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RESEARCH ARTICLE

Identifying determinants of waste management access in Nouakchott, Mauritania: a logistic regression model

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Abstract

Access to waste management services is crucial for urban sustainability, impacting public health, environmental well-being, and overall quality of life. This study employs logistic regression analysis on survey data collected from 1,032 household heads residing in Nouakchott, the capital of Mauritania. The survey investigated key household factors that determine access to waste management services. The findings reveal a significant interplay among waste service provision, the presence of cisterns, housing type and size, and access to electricity. Socioeconomic disparity in service access, with poorer housing formats like shacks receiving substandard services. In contrast, areas with robust electrification report better service access, although inconsistencies remain amid power outages. The research highlights the challenges faced by Riyadh municipality, particularly rapid growth and inadequate infrastructure, which hinder waste management efficiency. Overall, the results not only illuminate Nouakchott's unique challenges in service provision but also propose actionable recommendations for a sustainable urban future. These recommendations aim to inform and guide targeted policies for improving living conditions and environmental sustainability in urban Mauritania.

Policy Significance Statement

This study highlights critical household factors impacting access to waste management services in Nouakchott, underscoring the intersection of urban infrastructure, housing types, and socioeconomic disparities. It reveals that the availability of water infrastructure, such as cisterns, and the presence or absence of electricity significantly influence service provision. The findings emphasize the need for policy interventions that address infrastructure gaps and socioeconomic biases in service distribution, particularly in rapidly growing urban areas like the Riyadh municipality. This research offers valuable insights for policymakers aiming to improve urban living conditions and advance environmental sustainability in Mauritania.

1. Introduction

Mauritania, a West African country endowed with rich cultural and geographical diversity, faces numerous developmental challenges (Ebnou Abdem et al., 2023a). Nouakchott, its capital, stands at the heart of these challenges. As the country's primary economic and political hub, the city has

experienced rapid demographic growth, drawing individuals from all over the nation in search of better opportunities (Chenal and Kaufmann, 2008; Guerrero et al., 2013; Japan International Cooperation Agency (JICA), 2018; National Statistical Office, 2018; World Bank, 2021; Abdoullah et al., 2023; Chami, 2023; Ebnou Abdem et al., 2023a). However, this growth has exerted significant pressure on urban infrastructure, especially waste management (Aloueimine, 2006; Guerrero et al., 2013; Germany, 2014; World Bank, 2021).

Nouakchott's transformation from a modest fishing village to Mauritania's bustling capital has brought with it significant waste management challenges (Ebnou Abdem et al., 2023a). As the city expands, so does the volume of waste it generates. Addressing this issue necessitates robust systems for waste collection, treatment, and disposal. The city's waste management challenges stem from infrastructural constraints and socioeconomic factors (Aloueimine, 2006; Guerrero et al., 2013; Retech Germany, 2014).

From 2007 to 2014, the private operator Pizzorno played a pivotal role in managing the city's waste, ensuring the collection and transfer of household waste to a designated landfill 25 km away. The volume of waste processed by Pizzorno was significant, with notable numbers in 2010, 2011, and 2012 being 148,494.497 tons, 184,508.745 tons, and 211,758.464 tons, respectively (Retech Germany, 2014; Parrot et al., 2023). These numbers reflect a very high amount of waste. It is worth noting that the population of Nouakchott has doubled from 2012 to the present (National Statistical Office, 2018), consequently leading to a proportional increase in waste production. Additionally, Pizzorno only handles solid waste, leaving liquid and medical waste unprocessed (Retech Germany, 2014). Transitioning from Pizzorno, in 2015 and 2016, the Urban Community of Nouakchott (CUN) took over waste collection, transportation, and landfill management. Since July 2016, four private operators have shared the responsibility of waste transportation and collection, while the CUN oversees landfill management (Retech Germany, 2014; Parrot et al., 2023). Beyond these organizational changes, waste management in Nouakchott faces other significant challenges.

The city grapples with an alarmingly low recycling rate of 8% (Retech Germany, 2014; Bundhoo, 2018), which hints at a profound absence of effective recycling programs and a lack of awareness among the population. Consequently, the majority of recyclable materials end up being discarded improperly, wasting valuable resources and exerting additional pressure on already overburdened landfills.

Nouakchott's waste disposal practices reveal a bleak reality. A substantial portion of municipal solid waste, 37.3% (Aloueimine, 2006; Retech Germany, 2014), finds its resting place in landfills, while 54.7% is openly discarded, inflicting grave harm upon the environment and public health. This overreliance on landfills hints at an inadequacy in waste collection and management, demanding a more efficient and sustainable system. A disconcerting 75.6% of Nouakchott's household heads are bereft of access to essential waste management services, with a disheartening dissatisfaction rate exceeding 65% among those fortunate enough to have access (Japan International Cooperation Agency (JICA), 2018). This egregious lack of access compels households to resort to self-disposal methods or to depend on informal waste collectors, further compounding the inefficiencies in waste management. The dissatisfaction rate among the fortunate few who do have access underscores significant issues with the quality and reliability of the existing services (Aloueimine, 2006; Japan International Cooperation Agency (JICA), 2018; de la santé, 2021).

Only 30% of Nouakchott's urban areas benefit from municipal waste collection (Aloueimine, 2006; Retech Germany, 2014), a stark revelation of the gaping chasm in service provision. This formal waste collection system fails to extend its reach to all neighborhoods, leaving waste to accumulate in many parts of the city. Irregular collection schedules exacerbate the issue, allowing uncollected waste to linger on the streets for extended periods, diminishing both hygiene and aesthetics (Aloueimine, 2006; McAllister, 2015; Japan International Cooperation Agency (JICA), 2018; de la santé, 2021).

In addition, while much attention has been directed toward municipal waste, the management of biomedical waste (BW) in healthcare facilities presents its own set of challenges (de la santé, 2021). Notably, there is a lack of waste segregation at the source, an inappropriate collection and transportation system, and a shortage of adequately trained and equipped human resources. However, some health centers have made efforts to improve BW management. Within these facilities, the collection and

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transportation of BW are often handled by untrained support staff using basic bins and wheelbarrows without the necessary protective equipment (de la santé, 2021). For off-site BW transportation, many health structures rely on specialized private waste collectors, leading some without internal treatment systems to resort to creating internal wild dumps (de la santé, 2021). Due to investment constraints, the municipal solid waste management system remains the most feasible option for general waste collection and disposal. Yet, it falls short of ensuring the proper treatment and disposal of hazardous medical waste (de la santé, 2021). In the absence of specific data on BW characterization, estimates from 2003 indicated a daily production of 3,300 kg, which increased to over 7,000 kg/day by 2007. Updated estimates from 2016 suggest a total waste production of 2,340,234 kg, of which 468,047 kg is BW. Nouakchott alone accounts for nearly a third 32% of this, with a daily output of 2,024 kg (de la santé, 2021). Recent studies have identified over 165,155 healthcare structures in Nouakchott (de la santé, 2021).

This situation poses public health risks (Giusti, 2009; Behera and Narayan, 2020; Debrah et al., 2021b; de la santé, 2021; Kanhai et al., 2021; Sy et al., 2021; Pessoa Colombo et al., 2023a,b), as improper waste management can lead to the spread of infectious diseases, especially when the waste interacts with the general populace (Cudjoe and Acquah, 2021). In addition to these health concerns, there are significant economic and developmental implications (Giusti, 2009; Guerrero et al., 2013; Behera and Narayan, 2020; Yeo et al., 2020; Debrah et al., 2021a, 2021b; Kanhai et al., 2021). The accumulation of waste in urban areas can deter tourism and investment, while the spread of diseases further strains limited healthcare resources (Giusti, 2009; Guerrero et al., 2013; Cudjoe and Acquah, 2021). Moreover, the environmental consequences are far-reaching, affecting not only the immediate surroundings but also contributing to broader ecological imbalances (air, water, and soil) (Giusti, 2009; Guerrero et al., 2013; Yeo et al., 2020; Chikowore, 2021; Debrah et al., 2021a, 2021b; Khudyakova and Lyaskovskaya, 2021; Salisu et al., 2022; Ainooson, 2023). Inefficient waste management systems can lead to soil and water contamination, potentially harming agriculture and fisheries (Debrah et al., 2021b; Khudyakova and Lyaskovskaya, 2021), two vital sectors in Mauritania's economy. As the waste problem persists, it becomes a hindrance to the city's growth and development, hindering its potential to thrive sustainably and healthily (Giusti, 2009; Yeo et al., 2020; Debrah et al., 2021a, 2021b; Khudyakova and Lyaskovskaya, 2021).

