



Impact of Plastic Waste Pollution on Environment in Gombe Metropolis, Gombe State Nigeria

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Abstract

Plastic waste pollution has emerged as a major environmental concern in the world, Nigeria, and Gombe State metropolis, Gombe, Nigeria. This study assessed its impact on environmental health, particularly in relation to water industries and market areas, while also evaluating microbial contamination at dumpsites. A mixed-methods approach was employed, combining quantitative surveys, waste characterization, and microbiological analysis. A total of 237 respondents participated in the survey, while microbial populations were assessed across four sites: Inex Dumpsite, Main Market, Tumfure Market, and Old Market. Findings revealed a male-dominated respondent pool (59.1 %), with most participants aged 18–50 years (76.5 %). A significant majority (72.6 %) acknowledged the harmful effects of plastic waste on health and the environment, while 64.1% linked plastic waste to disease transmission and increased mortality. Waste management relied on community collection points (42.2 %) and private companies (38 %), with indiscriminate disposal and burning widely discouraged. Physio-chemical soil analysis indicated deviations from Federal Environmental Protection Agency (FEPA) standards, highlighting contamination risks (cadmium - 0.85 mg/kg, TOC- 8.0 %, and copper- 45.7mg/kg). Microbial analysis revealed high contamination at Inex Dumpsite, with the highest counts across all dilutions (e.g., 212.00 at 10⁻¹), while Tumfure Market showed the lowest 161.00 at 10⁻¹. Pathogens identified at the sites included *Escherichia coli*, *Staphylococcus aureus*, *Bacillus anthracis*, *Pseudomonas aeruginosa*, with *S. aureus* and *B. anthracis* pervasive across all sites. The study recommends intensified public awareness campaigns on proper plastic disposal and microbial hazards, alongside improved sanitation measures to mitigate pollution and health risks.

Keywords: Plastic, Waste, Pollution, Environment, Metropolis

Introduction

Plastics are basically petroleum derive non-biodegradable materials with a unique polymeric structure that offers low specific weight, low electrical and thermal conductivity, and high durability, excellent mechanical properties, reasonable pricing, etc. (Landon-Lane, 2018; Mazhandu et al., 2020). This high amount of waste plastics consequently affects the ecosystem through soil pollution by land filling, marine pollution by ocean dumping, air pollution by open dumping as they are not a part of our food chain (Mourshed et al., 2017; Paletta et al., 2019). According to World Bank group report, plastics comprise about 5 –12 % of the world's total waste generation (20–30 % by weight) (Awasthi et al., 2017; Kaza et al., 2018) and about 60% of plastics enter environment as plastic waste (Zhang et al., 2021). Management of waste generated from different sectors is the sole responsibility for agencies like the Federal Environmental Protection Agency (FEPA), Ministry of Environment, Local Authorities and Environmental Sanitation Authorities. Gombe State Environmental Protection Agency (GOSEPA) is not an exception (Sulaiman *et al.*, 2019).

Plastic waste pollution poses challenges to economic development not only animals are affected by this pollution. For example, by reduced tourism due to plastic pollution on shorelines, vessel damage and damage to public health (Hardesty, Good and Wilcox, 2015). Plastic bags constitute the large part of the litter found in catch basins and drain inlets of storm water management systems (Wagner, 2017). Environmental problem due to soil contamination by trace metals has received great global attention in recent times (Sulaiman et al., 2019). 80 % of diseases are water borne due to drinking of contaminated water in developing countries according to WHO (Khan et al., 2013) and about 3.1% deaths occur due to the unhygienic and poor quality of water (Pawari & Gawande, 2015). In many developing countries including Nigeria, poor water supply including Nigeria, had led to seeking for alternatives by residents (Bakker et al., 2008; Vedachalam et al., 2017). This Study aims to assess the impact of plastic waste pollution on environment in Gombe metropolis, Gombe State Nigeria.

Materials and Methods

Study area

This study was conducted in three key markets: Main Market, Cross Market, and Tumfure Market, as well as the water industries surrounding these markets and the INNEX waste dump site, all located within Gombe metropolis, the capital of Gombe State. Gombe State is situated in the North-Eastern region of Nigeria, between latitudes 10°15'N and 10°19'N, and longitudes 11°07'E and 11°15'E.

Research Design

This research employed a quantitative research design, which is well-suited to the nature of the study. Specifically, the study utilized a survey research design, as described by Saunders *et al.* (2009), which enables the collection of large amounts of data from a significant population at a relatively low cost. This can be achieved through various types of questionnaires. The study involved a survey approach to examine waste characterization at the final dumpsite in Gombe metropolis. The survey spanned four weeks, with 20 total days dedicated to data collection at the INEX waste dump site. Over five days each week (Tuesday to Saturday), water bottles, sachets, and packaging leather waste were sorted and weighed to assess their volume. Additionally, a Waste Management Questionnaire (WMQ) was developed to gather responses from participants regarding waste management practices.

Population of the Study

The target population for this study consists of 550 individuals residing in Gombe town. This group includes bottled water vendors, manufacturers, consumers, and market sellers. A total of 550 respondents were selected as the focus of this research.

