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Characterization and Planning of Household Waste Management: A Case Study from the MENA Region

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Abstract: Solid waste management is one of the most important environmental issues worldwide, particularly in MENA countries. The present study was carried out in the city of Algiers, the capital city of Algeria. This urban area is marked by an increase in waste flow combined with a demographic surge. In order to investigate waste production and its drivers, we used both multiple regression and correlation analyses to test this dependence. Geospatial analysis was performed using principal component analysis integrated with GIS in order to look at the spatial distribution of waste management and potential drivers of waste production. The results indicate that household waste management is influenced by drivers related to the size of the settlement and the characteristics of waste management companies ($p \leq 0.05$). The findings also show that none of the sociodemographic variables were found to significantly influence waste production. However, the spatial distribution is influenced by the geographic and sociodemographic characteristics of Algeria at all territorial levels. Algiers is still a landfill-based city in the MENA region, where mixed waste collection prevails in all districts. This study reinforces the importance of expanding source-separated waste collection schemes in order to increase the household waste diversion from landfills and, more importantly, shows how modern tools such as GIS, principal component analysis, and spatial analysis urban planning are useful for monitoring household waste, in line with circular economy principles.

Keywords: household waste; waste management; spatial analysis; urban planning; Algiers

1. Introduction

The world is experiencing an environmental crisis, marked by excessive production of waste, in particular household waste fed by consumerism and the effects of urbanization [1–3]. The most optimistic prediction says that 70% of humans will live in cities by the year 2050 [4]. However, 0.9 billion people lack access to regular waste collection services in urban areas worldwide, particularly in low- and middle-income countries [5]. The expansion of sanitation and waste management infrastructures in urban areas is crucial to achieving sustainable development goals by 2030. Furthermore, the model of a smart city (SC) goes beyond an urban space where information and communication technologies (ICT) are applied [6]. In fact, the aim of a smart city is to improve the performance and the quality of urban services (energy, transportation, and other infrastructures), intending to reduce costs, resource energy consumption, and wastage. Smart city environments evolve to improve the quality of life of citizens and the operational efficiency of complex urban systems [7].

Solid waste management (SWM) is one of the major challenges faced by smart cities (and cities, in general), especially due to population growth and urbanization [8]. The world's annual waste generation is actually 2.01 billion tons and 0.74 kg/person per day (33% of that is not managed in an environmentally safe manner) and is expected to increase to 3.40 billion tons in 2050 [9]. High-income countries generate about 34% of the world's waste, while the total quantity generated in low-income countries is expected to increase more than three times by 2050. The Middle East and North Africa region produces 6% of the world's waste. In addition, given the fastest growth of cities in the MENA regions, it is expected that by 2050, total waste generation is expected to increase twice (or thrice) [10]. Consequently, there is an urgent need for more efficient solid waste management in cities. SWM is also a major concern for national (and municipal) governments in order to preserve natural resources and the environment and protect human health. The emerging smart technologies already used in waste management, such as robot recyclers, internet of things (IoT), self-driving trucks, and waste level sensors, can further optimize the collection and treatment operations in the largest cities around the globe [11].

Generally, waste characterization and generation are among the most important factors to consider when selecting the most appropriate collection and treatment methods and also the final disposal [12]. This is especially the case in countries in the process of urbanization experiencing increasing population and lifestyle changes under the impact of massive migration from rural to urban zones, which leads to a considerable increase in urban waste generation.

Solid waste and household waste prediction can be conducted at different temporal (e.g., week, month, or year) or geographic (e.g., municipal, regional, national) levels. Country-level studies use previously collected data on the total annual waste amount, waste types, or socioeconomic data, which they often make available to international associations [13]. The applicability of such projections is highly dependent on model assumptions and the quality of data acquired [14]. Solid waste clustering enables discovering differences and similarities among analyzed regions or countries with respect to waste management. Moreover, they also allow for determining the relationships between clusters and demographic, socioeconomic, and waste generation characteristics. However, these inherent structures are difficult to observe in the original datasets because of the multidimensional nature of data [15].