Nouakchott's situation is not isolated. Across the African continent, waste management remains a pressing concern (Bundhoo, 2018; Oyekale, 2018; Godfrey et al., 2019; Loukil and Rouached, 2020; Yeo et al., 2020; Debrah et al., 2021a, 2021bOlatunji, 2022; Adedara et al., 2023; Moyen Massa and Archodoulaki, 2023). Only 55% of municipal solid waste is collected, and a staggering 90% finds its way to unregulated dumpsites. Between 2012 and 2016, Sub-Saharan Africa (SSA) witnessed a dramatic surge in waste production. This waste predominantly consists of organic material at 57%, plastics at 13%, paper at 9%, metal, and glass each at 4%, with the remaining 13% being other materials (Musavengane et al., 2019; Ayeleru et al., 2020; Adusei-Gyamfi et al., 2022; Debrah et al., 2022; Folarin, 2022; Ainooson, 2023; Matsimbe et al., 2023; Moyen Massa and Archodoulaki, 2023; Ndam et al., 2023). See Figure 1 below.

In addition, between 2012 and 2019, the amount of waste generated by countries in SSA increased by 55 million tons. By 2019, the population in the region had reached approximately 1.31 billion. It is projected that by 2025, SSA's waste generation will rise to 244 billion tons, with an expected population size of around 1.50 billion (Yeo et al., 2020; Debrah et al., 2021a; Debrah et al., 2022), as depicted in Figure 2. Furthermore, as highlighted by Yeo et al. (2020), Debrah et al. (2021a), only about 44% of the waste generated is collected, with organic waste constituting 60% of the uncollected waste. This uncollected waste poses environmental and health risks, emphasizing the need for urgent and effective solutions to ensure a healthy and sustainable environment (Yeo et al., 2020; Debrah et al., 2021a, 2021b; Debrah et al., 2022).

Several studies have investigated waste management practices in SSA countries, focusing on understanding the socioeconomic factors that contribute to the lack of access to waste management services (Getahun et al., 2012; Mamady, 2016; Adzawla et al., 2019; Chikowore, 2021; Chukwuone et al., 2022; Naghel et al., 2022).

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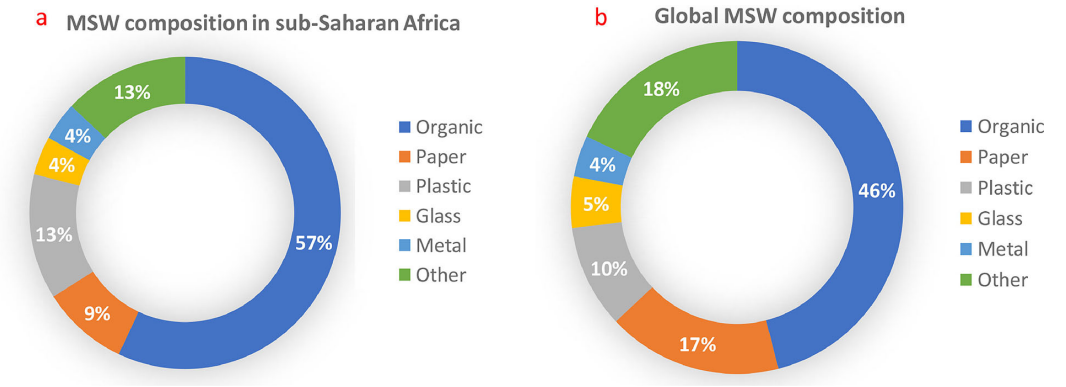

Figure 1. *Demographic distribution of waste composition in SSA countries (Adusei-Gyamfi et al., 2022).*

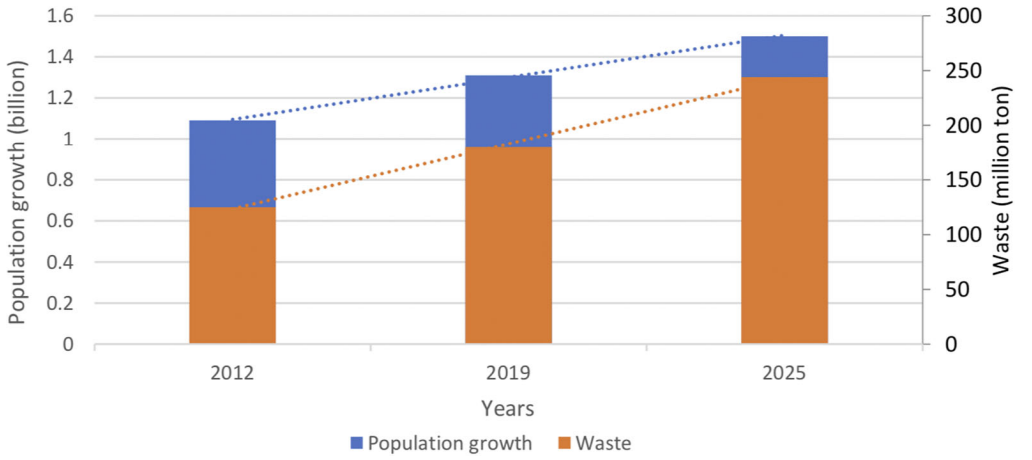

Figure 2. *Population growth and waste generation on yearly basis (Debrah et al., 2022).*

In Algeria (M'sila), Naghel et al. (2022) have proved that the challenges related to the household's waste management services access are multifaceted. Additionally, the issues stem from its demographic and spatial growth, evolving dietary patterns, and emerging environmental issues that have caught urban planners off guard, with a notable rise in organic waste (Naghel et al., 2022).

On the other hand, in Zimbabwe, research conducted by Chikowore (2021) has established a strong connection between gender and the willingness to pay for waste collection services. Moreover, the study found that gender, age, and education level have no association with waste receptacle facilities used by individuals (Chikowore, 2021).

In contrast, Mamady, in their study in Guinea (Mamady, 2016), demonstrated that factors such as educational background, income, and gender were not independently linked to indiscriminate waste disposal. However, they identified that living in unplanned residential areas was an additional contributing factor to indiscriminate waste disposal (Chikowore, 2021).

Similarly, a study conducted by Chukwuone et al. (2022) in Lagos revealed that a majority 67.42% of households in the coastal city engage in unauthorized waste disposal. In addition, several factors, such as household size, prior participation in community cleanup initiatives, receiving waste management information, paying waste management fees, and having a local dumpster, were identified as significant in reducing the likelihood of illegal waste disposal. Furthermore, the level of education, family size, and

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the amount paid as waste management fees had a substantial impact on the number of households that were willing to contribute to formal waste management (Chukwuone et al., 2022).

In addition, Getahun et al. (2012) demonstrated that in Ethiopia, higher family income and education levels are more closely associated with private or municipal waste collection. These factors are less associated with open dumping or landfill disposal (Getahun et al., 2012).

Furthermore, the findings of Adzawla et al. (2019) emphasize the importance of educating households about solid waste management, as it plays a pivotal role in promoting waste collection practices other than open dumping or burning in Ghana. Moreover, the characteristics of households' houses and the geographical location of households are critical factors influencing waste management services in this country (Adzawla et al., 2019).

While many cities face common waste management challenges, each is uniquely shaped by its socioeconomic, geographic, and cultural context. Notably, there is a gap in research regarding waste management in Nouakchott, Mauritania.