Sample Size and Sampling Technique

Sampling is a procedure or technique for drawing a representative's group of people or cases from a specific population (Creswell, 2002). Sample can be defined as an unbiased subset representing the population (Collis & Hussey, 2014). Random sampling technique was used. The sample size for this study from the target population of 550 bottle and sachet water handlers, manufacturer and food stuff consumers were calculated from the formula of Yamane (1967) because of the number of the population is finite; therefore:

$$n = N / [(1 + Ne^2)]$$

Where:

n = sample size

N = known population

e = alpha level i.e., e = 0.05 if the confidence interval is 95%

$$\Rightarrow n = 550 / [1 + 550 \times 0.05 \times 0.05] = 550 / [1 + 1.325] = 550 / 2.325 = 237.$$

The sample size for this study was two-hundred and thirty-seven (237) bottle and sachet water handlers to be the respondents of the study. Barlett et al., (2001) identified four basic types of sampling techniques as simple random sampling, systematic sampling, stratified sampling, and cluster or multi staged sampling.

For this study, stratified random sampling technique was used in drawing a sample of 237 bottle and sachet water handlers and manufacturers.

Additionally, 50 shop owners in the three markets were interviewed in three markets namely, Tumfure, Cross and Main Market.

Data Collection Instrument

The research instruments for this study include field observation and waste characterization, supplemented using Google Forms for digital data collection. Equipment required for plastic waste characterization consists of a Camry weighing scale, hand trowel, shovel, empty sacks, tarpaulin, heavy-duty waste sacks (polythene), cutlass, hand gloves, and a flat floor. Structured questionnaires were developed to gather responses from participants, as outlined by Collis and Hussey (2014). The questionnaire for this research consists exclusively of closed questions, which offer several advantages over open-ended questions. This format allows for easier data processing, comparison, and analysis of relationships between variables (Bryman & Bell, 2011).

Administration of Data Collection Instrument

The data collection instruments were administered randomly to respondents in various community locations using survey questionnaires.

Method of Data Collection

Physio-chemical parameters

Soil samples were collected, and the collection process involved digging to a depth of approximately 10 cm below the surface to obtain subsurface soil, which is less likely to be influenced by immediate surface conditions such as debris or recent contaminants and analyzed using standard laboratory procedures. Heavy metals such as Cd, Cr, Cu, Pb, Hg, Zn were quantified using Atomic Absorption Spectrophotometry (AAS). Ten (10) grams of soil sample was placed in a 50 ml beaker, and 5 ml of a concentrated aqua regia solution was added. This solution, prepared in a ratio of concentrated nitric acid (HNO₃), hydrochloric acid (HCl), and sulfuric acid (H₂SO₄) in 3:2:1 proportion, was used to break down the soil matrix. The beakers were covered with watch glasses and heated on a hot plate at 125° C for two hours. During digestion, additional portions of aqua regia were added gradually to maintain re-activity and ensure complete decomposition of the soil matrix, indicated by a clear, light-colored solution. After cooling to room temperature, the interior surface of the beaker and watch glass were rinsed with deionized water to recover any adhering residues. The digested mixture was filtered through Whatman Grade 1 filter paper, and the filtrate was diluted to 50 ml with deionized water in a volumetric flask, preparing it for metal analysis.

The concentrations of Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), and Zinc (Zn) in the digested samples were determined using Atomic Absorption Spectrophotometry (AAS). The instrument was calibrated using certified standard solutions for each metal, and specific wavelengths were set as follows: Cd (228.8 nm), Cr (357.9 nm), Cu (324.8 nm), Pb (283.3 nm), Hg (253.7 nm), and Zn (213.9 nm). Blanks and quality control samples were included to ensure accuracy and precision. The results were expressed in milligrams per kilogram (mg/kg) of dry soil weight (Turner et al., 2011). For other parameters, turbidity was measured with a portable data-logging spectrophotometer. The pH of the soil was determined using a digital pH meter after preparing a 1:1 soil-to-distilled water slurry (20 g soil + 20 ml water) and stirring for 30 minutes. The meter was calibrated using buffer solutions at pH 4.0, 7.0, and 9.0. Electrical conductivity was measured using a conductivity meter, with a 1:5 soil-to-water extract (20 g soil + 100 ml water) prepared and settled before analysis.

Magnesium content was analyzed via AAS following digestion with HNO₃ and HCl. Total Organic Carbon (TOC) was determined using the Walkley-Black method, which involved digestion with potassium dichromate (K₂Cr₂O₇) and concentrated sulfuric acid, followed by titration with ferrous ammonium sulfate. Phosphate content was quantified using a UV-Vis spectrophotometer after complex formation with ammonium molybdate and stannous chloride. Chloride content was assessed through argentometric titration, using potassium chromate as an indicator, and titrating with standard silver nitrate (AgNO₃). All procedures adhered to the standards outlined in the "Standard Methods for the Examination of Water and Wastewater" by the American Public Health Association (APHA, 1978). This ensured reliability, reproducibility, and consistency across all measured parameters. Notably, solid wastes on the soil surface were observed to impair soil aeration by blocking air penetration, making it difficult for earthworms and other soil organisms to burrow thus potentially reducing soil fertility (Udochukwu *et al.*, 2021; Udochukwu *et al.*, 2022).

To estimate the microbial population, Soil samples were collected aseptically at the surface of the sites with a soil auger in a sterile polythene bag and was taken straight to the laboratory for further analysis. About ml (9 ml) of sterile distilled water was added and agitated for a minute in 10 test tubes for each sample to avoid foreign materials. One gram (1g) of the soil was weighed into one test tube containing 9 ml of sterile distilled water and a 10-fold serial

dilution of each sample was performed. 0.5ml from each dilution level (10^{-1} , 10^{-5} , and 10^{-10}) was plated using the pour plate method on Nutrient Agar (NA) for total viable bacterial count. Aliquot of 0.1ml of the prepared dilution was aseptically transferred onto the surface of solidified Nutrient agar for the isolation of bacteria. It was spread well with the use of a sterile bent glass rod. Plates were prepared in duplicates and incubated at 37° C for 24 hr and were examined for bacterial growth. Different colonies observed were then purified by repeated streaking for each distinct colony on nutrient agar until pure colony was obtained. The purified bacterial isolates were transferred on sterile nutrient agar slants and stored for identification. Isolates were identified using the identification scheme provided in Bergy's manual of determinative Bacteriology (1997). The pure cultures were stored on agar slants at 4°C for further biochemical characterization. Gram staining was conducted to determine the Gram reaction and cellular morphology (rod or cocci) of the isolates.