Countries of MENA regions are still reliant on landfills as the main disposal route for household waste, but efforts are made to estimate source-separation collection schemes and recycling practices [16].

Algeria is the largest nation in Africa and the Arab world by area [17]. Its population of 44 million has a heterogeneous density (high population in the north and low in the arid regions), resulting in a high difference in waste generation between urbanized cities and the other regions. The waste management sector in Algeria is insufficiently regulated [18]. Daily and annual waste production can be estimated from the average rate of waste produced per person per day. In fact, an Algerian produces an average of 0.81 kg of household waste per day. This production continues to increase, exceeding 8.5 million tons in 2021 [16]. Algeria is marked by a significant increase in waste flows combined with a demographic surge and a saturation of urban waste management infrastructures [19]. In this context, several uncontrolled dumps have appeared on the Algerian territory, generating direct negative impacts on the environment through the creation of pollution, posing major risks to human health [20]. Hence, the Algerian government is constantly looking to adopt technological solutions in an attempt to treat household waste. These different solutions must protect people and communities, minimize negative impacts on the environment, and allow for efficient and less expensive treatment of waste [21,22].

Studies investigating urbanization, sustainable development, and, more specifically, waste management in North Africa (especially in Algeria, and even more precisely in Algiers) are scarce, incomplete, or even lacking [23,24]. The few existing studies are old and provide very few insights [25,26]. In the current context, studies addressing these themes could be of considerable importance [27].

Although several tools have been implemented for the planning and development of Algiers, the capital city of Algeria, none have been successful. This clearly reflects the failure of urban planning in the capital, which highlights the different management problems encountered by the city [28].

The aim of this study is to investigate and identify the elements and generating factors of the excessive production of household waste at the wilaya of Algiers, through a statistical and geospatial approach, as well as the management practices and their approaches to adopt a better strategy for the optimization of waste management. We hypothesize, according to our knowledge of the study area, that the increase in household waste is linked not only to population growth, but also to other factors such as education, standard of living, urban structure, recycling infrastructure, collection system, and economic and social development. This study will attempt to verify the aforementioned hypothesis, filling in a gap in the existing literature concerning the management of household waste in the study area.

2. Materials and Methods

2.1. Case Study Area

The present study was carried out in the city of Algiers, which is the political, administrative, and economic capital of the country. It is the seat of all central, political, and social institutions, major economic and financial establishments, major decision-making centers, and diplomatic representations.

The "wilaya" (administrative division) of Algiers is located in the north at the following coordinates: 36°46′34″ N, 3°03′36″ E. It occupies a geostrategic position. It spans more than 808.89 km^2 and is limited by the Mediterranean Sea to the north, the wilayas of Blida in the south, Tipaza in the west, and Boumerdès in the east.

According to the 2008 RGPH, the population of Algiers is about 2,987,160 inhabitants. In 2021, the population was estimated at 3.4 million inhabitants [29]. The population density amounts to ~4450 inhabitants/km^2. The wilaya of Algiers is made up of thirteen daïras (administrative districts), each comprising several "communes" (municipalities), for a total of fifty-seven communes.

The study area consists of the 57 communes composing the wilaya of Algier (see Figure 1).

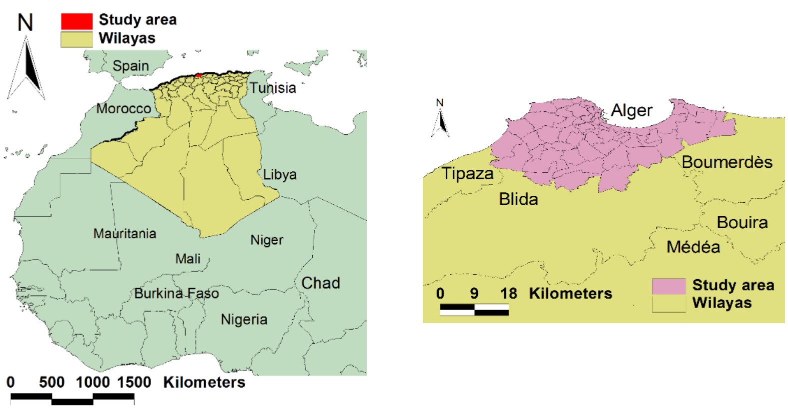

Figure 1. Location of the case study. The images present the location in an international context (**left**) and in detail (**right**).

