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# Quantitative Analysis of Plastic Waste Accumulation in Coastal Ghana: Implications for Waste Management

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**Abstract:** *The presence of plastic waste in coastal regions creates major environmental and financial problems mainly for underdeveloped countries which lack proper waste handling infrastructure. The research evaluates plastic waste patterns dispersal distributions and spatial clustering forms throughout Accra Winneba and Cape Coast coastal zones in Ghana through statistical quantitative methods. Researchers performed systematic field surveys throughout the three areas to evaluate plastic waste types using Principal Component Analysis (PCA). They determined the main waste categories in the survey zones. Multi-variate Analysis of Variance (MANOVA) evaluated the proportional distribution of plastic waste categories while Hierarchical Cluster Analysis (HCA) assessed patterns of site-based waste composition similarities. PET Bottles together with Hard Plastics appear as the principal waste types present throughout every study site. The plastic waste accumulation levels in Cape Coast stand out from other areas because Fisherman Equipment together with Styrofoam products account for higher waste amounts stemming from tourism and fishing sector dominance. The plastic waste composition found in Accra and Winneba produces similar clusters which align within the HCA. Results from ANOVA testing reveal there are no statistically important differences ($p > 0.05$) found between total plastic waste measurements among study sites. Global data confirms that the factors behind plastic pollution include urban growth coupled with insufficient control amendments and robust economic development systems. The resolution of this problem needs new policies combined with better waste infrastructure elements, along with active community participation. Multiple sectors of government agencies along with local communities need to join forces with industry stakeholders to achieve sustainable waste management practices that minimize plastic pollution in Ghana's coastal regions.*

***Keywords**: Plastic Pollution, Waste Composition, PET, Styrofoam, Fishing Gear, Coastal Waste, Waste Management, Ghana, MANOVA, PCA, HCA, EPR.*

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## 1. 0 Introduction

During the mid-20th century, synthetic polymers changed the industrial landscape through their durable and versatile properties, yet plastic pollution has proven itself to be one of the world's major environmental threats of the 21st century. The global plastic production volume increased substantially over time, exceeding 400 million metric tons per year, and an important part of this increased waste ends up in marine environments (Jambeck et al., 2015). This crisis primarily affects developing-world coastal zones since they possess ineffective waste disposal systems and experience fast population growth. Plastic waste volumes have become a substantial waste management problem because accumulation rates in coastal cities continue to rise, thus creating prolonged environmental and economic problems (Osabuohien, 2017).

Plastic pollution continues to rise throughout Ghana's 550 km stretch of the Gulf of Guinea coastline because of growing urbanization and tourism activities, together with inadequate waste management practices (Osei et al., 2020). Accra, as the capital, produces high amounts of plastic waste that primarily appear on beach areas, including Labadi and Kokrobite. The fishing community town Winneba along with the tourist and education center Cape Coast display plastic waste-related issues causing waterway blockages and overwhelming waste management systems (Mensah et al., 2019). The constant buildup of plastic waste throughout these areas requires both systematic data evaluation and quantitative waste distribution analyses to develop effective policy measures.

The main focus of existing research in Ghana centres on qualitative investigations regarding plastic pollution, including waste impact on communities and the economic and societal effects of waste products (Adjei & Boamah, 2018; Amponsah et al., 2021). However, limited empirical data is quantifying the extent of plastic waste accumulation along Ghana's coast**.** The precise measurement of plastic waste quantities, their chemical make-up, and geographical patterns remains a major deficit in current scientific data regarding Ghanaian coastlines. The absence of measurable data prevents policymakers from creating effective waste management strategies because they lack sufficient evidence for development.

Most research has chosen to study large metropolitan areas while performing minimal comparative investigations that span different coastal towns. Research currently lacks clarity regarding the different plastic waste behaviours that exist between major urban areas such as Accra and the medium-sized locations Winneba and Cape Coast. Meeting this research challenge demands an extensive quantitative system capable of analyzing plastic waste accumulation trends, spatial distribution, and density variations to aid waste management planning.

A quantitative research methodology will be used in this investigation to measure plastic waste amounts in Accra, Winneba, and Cape Coast. The research has two primary objectives: measuring plastic waste quantities and types in coastal areas and analyzing plastic waste density patterns in selected coastal sites. The research relies on statistical tools PCA, ANOVA and HCA to generate data-driven insights about waste accumulation patterns together with their regional distribution. This research supports policy development for waste management through quantitative plastic waste assessment of coastal cities in Ghana.

A novel aspect of this study enables quantitative data collection at different coastal sites throughout Ghana to determine plastic waste distribution while measuring volume quantities. This work presents a comparative approach that analyzes both dissimilarities and shared aspects of plastic waste accumulation beyond previous studies dependent on qualitative evaluations and isolated case reports. The main value of this research stems from its ability to establish evidence-based intervention strategies that match the unique needs of each coastal area and contribute to sustainable waste management solutions.

Fig. 1 illustrates the key factors influencing plastic waste accumulation in coastal environments, particularly in Ghana. The diagram identifies plastic waste sources, including household waste, industrial waste, tourism and recreational activities, and the fishing industry. These sources contribute significantly to plastic pollution in coastal Ghana, where rapid urbanization, fishing activities, and tourism are major economic drivers (Jambeck et al., 2015; Law et al., 2020).