Each bacterial isolate was identified through a series of standard biochemical tests following established microbiological protocols. The catalase test was performed by placing a drop of 3% hydrogen peroxide on a glass slide and mixing it with a small amount of bacterial culture; bubble formation indicated a positive reaction. For the coagulase test, rabbit plasma was used to detect the presence of the coagulase enzyme, a key virulence factor in *Staphylococcus* species. Urease activity was assessed using urea agar slants, where a color change to pink signified a positive result due to ammonia production. Citrate utilization was determined using Simmons citrate agar, with a shift from green to blue indicating the organism's ability to use citrate as a carbon source. The indole test was conducted by inoculating tryptophan broth and adding Kovac's reagent; a red ring formation confirmed indole production. Additionally, the oxidase test was performed using tetramethyl-p-phenylenediamine reagent, with a rapid color change to purple within 30 seconds denoting a positive reaction. Following identification, the occurrence of each organism in the four sampled sites was recorded as either present (1) or absent (0). The presence was confirmed if a specific organism was isolated and biochemically identified from the location. This data was then tabulated to show the distribution of bacterial species across the different market environments and dumpsite.

Data were analysed using SPSS version 23. Descriptive statistics (Frequencies, percentages, means and standard deviations), summarized questionnaire responses, inferential statistics including ANOVA and t-tests, were applied at a 5% significance level to assess relationships between plastic waste accumulation and environmental pollution.

Results

Demographic Characteristics of Respondents

Of the 237 respondents, I found a predominance of male participants (59.1 %) compared to females (40.9 %); Age-wise, the largest group was the 31-40 age range, comprising 38 % of respondents, followed by the 18-30 range at 31.6 % (Table 1a). Educationally, majority of participants had secondary education (42.2 %), with a notable portion (28.3 %) having tertiary education. Only a small percentage lacked formal education (8.4 %), indicating an educated population in this study (Table 1).

Table 1: Demographic Characteristics of Respondents

Characteristics	Frequency	Percentage (%)
1a-Gender		
Male	140	59.1
Female	97	40.9
1b-Age Group		
18-30	75	31.6
31-40	90	38.0
41-50	50	21.1
51 and above	22	9.3
1c-Educational Level		
No Formal Education	20	8.4

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Primary Education	50	21.1
Secondary Education	100	42.2
Tertiary Education	67	28.3

Environmental and Health Impacts of Plastic Waste

Most respondents acknowledged the adverse health and environmental effects of plastic waste (Table 2), where 72.6 % recognized its role in waterway blockage, a common cause of flooding. Similarly, 70.9 % highlighted mosquito breeding and infestation due to waste, with implications for malaria transmission. There was significant agreement regarding the spread of infectious diseases linked to poor waste management, with 64.1 % agreeing that waste contributes to disease spread and higher mortality rates. Additionally, 62.4 % noted increased health care expenses and loss of aesthetic appeal as consequences of plastic waste.

Table 2: Environmental and Health Impacts of Plastic Waste

Values outside brackets are counts and values inside bracket are percentages.

Key: SD = Strongly Disagree (1), D = Disagree (2), MA = Moderately Agree (3), A = Agree (4)

SA = Strongly Agree (5), Mean = Average score (1-5 scale). SD = Standard Deviation

Health Effects of Plastic Waste	SD (1)	D (2)	MA (3)	A (4)	SA (5)	Percentage sum of disagreed	Percentage sum of agreed
Waterway blockage leading to flooding	10 (4.2)	15 (6.3)	40 (16.9)	90 (38.0)	82 (34.6)	10.5	89.5
Infestation of flies and mosquito breeding	12(5.1)	20 (8.4)	37 (15.6)	98 (41.4)	70 (29.5)	13.5	86.5
Spread of infectious diseases	8 (3.4)	17 (7.2)	60 (25.3)	87 (36.7)	65 (27.4)	10.6	89.4
Increase in mortality due to disease	15 (6.3)	25 (10.5)	40 (16.9)	87 (36.7)	70 (29.5)	16.8	83.1
Increased treatment expenses	18 (7.6)	30 (12.7)	47 (19.8)	85 (35.8)	57 (24.1)	20.3	79.7
Loss of aesthetics	22 (9.3)	27 (11.4)	40 (16.9)	100 (42.2)	48 (20.3)	20.7	79.4

Public awareness on proper plastic waste management in various communities of the study area

The survey results reveal critical insights into public perceptions and systemic challenges regarding waste management in Gombe. Most respondents (70.4%) agreed that sorting waste reduces waste bulk (Mean = 3.44, SD = 1.10), indicating a general awareness of waste segregation benefits. However, nearly half (47.2%) either disagreed or strongly disagreed that waste management is solely a government duty (Mean = 2.92, SD = 1.33), suggesting that

many residents acknowledge shared responsibility in waste handling. Notably, an overwhelming 76.7% supported plastic reuse or recycling (Mean = 3.99, SD = 1.06), reflecting strong public endorsement of sustainable practices.