In Nouakchott, an alarming issue comes to light: household waste overwhelmingly constitutes more than 90% of the city's total solid waste (Aloueimine, 2006). Moreover, the economic toll of inadequate sanitation and subpar waste management in Mauritania amounts to a staggering USD 5.5 billion annually, representing a substantial 1 to 2.5% of the country's Gross Domestic Product (Debrah et al., 2022). Additionally, there has been an increase in dioxin emissions resulting from municipal waste incineration. In 2012, the Dioxin emission potential (kg TCDD) from incineration technology in urban areas of Mauritania stood at 0.0027473 kg TCDD per year (Cudjoe and Acquah, 2021). By 2025, this potential will have risen to 0.0110885 kg TCDD per year, reflecting an increase of over 350% (Cudjoe and Acquah, 2021). Dioxins are persistent organic pollutants that are highly toxic to human health and the environment (Cudjoe and Acquah, 2021). They can cause a range of health issues, including cancer, neurological developmental disorders, and congenital abnormalities (Cudjoe and Acquah, 2021).

These statistics underscore the urgency of understanding and addressing household waste management strategies, particularly in light of the complex interplay of socioeconomic and geographical factors that influence households' access to waste management services (Guerrero et al., 2013). Recognizing the intricate connections between waste challenges and socioeconomic factors is crucial for developing effective waste management strategies that align with Nouakchott's reality (Mukhtar et al., 2018; Cudjoe and Acquah, 2021). This article aims to fill this research gap by employing a logistic regression model to identify and predict the primary factors that impact access to waste management services in Nouakchott. In addition, it delves deep into the complex relationship between access to waste management services and the economic, social, and geographic backgrounds of households, shedding light on the urban service provision landscape in Nouakchott.

The structure of the manuscript is laid out in the following manner: Section 2 presents an introduction to the city of Nouakchott, describes the data sources used, details the data processing methods employed, and provides an overview of the model proposed. Section 3 discusses the main findings, including the identification of crucial factors influencing access to essential services and an evaluation of the predictive model's performance. Finally, Section 4 encapsulates the study's essential conclusions, explores their relevance to urban development strategies, and proposes avenues for subsequent studies.

2. Study framework and methodology

In this section, we explore the geographic scope of our study and detail the data sources, collection processes, and statistical analysis methods used.

2.1. Geographic scope

Nouakchott, Mauritania's sprawling capital situated on the Atlantic coast of the Sahara Desert, has undergone a swift transformation from a small fishing village to the metropolis it is today (Ebnou Abdem et al., 2023a). This rapid evolution, marked by escalating waste management challenges, can be attributed

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to its role as the nation's administrative and economic hub (Guerrero et al., 2013; Ebnou Abdem et al., 2023a). Historically, the city's unplanned urban and demographic growth, exacerbated by internal migrations due to the droughts of the 1970s and 1980s, led to informal expansion. These informal settlements, often lacking adequate infrastructure, became hotspots for waste accumulation (Chenal and Kaufmann, 2008; Ebnou Abdem et al., 2023a). Moreover, the rise of Nouakchott as an economic center has increased the production of industrial and commercial waste, adding another dimension to the waste management challenge. The city's proximity to the Sahara Desert and the Atlantic coast also presents unique challenges, especially concerning liquid waste management and salinity.

In 2022, its estimated population will reach approximately 1.7 million, making it the largest city in the country. This population is spread across various municipalities, each with its own unique challenges and characteristics (Abdoullah et al., 2023; Ebnou Abdem et al., 2023a). Recent data indicates that while Mauritania's total population stands at around (4.7) million, Nouakchott alone accounts for nearly 37% of this figure. Notably, the city's growth rate has significantly outstripped the national average. Between the 2000 and 2013 censuses, Nouakchott saw an annual growth rate of 4.3%, in contrast to Mauritania's 2.7% (Japan International Cooperation Agency (JICA), 2018). The demographic distribution of Nouakchott's residents by the municipality is illustrated in Figure 3 below.

Figure 3 offers an in-depth view of Nouakchott's demographic distribution by the municipality as of 2013. The municipalities of Arafat, Dar Naim, and Toujounine, primarily situated in the northern and

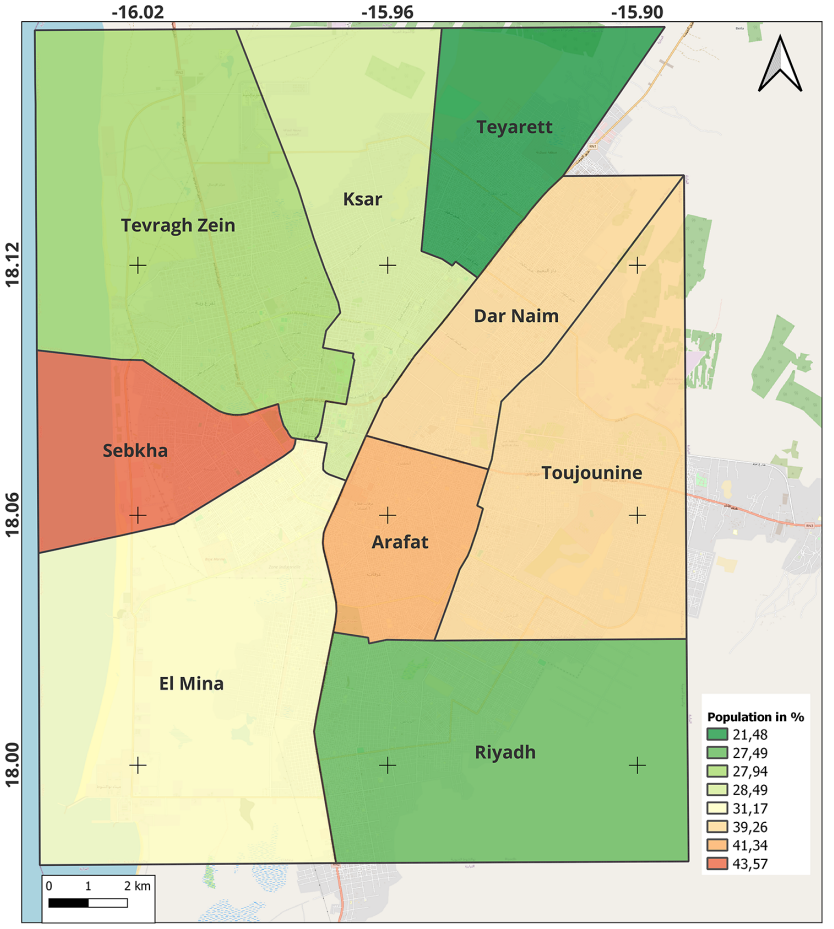

Figure 3. *Maps and population distribution by municipality of Nouakchott (Japan International Cooperation Agency (JICA), 2018).*

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southern parts of Nouakchott, have the most substantial population figures. Alongside the western municipalities of Sebkha, Ksar, and Tevragh-Zeina, they represent a considerable segment of the city's overall population. Nouakchott's rapid demographic growth and its informal urban sprawl have placed immense pressure on its vital urban services and infrastructure. A direct consequence of this population boom is the escalating waste generation. As the number of residents rises, the amount of waste they produce follows suit, intensifying the city's waste management challenges. Efficiently handling this waste is paramount, ensuring both the well-being of its inhabitants and the city's environmental sustainability. Having established the demographic and urban context of Nouakchott, it becomes imperative to delve deeper into the intricacies of its waste management landscape and the challenges it currently faces. The next subsection is dedicated to this task.