2.2. Data

The data used in this research come from many sources, including the two companies responsible for waste management in Algiers. Data were collected from the technical department of their general management. The two companies are EPIC EXTRANET, situated in Bab Ezzouar-Algiers, and responsible for 31 communes, and EPIC NETCOM, situated in Mohamed Nail-Algiers, and responsible for 26 communes.

Figure 2 displays the companies responsible for waste management in each commune within the area analyzed in the study.

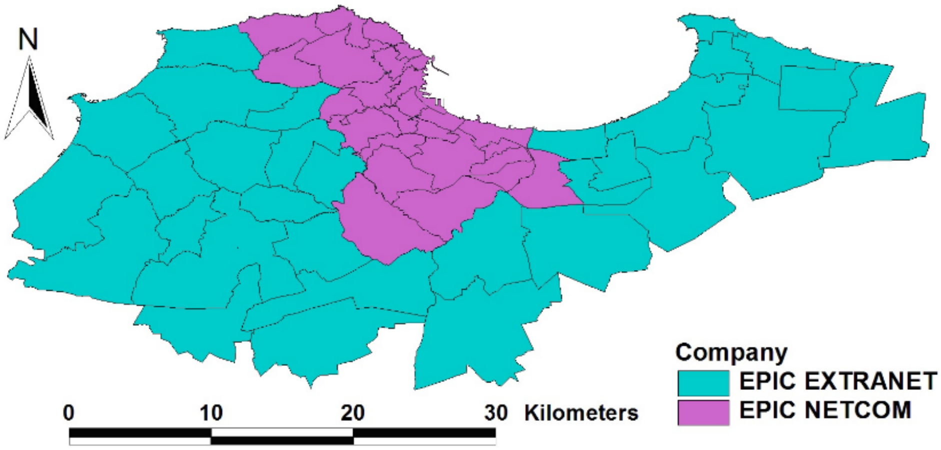

Figure 2. Spatial distribution of companies responsible for waste management across the study area.

Other data were acquired from the National Office of Statistics (ONS) situated in Ruisseau, Algiers, and the National Waste Agency (AND) situated in Hamma, Algiers.

2.3. Variables

Some of the variables used in this work are similar to those used in studies addressing municipal waste management issues in other countries [30–32]. However, some variables, such as the role of the environmental awareness group (EAG), availability of facilities and infrastructure (FI), and budget availability (BA), used in other studies, were excluded either because they were only present in one company, or were obsolete. Consequently, the selected variables were:

- Area (A): total area of the municipality.
- Population (P): total number of inhabitants in the municipality.
- Share of people with at least a college degree (C): number of individuals with medium or higher education.
- Share of active population (AP): part of the population engaged in work or studies.
- Number of garbage bins (G): Total number of garbage bins owned by the concerned company.
- Collection routes (R): predefined waste collection points.
- Number of staff in waste management companies (S): human resources available at the company.
- Company managing waste collection (CO): Extranet or Netcom.

Data provided by waste operators and the aforementioned variables were further processed using spatial analysis and GIS techniques. The scale of analysis, i.e., district level, reveals the local variations in household waste generation within urban administrative borders. The microlevel spatial analysis of such variables has benefits for decision makers, such as adapting urban waste management policies and infrastructure demands. Big data and machine learning could further predict waste generation flow at the microlevel, including building-level data [33]. Reliable historical waste-related data lead to better future predictions of household waste at the district or urban levels, improving the planning of waste management infrastructure by adopting feasible circular economy targets [34,35]. On the other hand, the pro-environmental behavior of residents could be used as an additional variable to examine waste generation patterns at the city level [36].