Table 3: Public awareness on proper plastic waste management in various communities of the study area.

Values outside brackets is count and values inside brackets are percentage

Awareness of Plastic Waste Management Practices	SD (1)	D (2)	MA (3)	A (4)	SA (5)	Percentage sum of disagreed	percentage sum of agreed
Sorting of waste reduces waste bulk	12 (5.1)	18 (7.6)	40 (16.9)	92 (38.8)	75 (31.6)	12.7	87.3
Waste management is solely a government duty.	47 (19.8)	65 (27.4)	30 (12.7)	50 (21.1)	45 (19.0)	47.2	52.8
Plastics should be reused or recycled	10 (4.2)	15 (6.3)	30 (12.7)	95 (40.0)	87 (36.7)	10.5	89.4

Key:

SD = Strongly Disagree (1), D = Disagree (2), MA = Moderately Agree (3), A = Agree (4)

SA = Strongly Agree (5), Mean = Average score (1-5 scale). SD = Standard Deviation

Table 4: Challenges in Efficient Plastic Waste Management.

(Values outside brackets is count and values inside brackets are percentages)

Challenges in Plastic Waste Management	SD (1)	D (2)	MA (3)	A (4)	SA (5)	Percentage sum of disagreed	Percentage sum of agreed
Inadequate of recycling industries in Gombe	20 (8.4)	25 (10.5)	30 (12.7)	100 (42.2)	62 (26.2)	18.9	81.1
Insufficient waste collection points	15 (6.3)	18 (7.6)	30 (12.7)	110 (46.4)	64 (27.0)	13.9	86.1
Lack of waste management law enforcement	22 (9.3)	30 (12.7)	50 (21.1)	92 (38.8)	43 (18.1)	22.0	78.0
Poor household waste management practices	18 (7.6)	35 (14.8)	47 (19.8)	87 (36.7)	50 (21.1)	22.4	77.6

Key:

SD = Strongly Disagree (1), D = Disagree (2), MA = Moderately Agree (3), A = Agree (4)

SA = Strongly Agree (5), Mean = Average score (1-5 scale). SD = Standard Deviation

Distribution of Plastic Bags Served Daily by Shop Owners in Three Markets

The distribution of plastic bags by retail vendors represents a critical component of urban plastic waste generation. Our survey of 150 shop owners across three major markets (Tumfure, Main, and Cross) reveals significant variations in plastic bag usage patterns that reflect both commercial practices and potential opportunities for waste reduction interventions. The data demonstrates a clear stratification of plastic bag distribution across the surveyed markets. Most notably, Main Market emerges as the highest plastic bag distributor, with 34 % of vendors dispensing more than 100 bags daily - more than double the proportion observed in Tumfure Market (16 %) and four times that of Cross Market (8 %). This heavy usage pattern suggests that Main Market, likely being the largest and most commercially active of the three, faces challenges in plastic waste management that warrant targeted policy interventions. Cross Market presents the most promising profile, with 16 % of vendors using fewer than 30 bags daily (twice the proportion of other markets) and only 8 % exceeding 100 bags. The market's predominant usage cluster (38 %) falls in the 51-70

bags range, indicating more moderate consumption patterns. This distribution may reflect either greater environmental consciousness among vendors, different product mix characteristics, or more effective existing waste management practices that could serve as a model for other markets. Tumfure Market shows a balanced but still concerning distribution, with 36% of vendors in the 51-70 bags category and another 24% distributing 71-90 bags daily. The simultaneous presence of both moderate (36%) and high-volume (16%) users suggests the need for differentiated intervention strategies within the same market space.

Table 5: Distribution of Plastic Bags Served Daily by Shop Owners in Three Markets
Values outside brackets are counts and values inside brackets are percentages

Daily Plastic Bags	Tumfure Market Freq. (%)	Main Market Freq. (%)	Cross Market Freq. (%)
<30	4 (8.0)	4 (8.0)	8 (16.0)
30-50	8 (16.0)	9 (18.0)	8 (16.0)
51-70	18 (36.0)	8 (16.0)	19 (38.0)
71-90	12 (24.0)	12 (24.0)	11 (22.0)
>100	8 (16.0)	17 (34.0)	4 (8.0)
Total	50 (100)	50 (100%)	50 (100)