2.2. Data

The data used in this study were sourced from a comprehensive social survey conducted in Nouakchott by the Japan International Cooperation Agency (JICA) between 2016 and 2018, culminating in October 2018 (Japan International Cooperation Agency (JICA), 2018). The survey employed a random sampling technique (Japan International Cooperation Agency (JICA), 2018; Ebnou Abdem et al., 2023a) to ensure sample representativeness, minimize biases, and enhance the generalizability of the findings. JICA's survey involved administering 126 questions to 1032 household heads, resulting in a dataset with 280 variables (Japan International Cooperation Agency (JICA), 2018; Ebnou Abdem et al., 2023a). The four major objectives of the survey were to understand households' demographics, engagement with urban services, living conditions, and city sustainability (Japan International Cooperation Agency (JICA), 2018; Ebnou Abdem et al., 2023a). To ensure the integrity and accuracy of the analysis, we conducted preliminary data cleaning using specialized software libraries in Python and R (Ebnou Abdem et al., 2023a). This process addressed missing data, outliers, and inconsistencies, ensuring that the final dataset remained representative of the population under study (Ebnou Abdem et al., 2023a). Any outliers or inconsistent data points were identified and subsequently removed to maintain data accuracy and reliability (Ebnou Abdem et al., 2023a). For a detailed description of our data curation process and criteria for anomaly detection, please refer to the Appendix.

2.3. Statistical analysis

Having completed the data preprocessing, we proceed to present the logistic regression model utilized to examine the socioeconomic and geographic determinants influencing households' access to waste management services (Abebaw, 2008;Behera and Narayan, 2020; Ebnou Abdem et al., 2023a). Access to waste management services is intricately linked to various socioeconomic and geographical factors characterizing households. These include access to water cisterns (McAllister, 2015), access to septic system removal services (McAllister, 2015), and access to water sewage systems (McAllister, 2015). Demographic variables like age (Mamady, 2016; Al-Khateeb et al., 2017; Adzawla et al., 2019), gender (Al-Khateeb et al., 2017; Oyekale, 2018; Adzawla et al., 2019; Behera and Narayan, 2020; Chukwuone et al., 2022), and education level (Mamady, 2016; Oyekale, 2018; Adzawla et al., 2019; Behera and Narayan, 2020; Chikowore, 2021; Chukwuone et al., 2022) also play significant roles. Employment status (Oyekale, 2018; Behera and Narayan, 2020), the type of housing (McAllister, 2015; Oyekale, 2018), and the number of rooms in a dwelling (Al-Khateeb et al., 2017) are further influential factors. Technological access, such as to the internet (McAllister, 2015; Oyekale, 2018) and electricity (McAllister, 2015; Oyekale, 2018), along with household income[1] (Mamady, 2016; Oyekale, 2018; Behera and Narayan, 2020), are also critical. The specific municipality (Al-Khateeb et al., 2017;Adzawla et al., 2019; Behera and Narayan, 2020), property ownership (Chikowore, 2021), and expenditure categories (Adzawla et al.,

[1] To simplify, we have divided household income into three levels: Low (124 euros), Medium (224 euros), and High (373 euros) [3].

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2019; Behera and Narayan, 2020) of household heads further influence access to these services. These factors were selected for their demonstrated potential relevance and impact on waste management access (Getahun et al., 2012; Guerrero et al., 2013; McAllister, 2015; Mamady, 2016; Al-Khateeb et al., 2017; Oyekale, 2018; Adzawla et al., 2019; Behera and Narayan, 2020; Chikowore, 2021; Debrah et al., 2021b; Chukwuone et al., 2022; Naghel et al., 2022). The model is defined as follows:

$$\begin{aligned}\log\left(\frac{p}{1-p}\right) = {} & \beta_0 + \beta_1 \times \text{Income} + \beta_2 \times \text{Water cisterns access} + \beta_3 \times \text{Age} \\ & + \beta_4 \times \text{Septic system removal access} + \beta_5 \times \text{Sewage Water access} + \beta_6 \times \text{Gender} \\ & + \beta_7 \times \text{Educational Level} + \beta_8 \times \text{Employment Status} + \beta_9 \times \text{Type of House} \\ & + \beta_{10} \times \text{Municipality} + \beta_{11} \times \text{Property Ownership} + \beta_{12} \times \text{Number.of.rooms} \\ & + \beta_{13} \times \text{Expenditures} + \beta_{14} \times \text{Internet access} + \beta_{15} \times \text{Electricity access}\end{aligned}$$

where $p = \mathbb{P}[\mathbf{Y} = \text{'Yes'}]$ represents the likelihood that a given household head has access to waste management services, based on the predictors included in this model. We used the glm() function in R to estimate the model, employing maximum likelihood estimation methods and optimization algorithms such as Newton–Raphson and BFGS (Seyid et al., 2022). The odds ratio (OR) provide information about the associations between the predictor variables and the likelihood of households having access to waste management services (Behera and Narayan, 2020; Ebnou Abdem et al., 2023a). Additionally, the 95% confidence intervals (CIs) are used to assess the significance of these associations. If the CI includes the value of one, it suggests that there is no statistically significant association (Ebnou Abdem et al., 2023a). On the other hand, if the CI does not include one, it indicates that there is a statistically significant association between the predictor variable and access to waste management services (Ebnou Abdem et al., 2023a).

3. Results

In this section, we first assess our model's performance through coefficient analysis and metric calculation, followed by a discussion of these findings' implications.

3.1. Evaluating predictive performance: coefficient analysis and metric calculation

In this part, we aim to showcase the predictive performance of our model defined in Section 2.3. To achieve this, we calculate three well-known metrics:

1. The likelihood ratio test (LRT) serves as a tool to assess whether a data set fits better with a complex model than a simpler alternative. By comparing LRT statistics against critical values from the chi-squared distribution, we can infer the necessity of the complexity. A statistic higher than the chi-squared critical value allows us to discard the null hypothesis, indicating a superior fit of the full model (Ebnou Abdem et al., 2023a).
2. Evaluating model predictions: This process quantifies how well a model forecasts outcomes, primarily through the accuracy metric—a gauge of the model's predictive correctness. High accuracy rates, approaching 1, reflect a model's proficiency in classifying data correctly, whereas rates nearing 0 imply ineffective prediction capabilities. For more details, see (Ebnou Abdem et al., 2023a).
3. Nagelkerke's R^2: Is adjusted to vary between 0 and 1 for easier interpretation. It is calculated from the log-likelihoods of the null and full models, providing a clearer assessment of model fit (Ebnou Abdem et al., 2023a).

Table 1 presents the values obtained for these three metrics.

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Table 1. *Statistical significance and predictive accuracy of the model*

Metric	Value
LRT	p–value $=1.78 \times 10^{-12}$
Accuracy	0.92
Nagelkerke'sR^2	0.94

Table 2. *Accuracy for each model*

Accuracy	Decision tree	SVM	Our model
Value	0.75	0.78	0.92

Table 1 summarizes our model's robustness: A p-value of 1.78×10^{-12} from the LRT confirms the model's superior fit over the null hypothesis, and a Nagelkerke's R^2 of 0.94, while a 92% accuracy rate attests to its reliable predictions.

Further emphasizing the robustness and efficiency of our model, we conducted a comparative analysis with two well-known models commonly used for predicting binary variables, which are (Meza et al., 2019; Jassim et al., 2022):

- Support vector machine (SVM) is a powerful classification algorithm that maximizes the margin between two binary classes (Jassim et al., 2022).
- Decision tree is used for both classification and regression tasks (Meza et al., 2019).

We applied these two methods to the data defined in Section 2.2 and computed the accuracy for each method. Table 2 presents the accuracy of each method.

Table 2 demonstrates that our model exhibits an accuracy of 0.92, surpassing the performances of the SVM model of 0.78 and the decision tree of 0.75. This superiority in terms of accuracy not only underlines the effectiveness of our logistic regression model but also its relevance in the specific context of waste management in Nouakchott.

After confirming our model's accuracy and effectiveness, we proceed to elaborate on the findings presented in Table 3 and to examine the implications highlighted by Figure 4.

