bags	64	93	94	**251**
Black polythene bags	99	74	76	**249**
Crisp/sweets wrappers and lollipop sticks	56	71	112	**239**
Plastic labels	38	22	31	**91**
Caps/lids	36	30	23	**89**
Others	17	18	23	**58**
Alcohol sachets	17	13	17	**47**
Disposable plastic drinking cups	11	11	24	**46**
Plastic cutlery and straws	15	12	13	**40**
Detergent wrappers	19	0	13	**32**
Plastic shoes and flip-flops	14	3	15	**32**
Plastic medical packaging	19	4	7	**30**
Plastic cosmetic packaging	8	5	5	**18**
Food containers (takeaway packs)	0	0	11	**11**

Plastic Item	August	September	October	Total Count
Pens	0	6	0	**6**
Sanitary towels and diapers	4	0	1	**5**
Nylon sacks	4	1	0	**5**
Rope	0	1	1	**2**
Foam	0	0	2	**2**
Combs/plastic hair brushes	0	1	0	**1**
Cigarette lighters	0	1	0	**1**
Total Count	**614**	**533**	**761**	**1908**

APPENDIX F: MEAN MICROPLASTIC ABUNDANCE THROUGH SEDIMENT CORE DEPTH EXPRESSED IN MICROPLASTICS/KG FOR EACH SAMPLING LOCATION

Sediment Core Depth (cm)	Panbros (Mean ± Standard Deviation)	Tsokome (Mean ± Standard Deviation)	Densu Estuary (Mean ± Standard Deviation)
0 – 5	380.00 ± 34.64	273.33 ± 50.33	260.00 ± 40.00
5 – 10	346.67 ± 30.55	353.33 ± 64.29	466.67 ± 50.33
10 – 15	320.00 ± 40.00	333.33 ± 50.33	346.67 ± 41.63
15 – 20	313.33 ± 80.83	300.00 ± 34.64	353.33 ± 30.55
20 – 25	293.33 ± 41.63	293.33 ± 30.55	326.67 ± 23.09
25 – 30	200.00 ± 40.00	226.67 ± 41.63	273.33 ± 30.55

APPENDIX G: AVERAGE POLYMER COMPOSITION IN NATIONAL MACROPLASTIC WASTE STREAM (ADAPTED FROM MIEZAH *ET AL*., 2015)

Polymer Type	National Macroplastic Waste Stream (%) [a]
Polyethylene	6.78
Polypropylene	1.40
Polystyrene	0.58
Polyethylene Terephthalate	2.90
Polyvinyl Chloride	0.47
Others	2.18
Total	**14.31% ≈ 14%**

[a] Adapted from Miezah *et al*. (2015)

APPENDIX H: QUESTIONNAIRE FOR PRIMARY STAKEHOLDERS

UNIVERSITY OF GHANA

COLLEGE OF BASIC AND APPLIED SCIENCES

INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES (IESS)

Introduction

My name is Nancy Abrahams, an MPhil Environmental Science student of the Institute for Environment and Sanitation Studies (IESS), University of Ghana. I am administering this questionnaire as part of my thesis which is focused on the issue of plastic waste accumulation in the Densu Delta Ramsar Site. This study seeks to assess the drivers of plastic waste accumulation in the Ramsar site, the state, effects as well as the appropriate response measures that can be put in place to tackle this problem. This questionnaire is to be administered solely to persons aged 18 years and above.

I would be very grateful if you take part in filling this questionnaire. This questionnaire would take about 25 minutes to complete. Confidentiality is assured and the information obtained would solely be used for the purpose of this research.

Your participation in the filling of this questionnaire would provide valuable insight into the issue of plastic waste accumulation in the Densu Delta Ramsar Site and would inform the recommendation of appropriate response measures that can be put in place to address this problem.

Your consent to participate in the completion of this questionnaire would be very much appreciated.

Kindly tick your response or write your response to the following questions in the lines provided.

PRIMARY STAKEHOLDERS (PERSONS LIVING AND/OR WORKING WITHIN THE CATCHMENT OF THE DENSU DELTA RAMSAR SITE)

SECTION A: DEMOGRAPHIC INFORMATION OF PARTICIPANT

1. Gender: a. Male [ ] b. Female [ ]
2. What is your age?

   a. 18 – 29 b. 30 – 39 c. 40 – 49 d. 50 – 59 e. 60 and above
3. What is your highest level of education?

   a. None b. Basic Level c. Secondary Level d. Tertiary Level
4. Do you live and/or work in this area?

   a. I live in this area b. I work in this area c. Both
5. How long have you lived and/or worked in this area?

   a. Less than 5 years b. 5 – 10 years c. 11 – 15 years d. 16 – 20 years

   e. 21 – 25 years f. 25 years and above
6. What is your occupation?