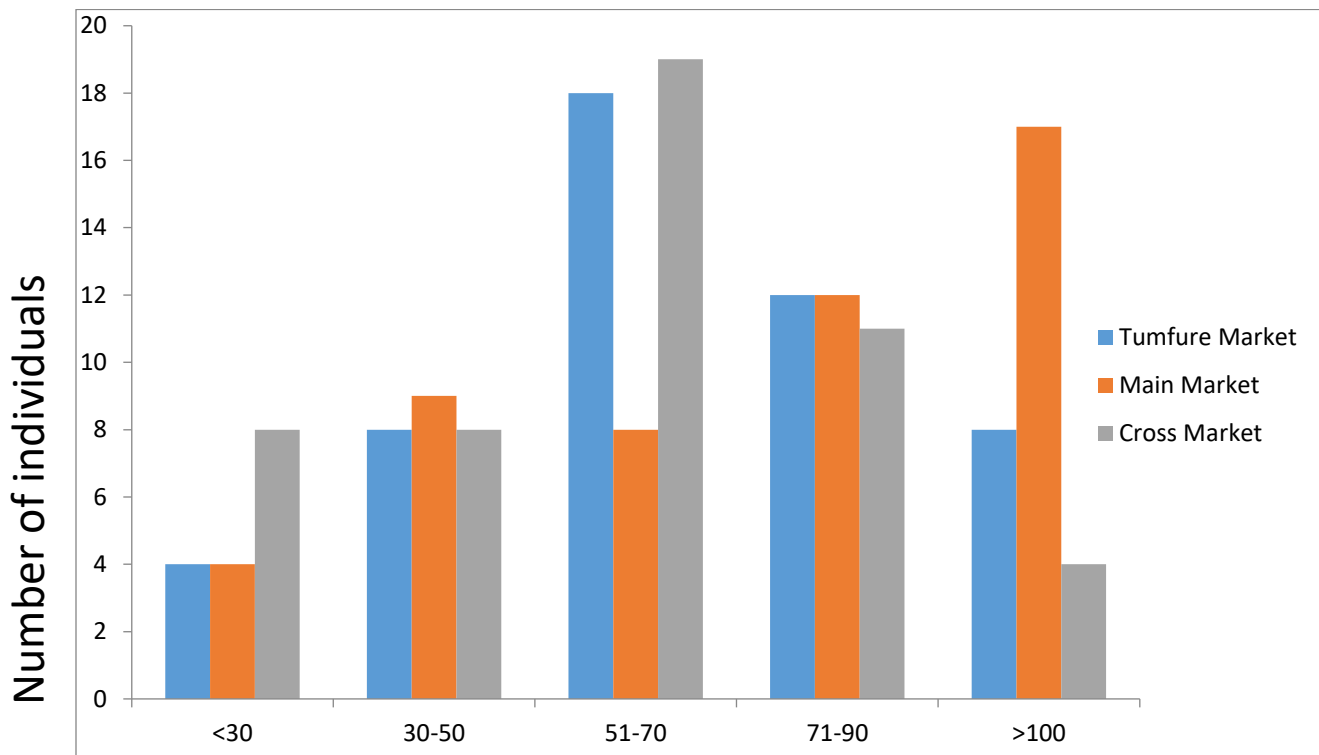


Figure 1: Distribution of Plastic Bags Served Daily by Shop Owners in Three Markets

Plastic Waste from Water Industries

A significant portion of water industries (94.9%) confirmed their reliance on plastic packaging, showing the prevalence of plastic use in local water distribution.

Number of Plastic Bags of water Produced Weekly from Water Companies

The weekly production levels of plastic bagged water by different water companies are presented in Table 6. The majority (38.8 %) of the companies produce between 201 and 300 plastic bags per week, while 23.2 % produce between 301 and 400 plastic bags. Smaller proportions (10.5 %) of companies have a production capacity exceeding 400 plastic bags weekly. Meanwhile, 21.1% of the companies fall within the 100–200 range, and only 6.3 % produce fewer than 100 plastic bags per week. This distribution suggests that most water companies operate within a mid-range production scale, possibly due to limitations in resources, demand fluctuations, or regulatory constraints.

Capacity of water sachets Production in Gombe metropolis (Daily)

The daily production capacities of sachet water factories in Gombe metropolis, organized by their output volume are represented in Table 5. The data reflects a diverse range of production capacities across different sizes of factories, underscoring the varied scale of operations in the sachet water industry within this area. In the category of factories producing fewer than 10,000 sachets per day, only two facilities are recorded, jointly producing 13,000 sachets daily with an average output of 6,500 sachets per factory. This group represents the lowest tier of production capacity in the study. The next level includes factories with daily production volumes between 11,000 and 50,000 sachets, a category that comprises most factories in Gombe with 20 facilities. Collectively, these factories produce 382,000 sachets each day, yielding an average output of 19,000 sachets per factory, which indicates that medium-capacity factories are the most common type of facility in Gombe's sachet water production sector. In the higher production range of 50,000 to 100,000 sachets per day, there are three factories collectively producing 160,000 sachets daily, averaging 53,333 sachets per factory. This group represents an increase in production capacity relative to the medium-scale producers. In the top production tier, comprising facilities with daily outputs between 101,000 and 150,000 sachets, three factories together produce 320,000 sachets each day, averaging 106,667 sachets per factory. Additionally, one factory in this category stands out by itself, producing a substantial 320,000 sachets per day, with an average output of 153,333 sachets. This represents the highest level of production capacity among all facilities in Gombe metropolis.

Table 5: Number of Plastic Bags of water Produced Weekly from Water Companies and Capacity of water sachets Production in Gombe metropolis (Daily)

5a. Number of Plastic Bags Produced Weekly	Frequency	Percentage (%)
Less than 100	2	6.3
100–200	6	21.1
201–300	11	38.8
301–400	7	23.2
More than 400	3	10.5
Total	29	100

5b. Capacity	Number of sachet water factories	Sachet water Produced	Mean sachets produced
Less than 10,000 sachets	2	13,000	6,500
11,000 – 50,000 sachets	20	382,00	191,00
50,000 -100,000 sachets	3	160,000	53,333
101,0000-150,000 sachets	3	460,000	153,333
320,000 sachets	1	320,000	320,00
Total	29	1,335,000	46,034