2.4. Quantitative Analyses

The quantitative analyses were based on statistical approaches used to look at the variables influencing the production of waste, especially the total amount of waste. Geostatistical analyses were also used in order to look at the spatial distribution of the production of waste and its potential drivers. For this purpose, multiple regression analyses were used to look at the possible drivers influencing the total amount of waste, using two models: a full model, looking at the simultaneous influence of all drivers, and a restricted model, obtained from the previous one using backward elimination, containing all drivers with a simultaneous statistically significant influence on the total amount of waste.

The variables included in these models were derived from the data obtained from the statistical office or based on the row data. The new variables were the average production of waste and the number of collection routes, obtained by averaging in each case the values for the eight months included in the row data. Education level was synthesized in only one index that presents the share of those with at least a college degree among all people. Another driver, the employment structure, was presented by the activity rate in the studied area.

The geospatial methods were based on a modified version, "principal component analysis integrated with GIS", a method developed for the identification of "hotspots" that are at the core of intervention policies [37]. This method has been also used in other studies due to its ability to compare the empirical dimension of the factors with the three dimensions [38]. Essentially, the method consists of (1) running a principal component analysis to identify the key variables that can be used to underline the spatial differentiation between different administrative units through differences between their values across the analyzed space, (2) creating an index using the percentage of variation explained by each variable as its weight, and (3) mapping the distribution of the index. The difference from previous applications of the method was that instead of looking at the initial eigenvalues and using a threshold value of 1.00 for the total variance explained, resulting in identifying only two principal components, we considered the extraction sums of squared loadings and used a threshold of 5% for the percentage of variance, identifying four principal components.

3. Results

In order to investigate waste production and its drivers, we used two types of analyses, i.e., multiple regression and correlation analyses to test the dependence, and principal component analysis integrated with GIS to look at the spatial distribution.

3.1. Results of Multiple Regression and Correlation Analyses

Multiple regression analysis used two models, a full model and a prediction model, obtained from the full model through backward elimination. Both models were significant overall ($p < 0.0001$). The overall coefficient of correlation, showing the percentage of variation explained by the model, was 0.892 for the full model and 0.888 for the prediction model. The influence of analyzed drivers is presented in Table 1.

The results of correlation analysis are presented in Table 2. The table displays all possible correlations between variables describing waste management and potential drivers, analyzing those significant ($p \leq 0.05$) and those marginally significant ($p \leq 0.1$). For the latest, it is expected that more data would turn them into significant correlations.

Table 1. Results of multiple regression analysis looking at the dependence of waste production (amount) on socioeconomic and territorial drivers: A—area, P—population, C—share of people with at least a college degree, AP—share of active population, G—number of garbage bins, R—collection routes, S—no. of staff in waste management companies, and CO—company managing waste collection. The table presents two models, a "full model", including all drivers, and a "prediction model", including only those significantly influencing waste production when considered simultaneously. **Bold** values indicate variables significant at $p \leq 0.05$.

Variable	Full Model					Prediction Model				
	DF	Type III SS	Mean Square	F Value	*p*-Value	DF	Type III SS	Mean Square	F Value	*p*-Value
A	**1**	**1,176,924.116**	**1,176,924.116**	**10.01**	**0.0027**	**1**	**1,488,816.135**	**1,488,816.135**	**13.24**	**0.0006**
P	**1**	**1,078,283.887**	**1,078,283.887**	**9.17**	**0.0040**	**1**	**1,105,096.310**	**1,105,096.310**	**9.82**	**0.0028**
C	1	161,008.924	161,008.924	1.37	0.2477					
AP	1	151,823.646	151,823.646	1.29	0.2615					
G	1	24,613.729	24,613.729	0.21	0.6494					
R	**1**	**1,569,441.511**	**1,569,441.511**	**13.35**	**0.0006**	**1**	**2,053,790.064**	**2,053,790.064**	**18.26**	**<0.0001**
S	**1**	**895,123.090**	**895,123.090**	**7.61**	**0.0082**	**1**	**1,126,868.026**	**1,126,868.026**	**10.02**	**0.0026**
CO	1	2075.647	2075.647	0.02	0.8949					