Table 3 shows that several factors significantly influence access to waste management services. The absence of electricity access negatively impacts waste management service access, with an OR of 0.27, suggesting that those without electricity are less likely to have proper waste services. The analysis of municipality variation indicates that Riyadh, with an OR of 0.28, has a reduced probability of access, possibly due to infrastructural challenges. Conversely, access to water cisterns increases the (OR = 2.97) of access to waste services, highlighting the importance of integrated utilities. Moreover, not having a septic system removal service decreases the likelihood of accessing waste management services (OR = 0.31), with a strong inverse association. In contrast, access to sewage water facilities shows significantly higher (OR = 6.94) levels of improved waste management access, indicating effective sewage systems are likely essential for efficient waste disposal. Education level emerges as a noteworthy factor; individuals with less than primary school education are nearly twice as likely to have access issues (OR=1.95), which could be attributed to socioeconomic factors that correlate with both education and service access. Furthermore, the number of rooms in a dwelling, which may reflect socioeconomic status, shows a modest but significant association (OR= 1.18), suggesting larger households have slightly better access to waste services. In housing types, those living in hangars are significantly more likely to have access to waste management services (OR = 18.5), while those in shacks are less likely to have access (OR = 0.14), indicating the impact of living conditions on service accessibility.

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Table 3. *Summary of OR with CI (95%), and p-values for significant factors*

Characteristic	OR	CI (95%)	*p*-Value
Electricity access			
Yes	—	—	—
No	0.27	0.06, 0.89	**0.040**
Municipality			
Arafat	—	—	—
Dar Naim	1.16	0.57, 2.35	0.7
El Mina	0.59	0.26, 1.29	0.2
Ksar	1.46	0.54, 3.69	0.4
Riyadh	0.28	2.13, 8.74	**0.001**
Sebkha	2.09	0.75, 5.61	0.15
Tevragh Zeina	0.34	0.07, 1.18	0.12
Teyarett	1.89	0.64, 5.20	0.2
Toujounine	1.85	0.93, 3.69	0.078
Water cisterns access			
No	—	—	—
Yes	2.97	1.21, 7.31	**0.017**
Septic system removal access			
Yes	—		—
No	0.31	1.98, 5.56	**0.0001**
Sewage water access			
No	—	—	—
Yes	6.94	2.85, 17.8	**0.0001**
Education level			
School without Bac	—	—	—
Baccalaureate	1.15	0.55, 2.33	0.7
Bachelor	0.95	0.45, 1.98	0.9
Lower than primary school	1.95	1.10, 3.45	**0.022**
Mahadras	1.48	0.79, 2.75	0.2
Master or Doctoral degree	0.41	0.15, 1.01	0.063
Number of rooms	1.18	1.03, 1.35	0.016
Type of house			
Individual house (attached)	—	—	—
Apartment	1.18	0.37, 3.62	0.8
Hangar	18.5	1.68, 494	**0.030**
Individual house (detached)	0.66	0.39, 1.12	0.13
Shack	0.14	0.02, 0.61	**0.021**

Bold values mean that this modality has a significant effect.

3.2. Integrated analysis of influential factors on waste management in Nouakchott

After evaluating our model's predictive performance through coefficient analysis and metric calculations, we identified significant factors influencing access to waste management services in Nouakchott. To deepen our understanding, we are now exploring the interactions between these factors to assess their combined impact on waste management access. This investigation includes analyses of how electricity access intersects with housing type, education levels, and municipal variables, offering nuanced insights

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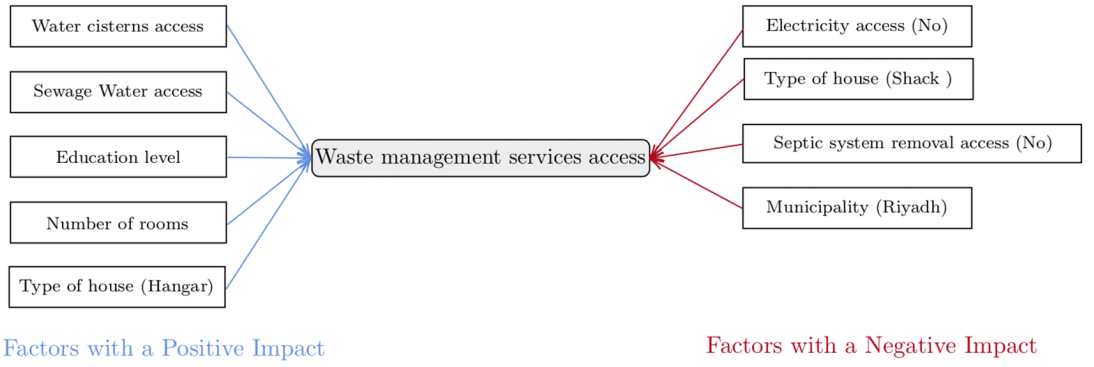

Figure 4. *Impact of factors on Waste Management Access Services in Nouakchott.*

into the multifaceted nature of waste management challenges in urban settings. Below, we present the specific interaction models we are examining:

1. Interactions of Electricity Access and Housing Type:

$$\begin{aligned}\log\left(\frac{p}{1-p}\right) &= \beta_0 + \beta_1 \times \text{Electricity access} \times \text{Type of House} \\ &+ \beta_2 \times \text{Septic System Removal Access} + \beta_3 \times \text{Number of Rooms} \\ &+ \beta_4 \times \text{Sewage Water Access} + \beta_5 \times \text{Water Cistern Access} \\ &+ \beta_6 \times \text{Education level} + \beta_7 \times \text{Municipality}\end{aligned}$$

2. Interactions of Electricity Access and Education Level:

$$\begin{aligned}\log\left(\frac{p}{1-p}\right) &= \beta_0 + \beta_1 \times \text{Electricity access} \times \text{Education level} \\ &+ \beta_2 \times \text{Septic System Removal Access} + \beta_3 \times \text{Number of Rooms} \\ &+ \beta_4 \times \text{Sewage Water Access} + \beta_5 \times \text{Water Cistern Access} \\ &+ \beta_6 \times \text{Type of House} + \beta_7 \times \text{Municipality}\end{aligned}$$

3. Interactions of Housing Type and Municipality:

$$\begin{aligned}\log\left(\frac{p}{1-p}\right) &= \beta_0 + \beta_1 \times \text{Municipality} \times \text{Type of House} \\ &+ \beta_2 \times \text{Septic System Removal Access} + \beta_3 \times \text{Number of Rooms} \\ &+ \beta_4 \times \text{Sewage Water Access} + \beta_5 \times \text{Water Cistern Access} \\ &+ \beta_6 \times \text{Electricity access} + \beta_7 \times \text{Education level}\end{aligned}$$

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4. Interactions of Municipality and Electricity Access:

$$\begin{aligned}\log\left(\frac{p}{1-p}\right) = {} & \beta_0 + \beta_1 \times \text{Municipality} \times \text{Electricity access} \\ & + \beta_2 \times \text{Septic System Removal Access} + \beta_3 \times \text{Number of Rooms} \\ & + \beta_4 \times \text{Sewage Water Access} + \beta_5 \times \text{Water Cistern Access} \\ & + \beta_6 \times \text{Type of House} + \beta_7 \times \text{Education level}\end{aligned}$$

5. Interactions of Housing Type and Sewage Water Access:

$$\begin{aligned}\log\left(\frac{p}{1-p}\right) = {} & \beta_0 + \beta_1 \times \text{Type of House} \times \text{Electricity access} \\ & + \beta_2 \times \text{Septic System Removal Access} + \beta_3 \times \text{Number of Rooms} \\ & + \beta_4 \times \text{Electricity access} + \beta_5 \times \text{Water Cistern Access} \\ & + \beta_6 \times \text{Municipality} + \beta_7 \times \text{Education level}\end{aligned}$$

where $p = \mathbb{P}[\mathbf{Y} = \text{'Yes'}]$ represents the likelihood that a given household head has access to waste management services.

Below are the detailed analyses of the interaction models in our study, shedding light on the interplay of various factors in waste management service access in Nouakchott.