   ……………………………………………..............

SECTION B: DRIVERS AND PRESSURES CAUSING PLASTIC WASTE ACCUMULATION IN THE RAMSAR SITE

7. What are the driving forces (social and economic factors and needs) causing the occurrence of accumulation of plastic waste in this area?

   □ Population growth which causes a rise in the need for shelter

 Economic growth which brings about a rise in the need to have a source of income

 Population growth which intensifies the need for food such as fish

 Urbanisation which generates a heightened demand for recreation

8. What are the activities that take place in this area which contribute to plastic waste accumulation in the open environment?

 Urban growth activities

 Petty trading activities

 Fishing activities

 Tourism-related activities

9. What are the ways by which you manage your plastic waste in this area?

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10. What are the other ways by which plastic waste enters and gets accumulated in this area?

 Surface runoff and flow of the Densu River from upstream

 Transport from ocean to Ramsar site

 Transport by wind action

SECTION C: STATE OF PLASTIC WASTE ACCUMULATION IN THE RAMSAR SITE

11. Does plastic waste disintegrate into smaller pieces (microplastics) over time?

a. Yes b. No c. Unsure

12. In your opinion, what is the current state of plastic waste accumulation in this area?

a. Low level of accumulation b. Moderate level of accumulation c. High level of accumulation

13. What was the state of plastic waste accumulation in this area in the past?

a. Less plastic waste than the current state b. More plastic waste than the current state

c. The state of plastic waste in the past is the same as the current state

14. What is the state of plastic waste accumulation in the Ramsar site after heavy rainfall or floods?

a. Less plastic waste in the Ramsar site b. More plastic waste in the Ramsar site

c. The plastic waste state remains the same before and after heavy rainfall or floods

SECTION D: IMPACTS OF PLASTIC WASTE ACCUMULATION IN THE RAMSAR SITE

15. What effects has plastic waste in this area had on you and other people in this area?

☐ Rise in public health concerns such as cholera and malaria due to poor sanitation caused by prevalence of plastic waste in the Ramsar site

☐ Negative impact on fishing and other sources of livelihood due to prevalence of plastic waste in the Ramsar site

☐ Reduction in level of attractiveness of Ramsar site leading to decrease in tourism potential

☐ Not aware of any socio-economic impacts

☐ Others……………………………………………………………………………………

16. In your opinion, what effects does macroplastics and/or microplastics have on the environment in this area (provision of ecosystem services)?

☐ Fish ingesting or becoming entangled in plastics

☐ Destruction of habitat of biodiversity

□ Reduction in water quality

□ Not aware of any environmental impacts

□ Others…………………………………………………………………………………………

SECTION E: RESPONSE MEASURES TO TACKLE PLASTIC WASTE ACCUMULATION IN THE RAMSAR SITE

17. In your opinion, what can be done by people who live and/or work in this area to improve the plastic waste situation?

□ Carrying out of regular clean up exercises

□ Contribution to the acquiring of waste bins to reduce the occurrence of plastic littering and to encourage attitudinal change

□ Separation of plastic waste for reuse and recycling

□ It is not the responsibility of persons within the Ramsar site

□ Others…………………………………………………………………………………………

18. In your opinion, what can the government or relevant institutions do to improve the plastic waste situation in this area?

□ Provision of waste bins at vantage points within the Ramsar site and upstream

□ Education of persons within the Ramsar site and upstream on responsible ways of managing plastic waste

□ Strict enforcement of laws against littering

□ Implementation of policies on the significant reduction of the reliance on single-use plastics

□ Others…………………………………………………………………………………………

APPENDIX I: SEMI-STRUCTURED INTERVIEW QUESTIONS FOR SECONDARY STAKEHOLDERS

UNIVERSITY OF GHANA

COLLEGE OF BASIC AND APPLIED SCIENCES

INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES (IESS)

Introduction

My name is Nancy Abrahams, an MPhil Environmental Science student of the Institute for Environment and Sanitation Studies (IESS), University of Ghana. I am undertaking this semi-structured interview as part of my thesis which is focused on the issue of plastic waste accumulation in the Densu Delta Ramsar Site. This study seeks to assess the drivers of plastic waste accumulation in the Ramsar site, the state, effects as well as the appropriate response measures that can be put in place to tackle this problem. The persons to be engaged in this interview must be aged 18 years and above.