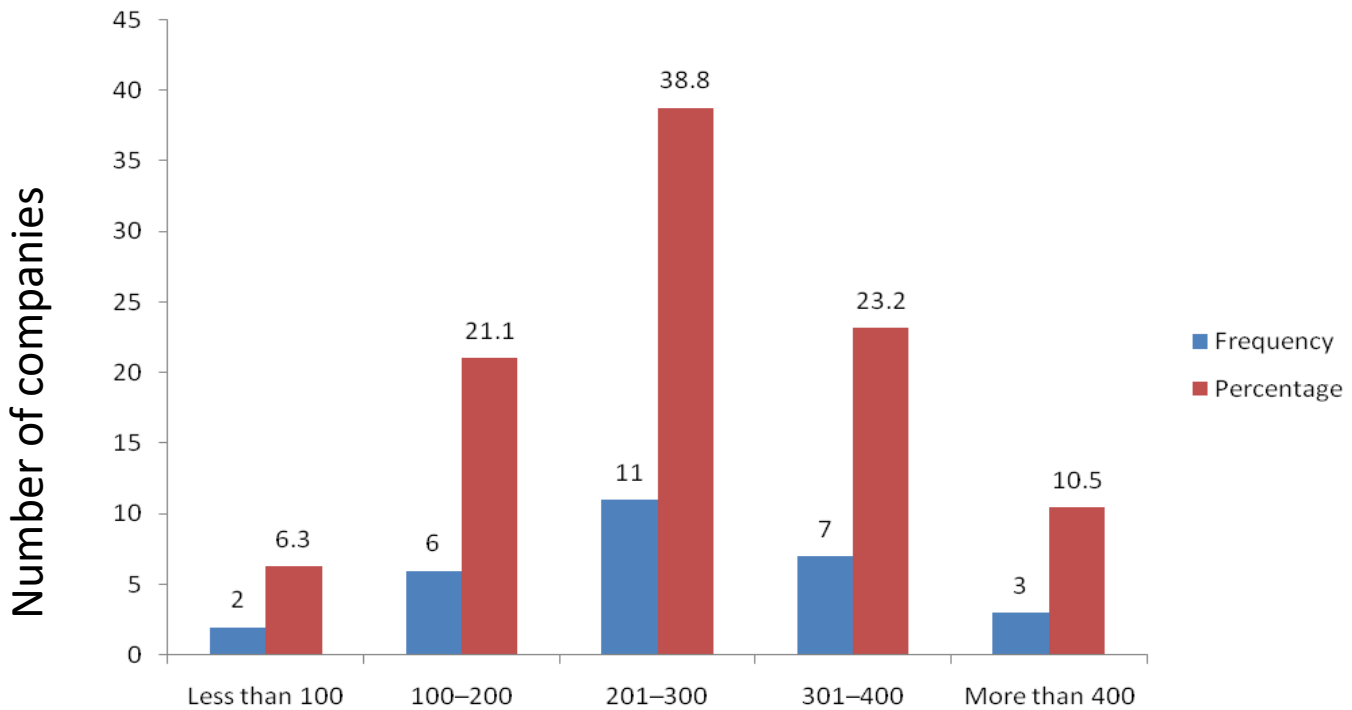


Figure 2: Weekly Sachet water production capacity of Sachet water packaging Companies in Gombe Metropolis.

Plastic Waste Handling before Disposal

When assessing preferred methods for plastic waste management, 42.2 % agreed that establishing a community collection point is beneficial, with a smaller yet notable proportion strongly agreeing (15.6 %). Utilizing private waste disposal services also received support, with 38% in agreement. GOSEPA - managed waste transport was similarly supported (35.9 % agreed). However, burning or indiscriminate disposal (such as throwing waste into open spaces) were strongly opposed; 50.6 % and 54.9 % of respondents respectively strongly disagreed with these methods, highlighting a general awareness of their environmental harm (Table 6).

Table 6: Plastic Waste Disposal method

Method of Plastic Waste Management	SD (1)	D (2)	MA (3)	A (4)	SA (5)	Percentage sum of disagreed	Percentage sum of agreed
Community collection point	20 (8.4%)	30 (12.7%)	50 (21.1%)	100 (42.2%)	37 (15.6%)	21.1	78.9
Transported by private waste disposal company	15 (6.3%)	25 (10.5%)	60 (25.3%)	90 (38.0%)	47 (19.8%)	16.8	83.1
Transported by GOSEPA to waste dumpsite	18 (7.6%)	27 (11.4%)	80 (33.8%)	85 (35.8%)	27 (11.4%)	19.0	81.0
Burning the waste	12(50.6%)	57 (24.1%)	30 (12.7%)	20 (8.4%)	10 (4.2%)	74.7	25.3
Throwing into available spaces	13(54.9%)	60 (25.3%)	20 (8.4%)	15 (6.3%)	12 (5.1%)	80.2	19.8

Key:

SD = Strongly Disagree (1), D = Disagree (2), MA = Moderately Agree (3), A = Agree (4)

SA = Strongly Agree (5), Mean = Average score (1-5 scale). SD = Standard Deviation

Types of Wastes Found at the Dumpsites

The composition of waste at the dumpsites indicates that organic waste dominates, accounting for 45% of the total waste. This highlights a significant opportunity for organic waste management strategies such as composting or bio-gas production. Plastic waste forms the second-largest category at 30%. The remaining waste types include glass and metal (10%), paper and cardboard (7%), hazardous waste (5%), and other miscellaneous waste like textiles and other waste (3%). The relatively low percentage of hazardous and other waste types still necessitates special attention due to their potential environmental and health hazards.