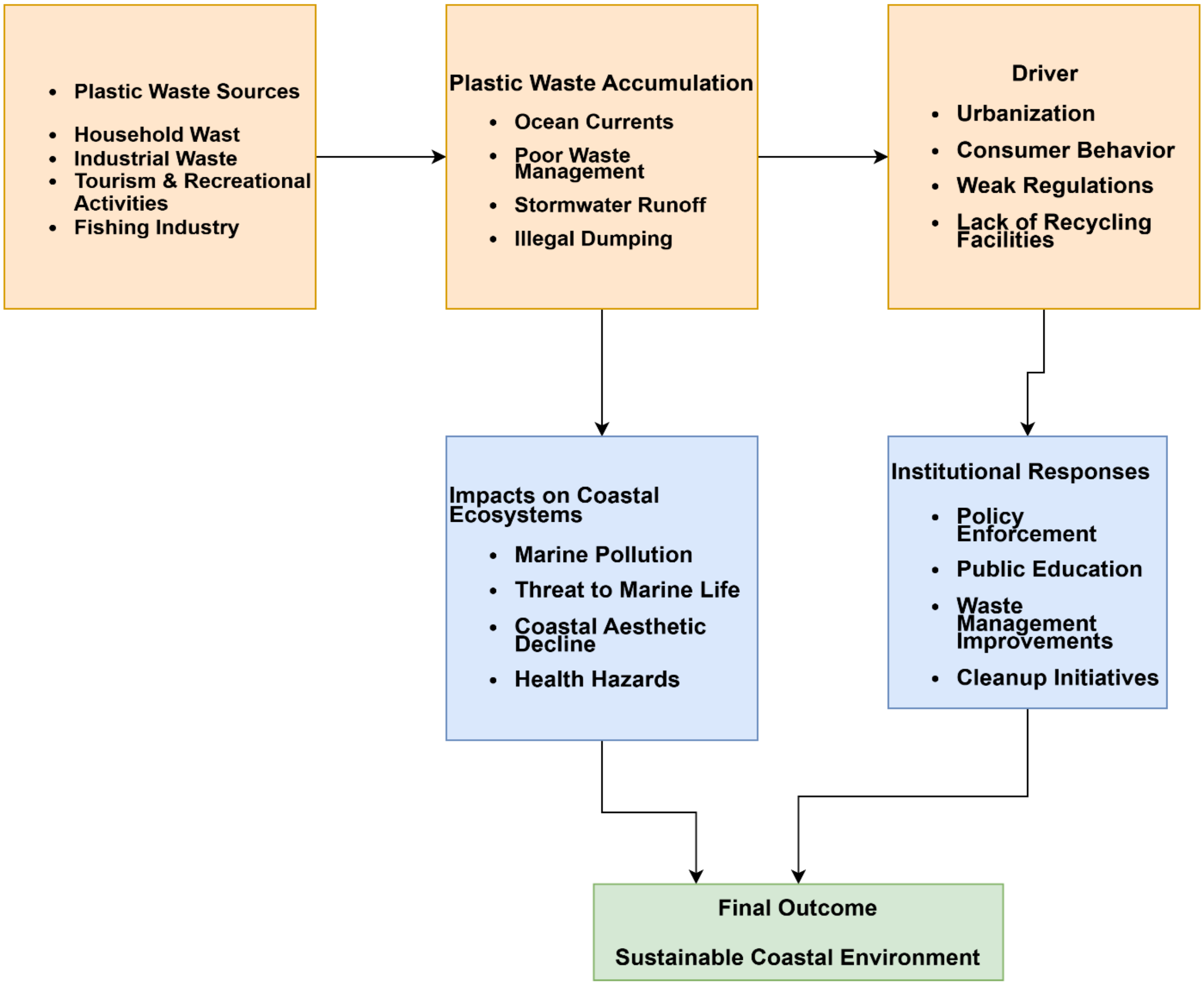


**Fig. 1. Conceptual Framework for Proportional Distribution of Plastic Waste Types Across Selected Coastal Cities in Ghana**

The accumulation of plastic waste occurs through several pathways, such as ocean currents, poor waste management, stormwater runoff, and illegal dumping. These mechanisms transport plastic waste into coastal areas, exacerbating environmental degradation. The underlying drivers of this issue include urbanization, consumer behaviour, weak regulations, and the lack of recycling facilities, all of which contribute to the persistent accumulation of plastic waste along the coastline (Borrelle et al., 2020; Nakatani et al., 2023).

The impacts of plastic waste on coastal ecosystems are severe, leading to marine pollution, threats to marine life, coastal aesthetic decline, and health hazards. The coastal economy of Ghana, which heavily relies on tourism and fisheries, is at risk due to plastic pollution and microplastic contamination affecting marine biodiversity and seafood safety (Ryan, 2015; Lusher et al., 2017).

Institutional responses, including policy enforcement, public education, waste management improvements, and cleanup initiatives, play a critical role in addressing plastic waste challenges. Evaluating the effectiveness of these strategies is essential for developing more sustainable waste management practices (UNEP, 2018; Rochman et al., 2016).

Ultimately, the goal is to achieve a sustainable coastal environment by implementing efficient waste management systems that balance economic growth with environmental protection. A quantitative analysis of plastic waste in coastal Ghana should assess waste generation rates, accumulation patterns, and the effectiveness of current waste management interventions, providing data-driven solutions to mitigate plastic pollution (Jambeck et al., 2018; Cózar et al., 2014).