Table 2. Correlation between the variables describing waste management and potential drivers: W—amount of waste, A—area, P—population, C—share of people with at least a college degree, AP—share of active population, G—number of garbage bins, R—collection routes, and S—no. of staff in waste management companies. For each correlation, the table displays the coefficient of determination r and its corresponding *p*-value below. **Bold** values indicate correlations significant at $p \leq 0.05$, and *italic* values correlations significant at $p \leq 0.1$.

.		W	A	P	C	AP	G	R	S
W	r	1.00000	**0.53687**	**0.83112**	−0.00077	**−0.36286**	*0.24162*	**0.82540**	**0.81927**
	p		**<0.0001**	**<0.0001**	0.9955	**0.0055**	*0.0702*	**<0.0001**	**<0.0001**
A	r	**0.53687**	1.00000	0.20285	**−0.44136**	**−0.53232**	0.05287	**0.26159**	**0.58813**
	p	**<0.0001**		0.1302	**0.0006**	**<0.0001**	0.6961	**0.0493**	**<0.0001**
P	r	**0.83112**	0.20285	1.00000	0.15169	−0.17607	**0.35841**	**0.82465**	**0.69092**
	p	**<0.0001**	0.1302		0.2600	0.1902	**0.0062**	**<0.0001**	**<0.0001**
C	r	−0.00077	**−0.44136**	0.15169	1.00000	**0.63193**	0.13437	0.11128	−0.04608
	p	0.9955	**0.0006**	0.2600		**<0.0001**	0.3190	0.4099	0.7336
AP	r	**−0.36286**	**−0.53232**	−0.17607	**0.63193**	1.00000	−0.14446	*−0.24338*	**−0.30994**
	p	**0.0055**	**<0.0001**	0.1902	**<0.0001**		0.2837	*0.0681*	**0.0190**
G	r	0.24162	0.05287	**0.35841**	0.13437	−0.14446	1.00000	*0.24407*	0.14963
	p	*0.0702*	0.6961	**0.0062**	0.3190	0.2837		*0.0673*	0.2666
R	r	***0.82540***	**0.26159**	**0.82465**	0.11128	*−0.24338*	*0.24407*	1.00000	**0.58743**
	p	**<0.0001**	**0.0493**	**<0.0001**	0.4099	*0.0681*	*0.0673*		**<0.0001**
S	r	**0.81927**	**0.58813**	**0.69092**	−0.04608	**−0.30994**	0.14963	**0.58743**	1.00000
	p	**<0.0001**	**<0.0001**	**<0.0001**	0.7336	**0.0190**	0.2666	**<0.0001**	

3.2. Results of Geospatial Analyses

The results of geospatial analysis are based on a principal component analysis, used to look at the territorial variables describing waste management and potential drivers of waste production. The results of the analysis are displayed in Tables 3 and 4. Table 3 shows the principal components and the percentage of variation explained by each; out of these, we considered the extraction sums of squared loadings and used a threshold of 5% for the percentage of variance to identify the principal components with a significant influence on the territorial distribution. Table 4 serves for identifying them with the variable most correlated to each one, as indicated by the highest value of the coefficient of determination.

The results presented in Table 3 indicate that the first four components, accounting altogether for over 90% of the total variation (in terms of the extraction sums of squared loadings), and identified in Table 4 with the amount of waste, share of people with at least a college degree, number of garbage bins, and area of the commune, can be used to analyze the territorial differences across the study area. This was achieved by mapping the spatial distribution of each variable (see Figures 3–6) and building an aggregated index weighting each variable based on the percentage of total variance explained (column "Extraction Sums of Squared Loadings" in Table 3) and mapping its spatial distribution (see Figure 7).