I would be very grateful if you take part in this interview. This interview would take about 30 minutes to complete. Confidentiality is assured and the information obtained would solely be used for the purpose of this research.

Your participation in this interview would provide valuable insight into the issue of plastic waste accumulation in the Densu Delta Ramsar Site and would inform the recommendation of appropriate response measures that can be put in place to address this problem.

Your consent to participate in this interview would be very much appreciated.

SECONDARY STAKEHOLDERS (INSTITUTIONS IN CHARGE OF THE ENVIRONMENTAL PROTECTION OF THE DENSU DELTA RAMSAR SITE)

SECTION A: BACKGROUND OF INSTITUTION

1. Position:

   ……………………………………………………………………………

2. What is the mandate and the functions of your institution?

   ………………………………………………………………………………………………………

   ………………………………………………………………………………………………………

   ………………………………………………………………………………………………………

   ………………………………………………………………………………………………………

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3. How does this mandate apply to the protection of the Densu Delta Ramsar Site from plastic waste accumulation?

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   ………………………………………………………………………………………………………

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   ………………………………………………………………………………………………………

   ………………………………………………………………………………………………………

SECTION B: DRIVERS AND PRESSURES CAUSING PLASTIC WASTE ACCUMULATION IN THE RAMSAR SITE

4. What are the driving forces (social and economic factors and needs) causing the occurrence of the accumulation of plastic waste (macroplastics and microplastics) in the Ramsar site from your institution's perspective?
5. What are the activities identified by your institution that take place in the Ramsar site which contribute to plastic waste (macroplastics and microplastics) accumulation?
6. What are the ways by which people manage their plastic waste in the Ramsar site?
7. What are the other ways by which plastic waste (macroplastics and microplastics) enters and gets accumulated in the Ramsar site?

SECTION C: STATE OF PLASTIC WASTE ACCUMULATION IN THE RAMSAR SITE

8. In your opinion, what is the current state of plastic waste (macroplastics and microplastics) accumulation in the Ramsar site?
9. What was the state of plastic waste accumulation in the Ramsar site in the past?
10. What is the state of plastic waste accumulation in the Ramsar site after heavy rainfall or floods?

SECTION D: IMPACTS OF PLASTIC WASTE ACCUMULATION IN THE RAMSAR SITE

11. What effects has plastic waste (macroplastics and microplastics) had on people in the Ramsar site?
12. What effects does macroplastics and microplastics have on the environment in the Ramsar site (provision of ecosystem services)?

SECTION E: RESPONSE MEASURES TO TACKLE PLASTIC WASTE ACCUMULATION IN THE RAMSAR SITE

13. Are there existing policies/initiatives that have been put in place to control the issue of plastic waste accumulation in the Ramsar Site?
14. If yes, what are these policies/initiatives?
15. When did they begin operation?
16. What are the outcomes of these policies/initiatives?
17. What are the challenges associated with these policies/initiatives?
18. How does your institution collaborate with other institutions to tackle the issue of plastic waste accumulation in the Ramsar site?
19. What other policies/initiatives can be put in place to tackle the issue of plastic waste accumulation in the Ramsar site?
20. What can be done by the people within the catchment of the Ramsar site to improve the plastic waste situation?

APPENDIX J: OVERVIEW OF INSTITUTIONS INTERVIEWED

Institution	Overview of Mandate
Institution A	A governmental institution in charge of promoting and overseeing overall development, environmental protection and betterment of the living standard of persons within its jurisdiction which forms part of the catchment of the Ramsar site
Institution B	A state institution responsible for the conservation of Ghana's wildlife and management of protected areas such as Ramsar sites
Institution C	A state institution in charge of promoting and overseeing overall development, environmental protection and the betterment of the living standard of persons within its jurisdiction which forms part of the catchment of the Ramsar site
Institution D	A governmental institution responsible for the protection and regulation of the environment in Ghana, provision of advice on environmental policy formulation and facilitation of their implementation
Institution E	A private company which engages in commercial salt production within the Ramsar site
Institution F	A governmental institution in charge of the management and regulation of water resources in Ghana and coordination of water-related policies