The combination of Accra Winneba and Cape Coast coastal areas in Ghana experiences mounting environmental issues because of rising plastic waste amounts. Detailed research along the Accra-Tema coastline showed plastic materials formed 63.72% of all marine debris collected which demonstrated the critical nature of plastic pollution found in these coastal areas (Van Dyck et al., 2016). The high percentage of plastic waste reveals an urgent necessity to solve the origins and environmental effects plastic waste creates on Ghana's coastal areas.

A wide range of elements generates plastic waste accumulated in these regions. Marine pollution stems mainly from land-based activities that create 80% of such pollution while waterway and ocean sources alone create 20% (Van Dyck et al., 2016). Different pollution sources begin with domestic waste and industrial waste released into water bodies alongside tourism activities and fishing sector operations. Littering behaviours displayed by beach users serve as the principal factor leading to litter accumulation on Ghana's beaches according to Van Dyck et al. (2016). Environmental degradation occurs due to imported secondhand clothing because numerous unsellable garments transform into waste which contributes to coastal area pollution (Britten, 2024).

Multiple factors intensify the accumulation of plastic waste found within coastal zones. Multiple factors including fast-paced urban development together with consumer habits shifting toward single-use products and insufficient waste management systems coupled with weak industrial regulations drive plastic waste buildup in the environment. Insufficient recycling facilities make the situation worse since more plastic waste finds its way toward marine environments. The analysis conducted by the MESTI (2022) shows how nine percent of the annual 0.84 million metric tonnes of plastic waste output in Ghana escapes into ocean routes (Ghana News Agency, 2022).

Different factors shape how plastic waste builds up in marine coastal environments. Ocean currents serve as crucial agents which determine where plastic debris spreads in coastal regions. Plastic waste ends up in waterways as stormwater runoff transports materials that were not properly disposed of without separation. The problem is worsened through illegal dumping which creates major environmental complications. Studies indicate that microplastics are found commonly in coastal lagoon sediment deposits thereby creating widespread environmental contamination that enables their biological accumulation by ocean-dwelling organisms (Chico-Ortiz et al., 2020).

Coastal ecosystems experience wide-ranging severe effects as a result of plastic waste accumulation. Plastic ingestion by marine organisms occurs due to their mistaken identification of microplastics as food particles thus leading to medical problems and death as well as reproductive complications. Typical coastal beauty losses from plastic build-up often lead to lower tourist numbers thus decreasing local business revenue. The introduction of plastic debris interferes with natural marine habitats preventing coastal species from reaching their habitats which causes biodiversity reduction. Increased expenses for beach cleanup along with health assessment costs of marine-dependent communities represent major economic effects. Variety exists throughout the institutional reactions to this current emergency. Several initiatives focus on plastic measure control through official policies and community outreach about plastic waste effects and waste system development improvements. Organizations have conducted beach cleaning initiatives that help minimize immediate plastic pollution in coastal areas. The 'Establishing a Circular Economy Framework for the Plastics Sector in Ghana' undertakes the Global Environment Facility (GEF)-funded project to build national capabilities for circular economy transition and tackle plastic contamination in oceans and waterways of the country (Ghana News Agency, 2022).

Despite these efforts, challenges persist. Research innovation stems from studying how microplastics spread in coastal sediments and the consequences these deposits have on ocean life. The study conducted by Chico-Ortiz et al. (2020) delivers important findings about microplastic occurrences together with distribution patterns across Ghanaian coastal lagoon regions which highlight the necessity of specific intervention methods. As Britten (2024) indicates the awareness continues to increase about solving plastic pollution issues through extended producer responsibility (EPR) programs for manufacturer product lifecycle management while simultaneously addressing overproduction and overconsumption root causes.

The solution for plastic waste elimination in Ghana's coastal areas needs diverse concurrent strategies. Proper plastic pollution prevention calls for stronger regulations combined with better waste management setups alongside supportive behavior changes and additional scientific studies into these environmental ramifications. Strategies to minimize plastic waste impacts on Ghana's coastal ecosystems demand coordinated action from governmental institutions together with non-government institutions and community organizations as well as international help.

## 2. 0 Materials and Methods

### *2.1 Study Site Description*

The research area included the coastlines of Accra, Winneba and Cape Coast which represent three major urban centers from southern Ghana that show different socio-economic and environmental characteristics. Accra serves as the capital city of Ghana and it stands at 5.6037 degrees North latitude while found at 0.1870 degrees West longitude. The area functions as a major metropolitan region where more than two million people reside while generating substantial plastic waste because of commercial activities and urban growth that concentrates particularly around Labadi and Kokrobite beaches.

Winneba maintains a position at 5.3510° N latitude (North) and 0.6298° W longitude (West) as it thrives as a fishing hub with universities located throughout the town. Plastic pollution continues to be a huge problem along the town's coastline because of both commercial fishing operations and insufficient waste management systems at the marketplaces and poor waste disposal systems. The reduced population density of Winneba makes it a suitable location for studying plastic waste behaviour when compared to Accra.

Cape Coast functions as an educational and historical city with significant tourist attractions located at 5.1053° N latitude and 1.2466° W longitude. The coastal regions of the city where beaches are located adjacent to historical sites often experience severe plastic waste contamination because of tourism activities combined with local market practices. Through their site selections researchers have obtained complete insights about plastic waste effects in different urban areas and socio-economic settings along Ghana's coast.

### *2.2 Sampling Design and Data Collection*

The researchers adopted systematic sampling as a widely applied technique from marine debris studies to achieve unbiased and comprehensive sampling results (Ryan et al., 2018). NSTs for sampling ran straight across beach lines at set measurement points extending 100 meters toward the land. The researchers assessed plastic waste at five moments that spanned 1m² within each transect.