Types of Wastes Found at the Dumpsites

Type of Waste	Examples	Quantity
Organic Waste	Food scraps, leaves, garden trimmings	45% of total waste
Plastic Waste	PET bottles, nylon bags, plastic cups	30% of total waste
Glass and Metal	Aluminum cans, scrap metals	10% of total waste
Paper and Cardboard	Newspapers, cardboard, office paper	7% of total waste
Hazardous Waste	Bottles, broken glassware	5% of total waste
Other Waste (e.g., textiles, e-waste)	Textiles, electronics, rubber	3% of total waste

Physio-chemical parameters of soil sample

The physico-chemical and heavy metal analysis of the soil sample reveals a varied profile when compared to the Federal Environmental Protection Agency (FEPA) limits of 1999. The soil pH is recorded at 7.30, which falls comfortably within the acceptable range of 6.50 to 8.50. This indicates that the soil is neutral, a condition favorable

for optimal microbial activity and nutrient availability essential for plant growth. Electrical conductivity is measured at 120 $\mu\text{S}/\text{cm}$, significantly lower than the maximum permissible limit of 1000 $\mu\text{S}/\text{cm}$. This low value suggests that the soil is not saline and is free from excessive soluble salts, thereby supporting healthy plant and microbial life. The calcium and magnesium levels are 12.62 mg/kg and 10.0 mg/kg respectively both well below their FEPA limits of 200.00 mg/kg and 50.00 mg/kg. These values indicate minimal risk of mineral toxicity and point to a relatively balanced mineral composition in the soil.

Table 7: Physio-chemical parameters of soil sample

Parameters	Soil Sample	FEPA Limit 1999
Ph	7.30	6.50–8.50
Conductivity (Ms/cm)	120	1000.00
Calcium (mg/kg)	12.62	200.00
Magnesium (mg/kg)	10.0	50.00
Total organic carbon (%)	8.0	5.00
Total nitrogen (%)	0.63	-
Phosphate (mg/kg)	1.20	5.00
Total chloride (mg/kg)	89.97	250.00
Cadmium (Cd)	0.85	0.01–0.50
Chromium (Cr)	95.30	100.00
Copper (Cu)	45.70	36.00
Lead (Pb)	55.60	85.00
Mercury (Hg)	0.02	0.05
Zinc (Zn)	120.00	140.00

* $p < 0.05$.

Microbial Population at Dumpsite

The analysis of microbial populations across different sites revealed notable variations in both load and species composition (Table 9-11). The Inex Dumpsite recorded the highest microbial counts at all dilution levels, indicating significant contamination likely due to accumulated organic waste and poor sanitation. In contrast, Tumfure Market exhibited the lowest counts, particularly at higher dilutions, suggesting relatively better environmental hygiene. Interestingly, the Old Market showed an unusually high microbial load at the highest dilution (10^{-10}), which may reflect the presence of resilient microbial species.

Biochemical testing identified a variety of microorganisms, including *Escherichia coli*, *Clostridium*, *Staphylococcus aureus*, *Bacillus* spp., *Klebsiella pneumoniae*, *Proteus mirabilis*, *Pseudomonas aeruginosa*, and *Enterococcus faecalis*.

Table 9: Microbial Population at the Dumpsite

Microbial Population	Inex Dump site	Main Market	Tumfure Market	Old Market
10^{-1}	212.00	161.00	143.00	175.00
10^{-5}	152.00	113.00	101.00	149.00
10^{-10}	95.00	71.00	59.00	179.00

Table 10: Biochemical Tests

Biochemical test

G/Stain	Cat	Coag	Urease	Cit	Ind	oxidase	Shape	Organisim
-	+	-	-	-	+	-	Rod	<i>E. coli</i>
+	-	-	-	+	-	-	Rod	<i>Clostridium</i>
+	+	+	+	+	-	-	Cocci	<i>S. aureus</i>
+	+	-	-	+	-	+	Rod	<i>Bacillus SPP</i>
+	+	-	+	+	-	+	Rod	<i>Proteus mirabilis</i>
-	+	-	+	+	-	+	Rod	<i>Pseudomonas aeruginosa</i>
+	-	-	-	-	-	-	Cocci	<i>Enterococcus feacalis</i>

Table 11: Organisms identified from soil samples taken from the Markets and Dump sites

	Inex	Main Market	Tumfure Market	Old Market	Total	%	
<i>E. coli</i>	3	1	2	2	8	19.51	
<i>S. aureus</i>	2	1	2	1	6	14.63	
<i>Clostridium</i>	2	2	0	1	5	12.20	
<i>Bacillus anthracis</i>	2	2	1	3	8	19.51	
<i>Pseudomonas</i>	3	2	1	1	7	17.07	
<i>Enterococcus feacalis</i>	2		0	0	2	4	9.76
<i>Proteus mirabilis</i>		2	0	1	0	3	7.32

Key: 1= Present, 0= Absent

Discussion

This chapter presents a comparative discussion of the study's findings, analyzing their alignment and divergence with similar research in the field. This study provides insights into waste management practices, the contribution of plastic waste and associated environmental and health impacts. The findings, statistically significant at $\alpha \leq 0.05$, highlight both congruence and discrepancies with existing literature. This study's findings on waste management practices, plastic waste contributions, and associated environmental and health impacts both align with and diverge from existing research in significant ways, offering insights that are locally relevant yet globally contextualized. The demographic profile of respondents, with a male predominance (59.1%) and a significant proportion aged 31–40 (38%), reflects trends observed in similar studies, such as Ayeleru et al. (2020), who noted comparable gender distributions in waste-related surveys, and Duru et al. (2019), who linked middle-aged demographics to higher engagement in waste management due to economic activity. When examining waste disposal methods, this study found that community collection points and private waste services were the most preferred, with mean scores of 3.45 and 3.55, respectively,

indicating a shift toward more formalized waste management systems. This aligns with Jambeck et al. (2015), who documented a global increase in structured waste disposal practices. However, the strong disapproval of open burning (mean = 1.80) and indiscriminate dumping (mean = 1.66) contrasts with findings from Geyer et al. (2017), who identified burning as a common practice in rural and less regulated areas.