The interaction between access to electricity and housing type reveals crucial information. Our model indicates that the absence of electricity combined with different housing types does not uniformly affect access to waste management services. For instance, in detached individual houses, the lack of electricity does not significantly impact waste management, suggesting that other factors play a more dominant role in these contexts. This finding is essential for urban planning, as it underlines that waste management policies should not only focus on improving electrical infrastructure but also take into account the diverse nature of residential habitats.

Moreover, the complex interplay between electrical infrastructure and housing type shows that certain neighborhoods, particularly those with precarious housing, may be more vulnerable to shortcomings in electricity access, directly affecting their waste management capabilities. This indicates that strategies to enhance access to waste management services should incorporate a deep understanding of the specific residential characteristics of each neighborhood. A more targeted and differentiated approach will better address the waste management needs of various resident groups, promoting a more equitable and sustainable waste management throughout the city.

Furthermore, the interaction between electricity access and education level in our model reveals nuanced aspects of waste management service access in Nouakchott. The combination of lack of electricity and various education levels generally does not have a significant effect, suggesting that electricity access, irrespective of education level, does not critically alter access to waste management services. However, the positive and significant association between lower education levels and access to waste management services, regardless of electricity, underscores the importance of education in raising awareness about waste management.

On the other hand, the interaction between housing type and municipality in our study highlights significant variations in access to waste management services based on the specific combination of these two factors. For example, living in a hangar in certain municipalities shows a positive influence on access to waste management services, which may reflect local infrastructure and service specifics. Conversely, some interaction terms, such as apartments in certain municipalities, do not show a significant effect, suggesting that other factors might be more determinant for access to waste management services in these cases.

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In addition, the interaction between electricity access and different municipalities in Nouakchott underscores the complexity of factors influencing waste management. While electricity access itself appears to have a positive impact, specific interactions with certain municipalities do not show statistical significance, indicating that electricity availability does not uniformly modify access to waste management services across all areas. This suggests that the characteristics and needs of each municipality should be considered distinctly in planning waste management services. For instance, in municipalities like "Riyadh," where the interaction is significant, improving electrical infrastructure could play a key role in enhancing access to waste management services.

Finally, the interaction between housing type and sewage water access in Nouakchott shows mixed results. For certain housing types, like detached individual houses, the lack of sewage water access significantly impacts access to waste management services, indicating that these dwellings are particularly vulnerable to shortcomings in sanitation infrastructure. However, for other types of housing, this interaction is not significant, suggesting that the impact of sewage water access can vary considerably depending on the housing type. These results highlight the importance of urban planning, which accounts for specific sanitation infrastructure needs for different types of housing, to enhance the overall efficiency of waste management in the city.

3.3. Waste management: Nouakchott in global comparison

In assessing the management of household waste in Nouakchott, Mauritania, a comparative analysis with studies from Ethiopia (Abebaw, 2008), Guinea (Mamady, 2016), Nepal (Behera and Narayan, 2020), Nigeria (Chukwuone et al., 2022), Palestine (Al-Khateeb et al., 2017), Zimbabwe (Chikowore, 2021), Algeria (Naghel et al., 2022), and Ghana (Adzawla et al., 2019) offers enlightening parallels and distinctions. Similar to patterns observed in Ethiopia (Abebaw, 2008) and other regions, socioeconomic factors such as household income and education levels are pivotal in shaping waste disposal methods in Nouakchott. However, unlike the gender-based approaches noted in Guinea (Mamady, 2016) and Ghana (Adzawla et al., 2019), our study did not find significant gender-based differences in waste management practices in Nouakchott, possibly reflecting unique cultural or societal dynamics. Echoing challenges faced by rapidly urbanizing cities in Zimbabwe (Chikowore, 2021) and Nigeria (Chukwuone et al., 2022), Nouakchott's urban expansion outstrips the development of adequate waste services. This is a common plight in many developing urban areas where infrastructure struggles to keep pace with growth. Our findings resonate with those from Ethiopia (Abebaw, 2008) and Palestine (Al-Khateeb et al., 2017) on the need for heightened public awareness and environmental education, given the common lack of awareness about the adverse effects of improper waste disposal. Insights from Nepal's study (Behera and Narayan, 2020) highlight how access to basic infrastructure like electricity and water cisterns profoundly influences waste management services, underscoring the importance of integrated urban development. The study's observation of an association between housing types and waste service accessibility in Nouakchott is akin to findings in Ghana (Adzawla et al., 2019), where socioeconomic factors play a significant role in service provision. This comparative analysis underscores that the challenges in waste management observed in Nouakchott are part of a larger narrative experienced by many developing urban areas, emphasizing the need for strategies that are tailored to local specifics but informed by global practices. The similarities and differences in socioeconomic, cultural, and infrastructural factors across these regions emphasize the importance of contextualizing Nouakchott's waste management strategies within a broader global context, thereby enhancing the generalizability and relevance of this study.

3.4. Discussion

Access to waste management services is a vital element of urban life, impacting public health and environmental sustainability in SSA countries (Getahun et al., 2012; Mamady, 2016; Adzawla et al., 2019; Chikowore, 2021; Chukwuone et al., 2022; Naghel et al., 2022). The crucial challenge lies in deciphering the social, economic, and geographic household factors that influence the provision of these

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services. The urgency of this challenge is exemplified in Nouakchott, where merely 24.4% of households enjoy access to such services. Compounding this issue is a significant gap in research focused on evaluating the household determinants that contribute to waste management service access. Our logistic regression model's findings provide insightful revelations about the socioeconomic and geographic determinants that shape access to waste management services. Each examined variable illuminates various aspects of service access, offering a robust foundation for crafting targeted policy interventions.

Access to electricity plays a critical role in the efficient provision of waste management services in Nouakchott. Our analysis reveals a significantly negative impact of its absence on the availability of these services. Despite a 94.1% rate of household electrification indicating widespread coverage, the remaining 5.9% of households face inadequate waste services, exacerbated by frequent power outages affecting even the city's central districts (Ebnou Abdem et al., 2023a). This shortfall in electricity directly impacts waste management, as a stable power supply is essential for the operation of waste collection and processing equipment, as well as for effective communication and coordination between waste management services and residents. Moreover, the disparity in access to electricity underscores broader issues of municipal neglect and social inequality, differentially affecting access to public utilities across various geographical areas of the city (Ebnou Abdem et al., 2023a). Specifically, residents of Western Nouakchott are more likely (OR = 1.89) to have access to electricity compared to those in the Northern and Southern regions, highlighting the need for equitable infrastructure development policies (Ebnou Abdem et al., 2023a). These findings resonate with the research presented by Guerrero et al. (2013), McAllister (2015), Cudjoe and Acquah (2021), Parrot et al. (2023), which illustrates the pivotal role of a consistent electricity supply for operating waste collection vehicles, running treatment facilities, and maintaining recycling centers within urban frameworks.

Furthermore, the negative association of Riyadh municipality with access to waste management services is a revealing indicator of broader infrastructural and governance issues. This municipality's experience of inadequate waste management infrastructure, characterized by the presence of slums, informal urbanization, and a lack of essential amenities for waste disposal, such as dedicated bins, is not unique. Limited budget allocations for waste management, problems with administrative efficacy, and demographic growth that exceeds service provision capacity all contribute to the situation (Aloueimine, 2006; Japan International Cooperation Agency (JICA), 2018). The trend of non-participation by residents in waste management programs only exacerbates the challenges faced by "Riyadh" (Aloueimine, 2006; Japan International Cooperation Agency (JICA), 2018). The areas within "Riyadh" that are left vacant often become unofficial sites for waste disposal, causing environmental and health concerns. This complex set of challenges aligns with the findings of researchers in studies conducted in Zimbabwe and Ghana (Adzawla et al., 2019; Chikowore, 2021). Addressing these issues by adopting a multisectoral approach is critical. It requires integrating local insights with proven strategies from other contexts to formulate a responsive waste management framework for "Riyadh." The provision of equitable waste services necessitates a municipal strategy that does not stop at administrative borders but rather encompasses the heterogeneous nature of urban development. By involving residents in the development and implementation of waste management strategies and aligning city planning with the dynamic demographic and spatial profile of "Riyadh," Nouakchott can begin to bridge the infrastructure divide. The goal is to foster an inclusive urban development plan that aligns the upgrade of waste management facilities with the city's electrification efforts, setting a course for a more inclusive and sustainable urban future.