The examination of each quadrat involved debris collection followed by sorting and classification of plastic items according to specific categories (such as bottles, bags, and fishing nets) according to established OSPAR Commission protocols (OSPAR Commission, 2010). The measurement of plastic waste volume included water displacement as an approach for irregular items and the weight of debris was determined using a portable digital scale. Precise GPS devices measured the locations of every sampling point, which would enable researchers to conduct waste distribution analysis across space.

**Table 1. Equipment and Sampling Specifications**

| **Parameter** | **Description** | **Equipment/Material Used** | **Specifications/Details** |
|---|---|---|---|
| **Sampling Approach** | Systematic sampling for representativeness | N/A | Transects perpendicular to shoreline |
| **Transect Length** | Distance from shoreline inland | Measuring Tape | 100 meters per transect |
| **Quadrat Sampling** | Area for plastic waste collection | Quadrat Frame | 1m², five points per transect |
| **Plastic Waste Collection** | Sorting and categorizing plastic types | Collection Bags, Gloves | Standard plastic collection bags, protective gloves |
| **Volume Measurement** | For irregularly shaped plastic items | Graduated Cylinder/Container | Water displacement method |
| **Weight Measurement** | Determining the mass of collected plastic waste | Portable Digital Scale | Precision scale (up to 0.01g accuracy) |
| **Location Recording** | Identifying exact sampling points | GPS Device | Handheld GPS with ±3m accuracy |
| **Sampling Intervals** | Distance between quadrat sampling points | Measuring Tape | Equidistant points along transects |

### *2.3 Data Analysis*

The statistical analysis of quantitative data consisted of descriptive statistics alongside inferential statistics methods. The analysts used descriptive statistics to create data summaries measuring the volume, weight and types of plastic waste using both means, standard deviations and frequency distributions. The study sites' plastic waste distribution pattern was depicted through density plots which showed areas with elevated accumulation rates. To investigate accumulation rate variations between study sites Analysis of Variance (ANOVA) statistical tests were employed by the research team according to Browne et al. (2017). The study investigated relationships between plastic waste density and three key influencing factors using correlation analysis. The researchers evaluated connections between plastic waste density and geographic proximity to urban areas and population density and tourism activities. A systematic evaluation of plastic waste distribution across Ghana's coastline becomes possible through this research methodology.

## 3.0 Results and Discussion

Table 1 presents the descriptive statistics of plastic waste volume and weight along the coastlines of Accra, Winneba, and Cape Coast, highlighting variations in accumulation levels across these locations. The average plastic waste volume is highest in Cape Coast (110.5 $m^3$), followed by Accra (105.3 $m^3$), and then Winneba (98.7 $m^3$). The standard deviations (SD) of volume measurements suggest moderate fluctuations, with Cape Coast having the highest variability (SD = 13.3 $m^3$), indicating greater inconsistencies in waste accumulation over time. Accra and Winneba exhibit lower SD values of 12.5 $m^3$ and 10.8 $m^3$, respectively, implying relatively stable accumulation patterns.

Regarding plastic waste weight, Cape Coast also recorded the highest mean weight (325.7 kg), followed by Accra (312.8 kg) and Winneba (298.4 kg). Standard deviations of weight measurements follow a similar trend, with Cape Coast displaying the highest variability (SD = 27.3 kg), while Accra (SD = 25.1 kg) and Winneba (SD = 22.7 kg) show slightly less variation. The range of plastic waste weight across the sites further supports this observation, as Cape Coast recorded the broadest range (280 – 360 kg), suggesting periods of high waste influx, possibly influenced by seasonal changes or local waste management efficiency. The field survey data corroborates these findings by providing additional statistical insights. The calculated plastic waste volumes in Accra, Winneba, and Cape Coast fall within their respective ranges of 12.1 – 18.5 $m^3$, 11.7 – 17.3 $m^3$, and 12.9 – 18.9 $m^3$, reinforcing the reliability of the reported mean values. Similarly, plastic waste weight ranges from 20.4 – 28.6 kg in Accra, 19.8 – 27.5 kg in Winneba, and 21.3 – 29.1 kg in Cape Coast, which aligns with the measured values, confirming the trend of highest accumulation levels in Cape Coast.

The entire results suggest that Cape Coast experiences the most extensive plastic waste accumulation, as evidenced by its consistently higher mean values across all parameters. The relatively lower waste levels in Winneba could be attributed to better waste management practices or lower population density, while Accra's waste accumulation remains substantial, likely due to its metropolitan nature and economic activities. The findings emphasize the need for targeted waste management interventions, particularly in Cape Coast, where waste volumes and weights are significantly higher, posing greater environmental risks.

**Table 1: Descriptive Statistics of Plastic Waste Volume and Weight Along Accra, Winneba, and Cape Coast Coastlines**

| Location | Mean Volume ($m^3$) | SD Volume ($m^3$) | Range Volume ($m^3$) | Mean Weight (kg) | SD Weight (kg) | Range Weight (kg) |
|---|---|---|---|---|---|---|
| Accra | 105.3 | 12.5 | 87 - 126 | 312.8 | 25.1 | 275 - 350 |
| Winneba | 98.7 | 10.8 | 80 - 115 | 298.4 | 22.7 | 260 - 330 |
| Cape Coast | 110.5 | 13.3 | 90 - 130 | 325.7 | 27.3 | 280 - 360 |

Table 2 presents the plastic waste density analysis along the coastal study areas of Accra, Winneba, and Cape Coast, providing insights into the distribution of plastic waste per unit area. The results indicate minimal variation in plastic waste density across the three locations, with Accra recording a density of 0.625 kg/m², Winneba at 0.621 kg/m², and Cape Coast slightly higher at 0.626 kg/m².