The environmental and health risks associated with plastic waste were widely recognized by respondents, with 72.6 % linking plastic waste to flooding due to blocked waterways (mean = 3.93), a finding consistent with Verma et al. (2016), who highlighted similar issues in densely populated urban areas. Unlike studies from regions with advanced waste systems, where aesthetic concerns are secondary, this study found that visual pollution (mean = 3.24) was a significant local issue, underscoring how regional priorities differ based on infrastructure and environmental conditions. Public awareness of recycling and reuse was notably high (76.7 %, mean = 3.99), mirroring global advocacy by UNEP (2018) for community-based waste initiatives. However, the study diverged from Kaza et al. (2018), who emphasized government-led waste management, as 47.2% of respondents here endorsed a collective responsibility approach. This reflects a growing trend in developing regions toward participatory waste governance, where communities play an active role alongside authorities.

The study also revealed heavy reliance on plastics in local markets (80.2%) and the water packaging industry (94.9%), trends that align with global patterns reported by the World Bank (2018). The heavy metal profile of the soil reveals potential environmental and public health risks. Cadmium (0.85 mg/kg) exceeded the FEPA safe range of 0.01–0.50 mg/kg, highlighting contamination likely arising from anthropogenic sources such as improper waste disposal, industrial activities, or agrochemical usage (Kumari et al., 2024). Cadmium is highly toxic, even at low concentrations, and can accumulate in food crops, posing risks to human health including renal dysfunction and skeletal damage (Zhao et al., 2023).

Copper was also found at elevated levels (45.70 mg/kg), slightly above the permissible limit of 36.00 mg/kg. While copper is an essential micro-nutrient, excessive concentrations can inhibit enzymatic activities and interfere with nutrient uptake (Mir et al., 2021). Chromium was present at 95.30 mg/kg close to the upper FEPA limit of 100.00 mg/kg. Although not currently alarming, continued accumulation could pose ecological risks, especially considering that certain chromium species (e.g., Cr(VI)) are carcinogenic and mutagenic (Sharma et al., 2022). Lead (55.60 mg/kg) and mercury (0.02 mg/kg) were both below their respective FEPA limits, though their persistence and toxicity warrant ongoing monitoring. Lead exposure can impair neurological development, particularly in children (Bjorklund et al., 2024), while mercury's bioaccumulation in aquatic and terrestrial food chains can have long-term toxicological effects (Kumar et al., 2023). Zinc (120.00 mg/kg) was within acceptable levels, supporting its role as an essential element in enzyme activation and protein synthesis (Hoxhaj & Manning, 2020).

However, unlike Andrady et al. (2015), who noted a shift toward biodegradable alternatives in some regions, this study found minimal adoption of sustainable substitutes, pointing to gaps in policy enforcement and technological accessibility. Waste composition analysis further showed that plastic (45 %) and organic waste (30 %) dominated the waste stream. Statistical validation through paired t-tests confirmed a strong relationship between plastic waste and environmental degradation ($t = 8.34$, $p = 0.001$), reinforcing Geyer et al. (2017) macroeconomic assessments of plastic pollution. However, while Geyer et al. (2017) focused on global economic consequences, this study provided a granular, community-level analysis, emphasizing actionable interventions tailored to the study region's unique challenges.

The microbial analysis revealed alarming contamination levels, particularly at Inex Dumpsite, which recorded the highest microbial counts (212.00 at 10^{-1} dilution). This is consistent with studies linking poorly managed waste sites to increased microbial loads, including pathogenic bacteria (Ukpong et al., 2019). The presence of *Escherichia coli*, *Staphylococcus aureus*, *Bacillus anthracis*, and *Pseudomonas aeruginosa* indicates fecal contamination and poor sanitation, posing risks of gastrointestinal, skin, and respiratory infections (WHO, 2020). The ubiquitous detection of *S. aureus* and *B. anthracis* across all markets suggests widespread environmental contamination, likely due to improper waste handling and open dumping. The presence and abundance of *Bacillus* species identified in this study is not surprising because of their ability to produce spores are also indigenous to soil environment and known to persist in such environments (Atlas & Bartha, 2007). The unusually high microbial count at Old Market (179.00 at 10^{-10}

dilution) may reflect resilient microbial strains, warranting further investigation. Such findings emphasize the need for stricter hygiene controls in public markets, where organic waste and plastic debris create ideal conditions for microbial persistence (Akinbode et al., 2021). While this study's findings on waste composition, disposal trends, and health risks align with broader global research, they also reveal critical divergences particularly in local perceptions of responsibility, infrastructural limitations, and the persistence of plastic dependence. These distinctions highlight the importance of context-specific waste management strategies, particularly in urbanizing regions where systemic gaps and environmental hazards demand urgent attention.

Conclusion

In conclusion, this study has provided valuable insights into the contributions of water industries and marketplaces to plastic waste pollution in Gombe State metropolis. The findings have highlighted the need for effective plastic waste management strategies, including the establishment of recycling industries, improvement of waste collection points, and enforcement of waste management laws. The study has also underscored the importance of public awareness and education on proper plastic waste management practices. The results of this study have significant implications for policymakers, planners, and stakeholders involved in solid waste management in Gombe State metropolis.

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