In addition, the presence of water cisterns in Nouakchott is a contributing factor to better access to waste management services. In the arid environment of the city, where water resources are scarce, cisterns signify more than just water security; they may also indicate the existence of a well-maintained broader infrastructure network. This connection suggests that areas equipped with water cisterns are likely to benefit from advanced urban planning, which typically includes more efficient waste management systems (Guerrero et al., 2013). This positive relationship has been noted in various studies conducted in developing countries, albeit with different degrees of impact (Guerrero et al., 2013). Moreover, the confluence of water storage and waste management infrastructure might denote a higher caliber of

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municipal services, potentially enabling the use of shared logistical and vehicular resources for multiple utility purposes. For example, equipment and vehicles for water distribution could be repurposed for waste collection, serving as a testament to the practicality of integrated service provision. This synergy offers a valuable lesson in urban development: investments made in one area of utility service can have ancillary advantages for other areas, thus improving the general standards of urban living. It underscores the potential for cross-functional benefits, which can bolster the city's development and the welfare of its inhabitants.

On the other hand, access to sewer services and septic system services is profoundly indicative of the state of sanitation in Nouakchott. The stark contrast in waste management service access between households with and without these facilities points to inequality with significant potential health implications. The high OR for households with sewer service access confirms that where the sewer network is extended, waste management services are likely more comprehensive. Conversely, the lack of access to septic system services and its negative impact on waste service access reflects a gap in sanitation infrastructure that could exacerbate public health risks, highlighting an urgent need for intervention in areas lacking these basic services (Guerrero et al., 2013).

The influence of education on access to waste management services is nuanced. The result indicates that those with education levels lower than primary school are more likely to have access to waste management services, which may reflect targeted efforts to improve services in lower-income or less-educated neighborhoods. This suggests that education campaigns and service provision efforts need to be sensitive to the varying levels of education within the population to ensure that messages and services are appropriately tailored and delivered. This result indicates that the challenges faced in Nouakchott differ from those faced in Ethiopia (Getahun et al., 2012), Guinea (Mamady, 2016), and Lagos (Chukwuone et al., 2022), where studies have shown that households with higher levels of education are more likely to have access to waste management services. However, this finding aligns with the findings of Chikowore (2021) in Zimbabwe.

Housing type and size significantly influence waste management service access. Households with a greater number of rooms often have better service access, suggesting a possible preference for servicing larger or wealthier families. This pattern aligns with the findings of Chukwuone et al. (2022) in Lagos.

This study exposes concerning socioeconomic disparities in access to waste management services across Nouakchott's residential landscape. The stark difference in service availability between households in hangars (often signifying larger, more permanent dwellings) and those in shacks (typically associated with lower socioeconomic status) underscores a worrisome trend. This aligns with global observations on inadequate waste collection in informal settlements due to limited infrastructure and logistical challenges (Mukhtar et al., 2018; Fernando and Zutshi, 2023).

Furthermore, the negative association between a lack of electricity and waste service access exposes another layer of disparity. Households without electricity, which are more likely to be found in impoverished areas, face the double burden of limited waste collection due to reliance on electricity for waste management equipment and a lack of proper lighting and appliances. This resonates with research by Zohoori and Ghani (2017), Morais et al. (2022) who found a correlation between low-income neighborhoods and inadequate waste collection services.

The specific challenges faced by Riyadh municipality further illustrate the plight of marginalized communities. Its struggles with rapid urbanization, coupled with underdeveloped infrastructure and administrative hurdles, exacerbate the existing socioeconomic divide. This aligns with research by Mbwilo and Mahenge (2022) in Tanzania, who documented how unplanned settlements on the outskirts of cities often lack basic services like waste management due to inadequate infrastructure and resource allocation.

These disparities have significant implications for public health and environmental sustainability in Nouakchott's marginalized communities. Inadequate waste collection fosters unsanitary living conditions, attracts disease-carrying vectors, and increases the risk of respiratory illnesses. It can also lead to environmental pollution through overflowing landfills and improper waste disposal practices (Yeo et al., 2020; Debrah et al., 2021a, 2021b; Debrah et al., 2022).

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4. Conclusions

4.1. Summary of key findings and recommendations

This study has underscored several significant factors influencing access to waste management services in Nouakchott. The association between water infrastructure, such as the presence of cisterns, and access to waste services highlights the integration of urban infrastructure. The type and size of housing influence access to these services, with households in hangars enjoying better access to these services while those in shacks experience inadequate provision, suggesting a socioeconomic bias in these services' access. Furthermore, the analysis reveals that a lack of access to electricity significantly hinders service access, as shown by the adverse effects of power outages on access to waste services. Even with a high rate of electrification, households without electricity are at a disadvantage, which signals a need for infrastructure that can keep pace with Nouakchott's growing demands. "Riyadh" municipality, in particular, contends with a multitude of challenges, such as rapid demographic changes, underdeveloped infrastructure, and administrative inefficiencies, all of which undermine the provision of waste management services.

Addressing these issues requires a holistic and integrated set of strategies.

1. Integrated Municipal Infrastructure Development: First, developing an integrated municipal infrastructure that links water cisterns with waste service expansion is vital. This approach will extend waste management services equitably to all residential areas, including those currently underserved, directly addressing the crucial role of water infrastructure in waste management access discovered in our research.
2. Incorporation of Informal Recycling into Formal Waste Management: Additionally, incorporating informal recycling into formal waste management processes will bridge existing service gaps, support low-income communities, and enhance environmental sustainability. This strategy aims to rectify the socioeconomic disparities in service access that our study identified. This approach of integrating informal recycling into formal waste management systems has been successfully applied in Pune, India, where the collaboration with the SWaCH (Estrada et al., 2023) cooperative has led to tangible improvements in waste management efficiency, offering a model for addressing socioeconomic disparities in service access (Estrada et al., 2023).
3. Improvement of Electricity Access: Improving electricity access is another critical area. Enhancing the waste management infrastructure, along with electricity access, is essential for preventing service interruptions and catering to Nouakchott's growing needs, as highlighted by our analysis of electricity's significant impact on waste management services.
4. Education and Awareness Campaigns: Education and awareness campaigns are equally important. Launching comprehensive campaigns on waste management across all community segments that are culturally relevant and promote active participation will reflect our findings on the diverse residential patterns and their influence on waste services (Debrah et al., 2021b). Kampala, the national and economic capital of Uganda, has successfully implemented education and awareness campaigns on waste management. These campaigns have been particularly effective in promoting active community participation and addressing diverse residential patterns, thereby positively influencing waste management services in the city (Fredrick et al., 2018).
5. Participatory Urban Planning: Embracing a participatory approach to urban planning, especially in diverse neighborhoods like Riyadh, is recommended. This approach involves residents in the planning process (crowdsourcing; Diop et al., 2022), yielding valuable insights for tailor-made solutions.
6. Cost–Benefit Analysis: Furthermore, a detailed cost–benefit analysis to evaluate the economic impact of the proposed waste management improvements in Nouakchott is imperative. This analysis will balance the initial and ongoing costs of new infrastructure against economic benefits such as job creation, improved public health outcomes, property value enhancement, and environmental quality preservation (Naghel et al., 2022). Such an economic evaluation is essential for justifying investments and crafting policies that reflect the true value of a clean, safe, and well-managed urban environment (Debrah et al., 2021b).