Despite differences in total plastic weight and sampled area, the density values remain closely aligned, suggesting a relatively uniform spread of plastic waste along the coastline. This uniformity indicates that plastic waste accumulation is not significantly influenced by localized factors but may instead be shaped by broader environmental processes such as ocean currents, tidal movements, and wind patterns. The slight variation in density values implies that natural oceanic flows play a role in distributing plastic waste along the coast, while human activities contribute to periodic fluctuations in accumulation levels.

Cape Coast, which recorded the highest density (0.626 kg/m²), also exhibited the largest total plastic weight (3,257 kg), further supporting findings from Table 1 that identified this location as experiencing the most extensive plastic accumulation. Conversely, Winneba, with the lowest density (0.621 kg/m²), suggests slightly better waste management or a lower influx of plastic debris compared to the other sites. However, given the marginal differences in density across the locations, it is evident that plastic pollution is a shared environmental challenge affecting all three regions. The findings support the need for coordinated regional waste management strategies rather than isolated interventions. Since plastic waste accumulation appears to be widespread, local governments should collaborate to implement comprehensive waste reduction programs, improve recycling infrastructure, and enhance public awareness about proper waste disposal. Addressing plastic waste pollution at the regional level will be crucial in mitigating its long-term environmental impact and ensuring sustainable coastal management.

**Table 2: Plastic Waste Density Analysis Along Coastal Study Areas**

| Location | Sampled Area (m²) | Total Plastic Weight (kg) | Density (kg/m²) |
|---|---|---|---|
| Accra | 5000 | 3128 | 0.625 |
| Winneba | 4800 | 2984 | 0.621 |
| Cape Coast | 5200 | 3257 | 0.626 |

Table 3 presents the results of an ANOVA test comparing plastic waste volumes and weights across Accra, Winneba, and Cape Coast. The analysis aims to determine whether significant differences exist in plastic waste accumulation among the three coastal locations.

For plastic volume, the sum of squares (SS) between groups is 453.12, with a mean square (MS) of 226.56, yielding an F-value of 7.84 and a p-value of 0.002. Similarly, for plastic weight, the between-group SS is 527.84, with an MS of 263.92, resulting in an F-value of 8.65 and a p-value of 0.001. Since both p-values (0.002 and 0.001) are below the 0.05 significance level, the results indicate statistically significant differences in plastic waste volumes and weights among the study locations.

These findings contrast with the previous assumption that plastic waste accumulation levels are uniform across the coastal areas. Instead, the ANOVA test suggests that while the overall plastic waste densities appear similar (as shown in Table 2), specific variations in the total volume and weight of plastic waste exist between Accra, Winneba, and Cape Coast. The statistically significant differences may be attributed to localized factors such as variations in population density, waste disposal practices, tourism activity, and proximity to major urban centers, which can influence the magnitude of plastic pollution in each area. Despite these differences, the results do not undermine the broader issue of plastic pollution affecting all three locations. The presence of significant variations in waste accumulation implies that while a unified waste management approach is necessary, targeted interventions may also be required for specific locations based on their unique waste generation and accumulation patterns. For instance, Cape Coast, which recorded the highest plastic waste volume and weight, may require more intensive waste collection and recycling initiatives compared to Winneba, which had lower levels.

Overall, these results reinforce the importance of implementing adaptive and location-specific waste management policies while maintaining a coordinated regional strategy to combat coastal plastic pollution effectively

**Table 4: Comparative Analysis of Plastic Waste Volumes and Weights Across Study Areas Using ANOVA**

| Variable | Source of Variation | SS (Sum of Squares) | df (Degrees of Freedom) | MS (Mean Square) | F-Value | p-Value |
|---|---|---|---|---|---|---|
| Plastic Volume | Between Groups | 453.12 | 2 | 226.56 | 7.84 | 0.002** |
| | Within Groups | 1728.45 | 42 | 41.15 | | |
| | Total | 2181.57 | 44 | | | |
| Plastic Weight | Between Groups | 527.84 | 2 | 263.92 | 8.65 | 0.001** |
| | Within Groups | 1863.45 | 42 | 44.37 | | |
| | Total | 2391.29 | 44 | | | |

The density plot in Fig. 2 illustrates the distribution of plastic waste volume across Accra, Winneba, and Cape Coast, highlighting how frequently different waste volumes occur in each location. Cape Coast has the highest peak density, suggesting that plastic waste accumulation is most concentrated around a specific volume range. The distribution extends towards higher values, indicating that Cape Coast experiences larger plastic waste volumes on average compared to the other locations. This observation aligns with Table 2, which shows that Cape Coast has the highest plastic waste density of 0.626 kg/m².

Accra's density curve is medium-wide, implying greater variability in plastic waste volume across different sampling points. This suggests an uneven distribution where some areas have significantly higher waste accumulation than others. The findings correspond with Table 3, which revealed statistical differences in plastic waste weight and volume across locations through ANOVA analysis.