Table 3. Results of the principal component analysis showing the principal components explaining the territorial differences of communes with respect to waste management and potential drivers.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.823	47.788	47.788	3.823	47.788	47.788
2	1.912	23.902	71.690	1.912	23.902	71.690
3	0.936	11.705	83.394	0.936	11.705	83.394
4	0.589	7.357	90.752	0.589	7.357	90.752
5	0.291	3.640	94.391	0.291	3.640	94.391
6	0.261	3.260	97.651	0.261	3.260	97.651
7	0.109	1.365	99.016	0.109	1.365	99.016
8	0.079	0.984	100.000	0.079	0.984	100.000

Table 4. Results of the principal component analysis identifying the four principal components explaining over 5% of the variance (column "Extraction Sums of Squared Loadings" in Table 3) with the corresponding variables. The correspondence is indicated by the highest value of the coefficient of determination in each column (1–4), underlined using a **Bold** font.

Variable	Component			
	1	2	3	4
Area	0.620	−0.559	0.124	**0.461**
Population	0.846	0.396	−0.015	−0.196
Share of people with at least a college degree	−0.130	**0.889**	0.088	0.227
Share of active population	−0.505	0.688	0.273	0.251
Garbage bins	0.338	0.263	**−0.872**	0.220
Amount of waste	**0.953**	0.121	0.128	−0.003
Collection routes	0.830	0.311	0.063	−0.321
No. of staff in waste management companies	0.861	0.014	0.239	0.268

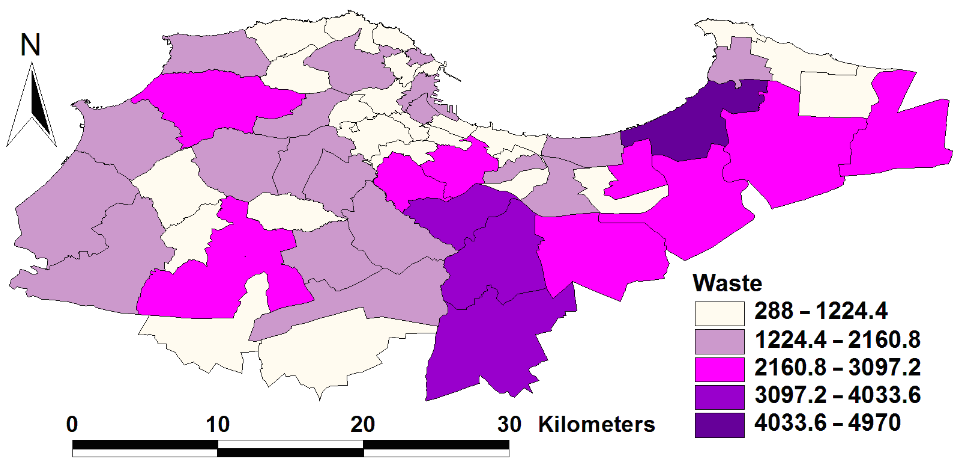

Figure 3. Spatial distribution of the production of waste across the study area. The distribution is based on creating five equal intervals based on the amount of waste generated in each unit (in metric tons).