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7. Learning from Other Cities: The successful implementation of waste management strategies in Nouakchott can draw valuable lessons from other cities that have faced similar challenges. For instance, the integration of formal and informal sectors in solid waste management in countries like India has demonstrated increased efficiency and inclusivity in service provision (Sengupta et al., 2022). This integration showcases a partnership between the municipality and informal recyclers, leading to improved waste collection and recycling rates (Sengupta et al., 2022). Similarly, initiatives in Bogotá have combined community engagement with technological innovation to optimize waste collection routes and reduce operational costs (Neville and Cortés, 2023). However, not all interventions yield positive outcomes; for example, Accra's efforts to decentralize waste management encountered setbacks due to insufficient infrastructure and public engagement, resulting in uneven service distribution (Kyere et al., 2019). These experiences emphasize the necessity for a tailored approach that considers local conditions while benefiting from established practices elsewhere. By analyzing both successful and challenging cases, Nouakchott can anticipate potential obstacles and adapt strategies to align with its unique urban landscape and governance structure.

As we reflect on the significant factors influencing access to waste management services identified in this study, it becomes clear that addressing these challenges requires not only immediate interventions but also a forward-looking approach to research. The insights garnered from Nouakchott provide a foundational understanding, yet they also open the door to broader inquiries that could further illuminate the complexities of waste management in urban settings. Therefore, the progression from our current findings to new research opportunities represents a logical and crucial evolution to deepen our understanding of the challenges associated with urban waste management, thereby ensuring the adaptation and effectiveness of solutions in an urban context that continues to change.

The proposed recommendations for enhancing waste management in Nouakchott prioritize scalability and sustainability. To achieve this, integrating waste collection infrastructure with water cistern installations during city expansions ensures a standardized approach from the outset. Additionally, incorporating informal waste pickers progressively into formal collection routes allows for adaptability and expansion while fostering sustainability.

Moreover, focusing on renewable energy sources like solar power for waste collection vehicles and processing facilities ensures scalability and reduces dependence on the central grid. Culturally adaptable education campaigns and participatory urban planning further enhance scalability, empowering local communities to participate effectively in future initiatives while promoting long-term sustainability.

4.2. Study limitations and prospects for future studies

The study's scope and data present certain limitations, providing avenues for future research. Focusing solely on household-level data from Nouakchott may not fully capture the spectrum of waste management challenges and opportunities in Mauritania. Therefore, extending research to a national scale can yield insights into regional variances and enable a comprehensive strategy for the country.

Another limitation is the temporal aspect of the dataset, with the data being 6 years old. Efforts are underway to update this dataset to ensure its relevance and accuracy. Subsequent analysis will involve examining these updated data alongside the findings of this study, particularly focusing on how any changes over this period may have influenced waste management practices in Nouakchott. Utilizing advanced time series models such as nonlinear autoregressive network (Younes et al., 2015) will facilitate a comprehensive assessment of waste management trends over the entire duration, considering the evolution of demographics and contextual factors. This sophisticated model offers a coherent framework for analyzing complex interactions and capturing temporal patterns in waste management practices,

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aligning well with the dynamic nature of waste management systems and demographic changes (Younes et al., 2015).

Furthermore, the use of the logistic regression model in our study, chosen for its efficiency in modeling the probabilities of access to waste management services based on multiple independent predictors, offers advantages in terms of simplicity of interpretation, robustness, and prediction accuracy. However, it also has notable limitations; specifically, it does not capture the more subtle indirect effects of these factors. Logistic regression overlooks the intricate web of influences, such as how public awareness initiatives might indirectly affect access to waste management services through changes in community behavior, or how socioeconomic changes influence waste management practices. This highlights the challenges in capturing complex interactions and underlying effects between variables, raising significant questions about the results' generalizability.

In response to this limitation, our future work will consider the use of more sophisticated models. Structural equation modeling (SEM) (Ebnou Abdem et al., 2023b, 2023c) will be employed to analyze complex relationships between observed variables like household income, education level, direct access to waste management services, and latent variables such as environmental awareness and socioeconomic status. The latent class model (Long et al., 2023) will facilitate the exploration of heterogeneous population subgroups, identifying distinct categories of households based on patterns of waste management service utilization and attitudes toward recycling and sustainability.

In addition, a current work integrating the path analysis model (Seyid et al., 2023) with logistic regression enhances our ability to examine how factors such as socioeconomic status, environmental policies, and community engagement initiatives interact to influence waste management service accessibility. This comprehensive approach allows for a deeper understanding of the causal relationships and indirect effects that shape waste management outcomes.

Moreover, the study did not fully incorporate the impact of external factors such as governmental policies, socioeconomic changes, and public awareness initiatives (Marshall and Farahbakhsh, 2013; McAllister, 2015; Mukhtar et al., 2018). This was primarily due to the lack of comprehensive data on these aspects in our current dataset. However, acknowledging the significance of these elements is crucial for a holistic understanding of waste management dynamics in Nouakchott (Marshall and Farahbakhsh, 2013; McAllister, 2015; Mukhtar et al., 2018). Ongoing research employing confirmatory factor analysis and SEM (Ebnou Abdem et al., 2023b, 2023c) aims to uncover both visible and invisible factors and clarify the relationships between them. These factors are effectively categorized by applying the PESTLE (Political, Environmental, Social, Technological, Legal, and Economic) framework (Mukhtar et al., 2018), enhancing our understanding of waste management challenges and solutions in developing urban contexts like Nouakchott, as well as in other African cities.

Finally, a longitudinal study is being conceptualized to monitor the progress of waste management services following the implementation of the recommended strategic interventions. This study will focus on tracking service accessibility changes over time, the effectiveness of policy changes, and the sustainability of infrastructure improvements in both urban and rural settings within Mauritania.

Data availability statement. The data presented in this study are available on request from the corresponding author.

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Author contribution. Conceptualization: S.A.E.A., R.A., E.B.D.; Data curation: S.A.E.A.; Data visualization: R.A., M.A.; Formal analysis: S.A.E.A., E.B.D.; Investigation: J.C.; Methodology: S.A.E.A., R.A., E.B.D., M.A.; Project administration: J. C.; Resources: J.C.; Supervision: J.C.; Validation: S.A.E.A., M.A., J.C.; Writing original draft: S.A.E.A.; Writing—review and editing: S.A.E.A., R.A., E.B.D., M.A. All authors approved the final submitted draft.

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A. Appendix

Tables A1 and A2 provide a detailed summary of the survey data collected, including variables such as income groups, access to waste management services, and household characteristics (Ebnou Abdem et al., 2023a).

Table A1. *Statistical summary of variables*

Variable	Modalities	Frequency (%)
Income group	Low	28.7
	Medium	28.1
	High	43.2
Waste management access	No	75.6
	Yes	24.4
Water cisterns access	No	95
	Yes	5
Septic system removal access	No	17.8
	Yes	82.2
Sewage water access	No	94.5
	Yes	5.5
Gender	Man	63.0
	Woman	37.0
Educational level	Lower than primary school	21.3
	Primary school	16.3
	Mahadras	15.1
	Baccalaureate	9.8
	Master/Doctoral degree	8.4
	High school	8.0
Employment status	Full–time work	49.4
	Unemployed	12.9
	Part–time work	37.7

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Table A2. *Statistical summary of variables*

Variable	Modalities	Frequency (%)
Type of house	Individual house (attached)	45.7%
	Individual house (detached)	28.1%
	Individual house with boutique	9.2%
	Collective housing	7.3%
	Shack	5.5%
	Apartment	3.4%
Municipality	Arafat	20.9%
	Dar Naim	15.8%
	Toujounine	14.9%
	El Mina	13.3%
	Riyadh	13.2%
	Sebkha	5.9%
	Tevragh Zeina	5.9%
	Teyarett	4.7%
	Toujounine	14.9%
Property ownership	Privately–owned rental unit	32.3%
	Government–owned rental unit	2.2%
	Self–owned	62.5%
Age	[22,50[	62.7%
	[50, 65[	30.1%
	[65,90[	7.2%
Number of rooms	*	[Q1 = 2, Q3 = 4]
Expenditures by household heads	Food	62.1%
	Education	0.1 %
	Electricity	0.4%
	Residence (rent)	35.1%
	Telephone	0.1%
	Transportation	1.2%
	Water supply	0.9%
Internet access	Yes	14.9%
	No	85.1%

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