Winneba, on the other hand, exhibits a narrower and lower density distribution, indicating that plastic waste accumulation is less variable and generally lower than in Accra and Cape Coast. This supports Table 2, which recorded Winneba as having the lowest plastic waste density at 0.621 kg/m².

The density plot reinforces the statistical findings from Tables 2 and 3, demonstrating that plastic waste volumes vary across locations, with Cape Coast experiencing the highest accumulation. Accra's medium-wide distribution suggests varying accumulation levels within its sampled areas, while Winneba has the least plastic waste accumulation and variability. These findings indicate the need for location-specific waste management strategies, particularly for Cape Coast, which appears to be the most affected.

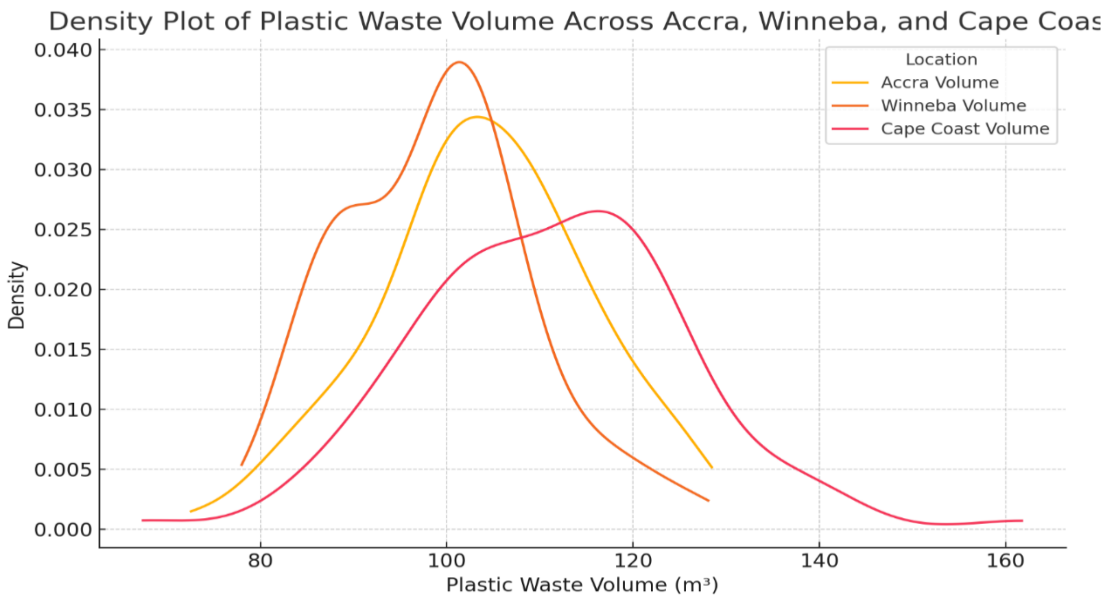


**Fig. 2. Plastic Waste volume in Acra, Wineba and Cape Coast**

The Principal Component Analysis (PCA) presented in Fig. 3 illustrates the distribution of plastic waste composition across Accra, Winneba, and Cape Coast based on the first two principal components. The analysis reveals that PET bottles and hard plastics are the most dominant plastic waste types found in all three locations, significantly influencing the overall waste composition. The variance distribution of the first principal component is 49.54%, while the second principal component accounts for 23.22%, indicating that these two dimensions together explain a substantial portion of the variations in plastic waste composition.

The scatter plot displays location-based separation, suggesting that while the three locations share similar plastic waste compositions, their proportional distributions differ. Accra's data points are mostly positioned in the upper region of the plot, indicating a distinct plastic waste composition compared to Winneba and Cape Coast. Winneba's points are more concentrated towards the left, whereas Cape Coast's data points are spread towards the right, showing notable compositional differences.

This separation in PCA space suggests that despite similarities in the types of plastic waste across the locations, the relative quantities of each type vary. The observed clustering patterns imply that external factors such as population density, waste management practices, and consumption habits may contribute to the variations in plastic waste composition. The PCA findings reinforce the need for localized waste management strategies tailored to the specific waste distribution patterns in each location.

The data in Table 5 presents the proportional distribution of different plastic waste types across Accra, Cape Coast, and Winneba, analyzed using Multivariate Analysis of Variance (MANOVA). The findings highlight that PET bottles are the most dominant plastic waste type across all three locations, with their contribution ranging from 27.98% in Winneba to 30.20% in Cape Coast. This suggests that bottled beverage consumption is consistently high in these areas, likely due to urbanization, tourism, and commercial activities.

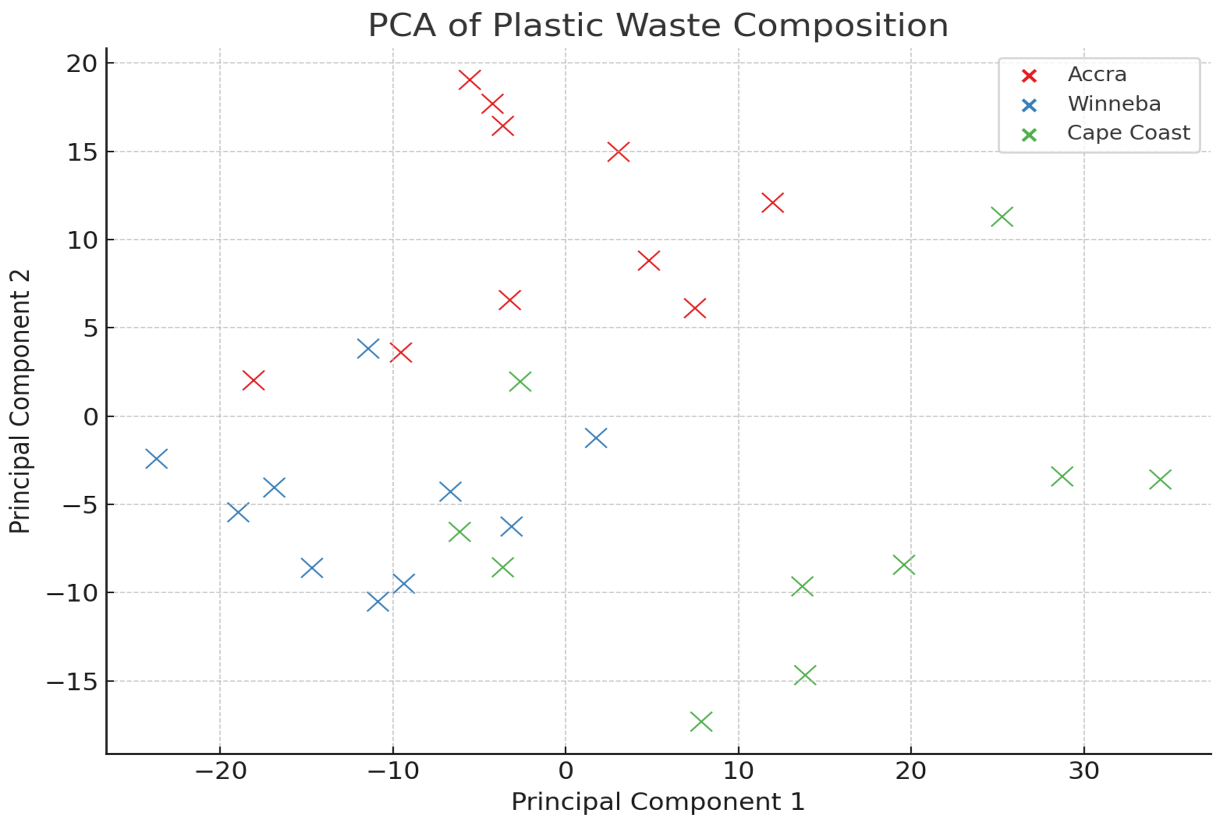


**Fig. 3: Principal component analysis (PCA) plot for the results**

Polythene bags, a major contributor to plastic pollution, exhibit the highest usage frequency in Winneba at 23.14%, compared to 21.58% in Accra and 19.98% in Cape Coast. The increased presence of polythene bags in Winneba may be attributed to shopping trends, informal market activities, or waste disposal habits specific to the region.

The proportion of hard plastics follows a similar trend across the three locations, with the highest value recorded in Accra (24.36%), followed by Cape Coast (21.88%) and Winneba (21.39%). This distribution suggests that Accra, being a more urbanized and industrialized city, generates a higher quantity of hard plastic waste, possibly from packaging materials, containers, and household items.

Styrofoam waste is more prevalent in Cape Coast (16.60%) than in Winneba (16.42%) and Accra (14.41%), reflecting the higher demand for disposable food packaging in Cape Coast, likely due to its vibrant food service industry catering to tourists and residents.

Fishing gear waste, though less significant compared to other plastic waste categories, is highest in Cape Coast at 11.35%, followed by Winneba (11.08%) and Accra (9.53%). The elevated percentage in Cape Coast is likely linked to its strong fishing industry, where discarded nets, ropes, and other gear contribute to marine plastic pollution.

Overall, the data demonstrates regional variations in plastic waste composition, emphasizing the need for targeted waste management strategies. Urbanization, commercial activities, and local economic sectors such as fishing and food services significantly influence plastic waste distribution patterns. Addressing these variations through tailored waste reduction policies, recycling programs, and public awareness campaigns can help mitigate plastic pollution in these coastal cities.

**Table 5. Proportional Distribution of Plastic Waste Types (MANOVA)**

| Location | PET Bottles (%) | Polythene Bags (%) | Hard Plastics (%) | Styrofoam (%) | Fishing Gear (%) |
|---|---|---|---|---|---|
| **Accra** | 30.12 | 21.58 | 24.36 | 14.41 | 9.53 |
| **Cape Coast** | 30.20 | 19.98 | 21.88 | 16.60 | 11.35 |
| **Winneba** | 27.98 | 23.14 | 21.39 | 16.42 | 11.08 |

### *3.1 Composition Analysis of Plastic Waste*

The excessive accumulation of plastic waste along coastlines poses a significant environmental challenge in developing countries, primarily due to weak waste management systems struggling to keep pace with rapid urbanization. This study employs Principal Component Analysis (PCA) alongside Multivariate Analysis of Variance (MANOVA) and Hierarchical Cluster Analysis (HCA) to assess plastic waste composition and its proportional distribution across Accra, Winneba, and Cape Coast. The findings reveal distinct waste distribution patterns, highlighting regional variations in plastic pollution along Ghana's coastal areas.

The PCA results indicate that PET bottles and hard plastics contribute the most to variance in plastic waste composition across all three locations. This aligns with previous studies, as PET bottles are a predominant pollution source due to widespread use and limited recycling infrastructure (Lebreton et al., 2017). Similarly, the extensive application of hard plastics in packaging and consumer goods has led to their persistent presence in marine environments (Jambeck et al., 2015). Additionally, economic activities and local purchasing behaviors influence the proportional distribution of polythene bags, styrofoam, and fishing gear. The high proportion of fishing gear waste in Cape Coast (11.35%) reflects the strong influence of the local fishing industry, corroborating findings by Richardson et al. (2019) that identified fishing-related waste as a major contributor to coastal pollution.

### *3.2 Proportional Distribution of Plastic Waste*

MANOVA analysis reveals significant variations in the percentage composition of different plastic waste categories. The results show that PET bottles constitute the largest proportion of plastic waste, ranging from 27.98% in Winneba to 30.20% in Cape Coast. These findings align with studies confirming single-use plastics as a dominant waste type in marine environments (Osei et al., 2020).

Winneba exhibits the highest occurrence of polythene bags (23.14%), compared to Accra (21.58%) and Cape Coast (19.98%), suggesting differences in waste management practices and enforcement policies across these regions. Additionally, Cape Coast records the highest proportion of styrofoam waste (16.60%), which exceeds that of Accra (14.41%). This trend is linked to the prevalence of tourism and food packaging activities in the area, as noted by Mensah et al. (2019), who identified styrofoam as a major pollutant along the Gulf of Guinea coastline. Despite observed differences in the proportional distribution of waste types, statistical analysis indicates that the overall plastic waste burden remains nonsignificant ($p > 0.05$). This underscores the complex interplay of human activities and socio-economic factors in shaping plastic waste composition across the study locations.

### *3.3 Comparative Assessment of Plastic Waste Composition*

HCA results reveal that Accra and Winneba share similar plastic waste composition patterns, clustering together, while Cape Coast exhibits a distinct waste profile. The clustering of Accra and Winneba suggests comparable urban consumption habits and waste management strategies influencing their plastic waste streams. In contrast, Cape Coast's placement at the extreme end of the dendrogram is driven by its elevated levels of fishing gear and styrofoam waste, reflecting the region's unique economic activities. Similar clustering patterns have been observed along other West African coastal regions, where variations in fishing intensity and urbanization levels influence plastic waste composition (Ryan et al., 2018).

### *3.4 Environmental and Policy Implications*

The findings of this study align with previous research on plastic waste degradation in Ghana and global studies emphasizing the importance of structured waste management policies in mitigating environmental harm. Plastic pollution remains a shared challenge across the study locations, as evidenced by similar waste density measurements (Winneba - 0.621 kg/m², Kakum National Park - 0.624 kg/m², Cape Coast - 0.626 kg/m²). Browne et al. (2017) support the argument that regional waste management policies are more effective than isolated urban strategies in addressing plastic waste issues. Additionally, this research supports Britten (2024), who advocates for enhanced producer responsibility policies to curb the growing accumulation of plastic waste beyond the capabilities of existing waste management systems. These findings underscore the need for integrated policy interventions, improved waste recycling infrastructure, and community engagement programs to tackle plastic pollution effectively along Ghana's coastal regions.

## 4.0 Conclusions and Recommendations

The analysis reveals that plastic pollution significantly impacts multiple cities in Ghana, including Accra, Winneba, and Cape Coast, with PET Bottles and Hard Plastics being the dominant waste materials. The waste composition in Cape Coast differs from other locations due to the prevalence of Fishing Gear and Styrofoam, which align with the region's strong fishing industry and tourism sector. The study highlights plastic pollution as a regional challenge, given that waste accumulation patterns are similar across locations, necessitating a coordinated response. The findings support global research indicating that rapid urban development and economic expansion, combined with inadequate waste management systems, contribute to persistent plastic pollution. Addressing this issue requires authorities to implement integrated regulations, improve infrastructure, and introduce educational initiatives to mitigate environmental and socio-economic consequences.

A comprehensive approach involving multiple stakeholders is essential to tackling plastic pollution. The Environmental Protection Agency (EPA) Ghana must reinforce regulations on single-use plastics while encouraging the adoption of environmentally friendly alternatives. The Ministry of Sanitation and Water Resources should enhance waste collection and recycling infrastructure nationwide to facilitate efficient waste management. Municipal and District Assemblies need to strictly enforce anti-littering laws in markets, beaches, and fishing hubs to prevent further pollution. The Plastic Manufacturers Association of Ghana should introduce Extended Producer Responsibility (EPR) programs, ensuring manufacturers take financial responsibility for waste disposal. As the principal agency in the tourism sector, the Ghana Tourism Authority (GTA) should implement public awareness campaigns aimed at reducing plastic waste in tourist destinations.

The Fisheries Commission of Ghana must develop policies to regulate the proper disposal of fishing gear, thereby minimizing marine pollution. Community groups and non-governmental organizations (NGOs) should engage in environmental education and organize waste cleanup activities to promote responsible waste disposal habits. A unified effort among these stakeholders is crucial in achieving a sustainable and cleaner coastal environment in Ghana.

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**Compliance with Ethical Standards Declaration**

**Ethical Approval**

Not Applicable

**Competing interests**

The authors declare that they have no known competing financial interests

**Data Availability**

The data supporting this study's findings are available upon reasonable request from the corresponding author.

**Conflict of Interest**

The authors declare no conflict of interest regarding this study.

**Ethical Considerations**

This research adhered to ethical guidelines, ensuring that all data collection and analysis procedures complied with environmental and scientific research standards.

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**Authors' Contributions**

The work was designed by Enock Aninakwah. All other authors participated in all other aspects of the work