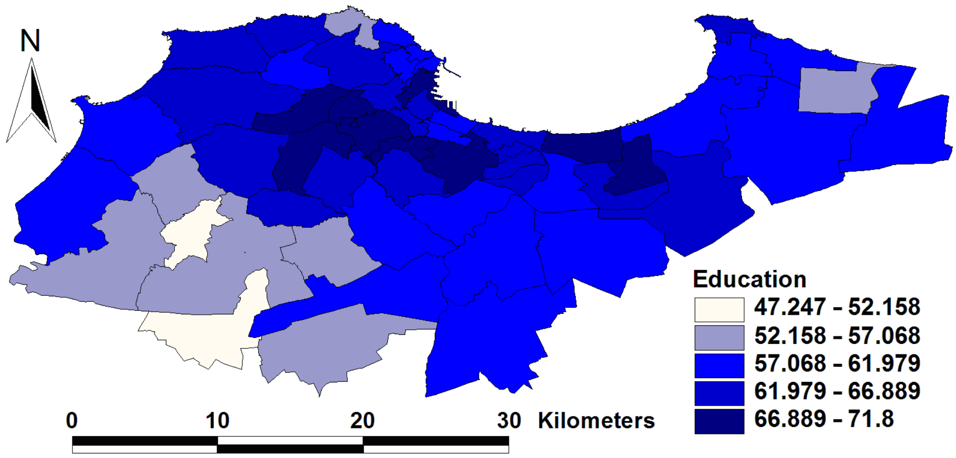

Figure 4. Spatial distribution of the share of people with at least a college degree across the study area. The distribution is based on creating five equal intervals based on the share of people with at least a college degree from the total population.

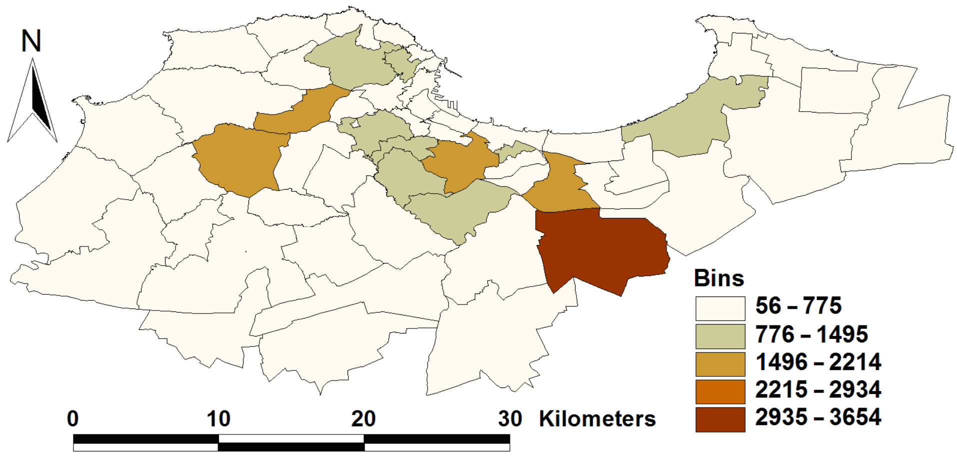

Figure 5. Spatial distribution of the number of garbage bins across the study area. The distribution is based on creating five equal intervals.

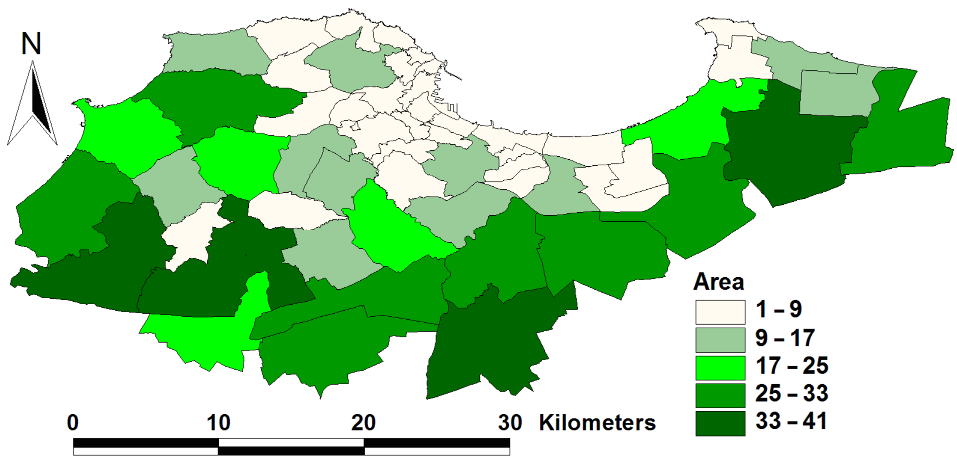

Figure 6. Spatial distribution of the total commune area across the study area. The distribution is based on creating five equal intervals for the total area of communes, in km^2.

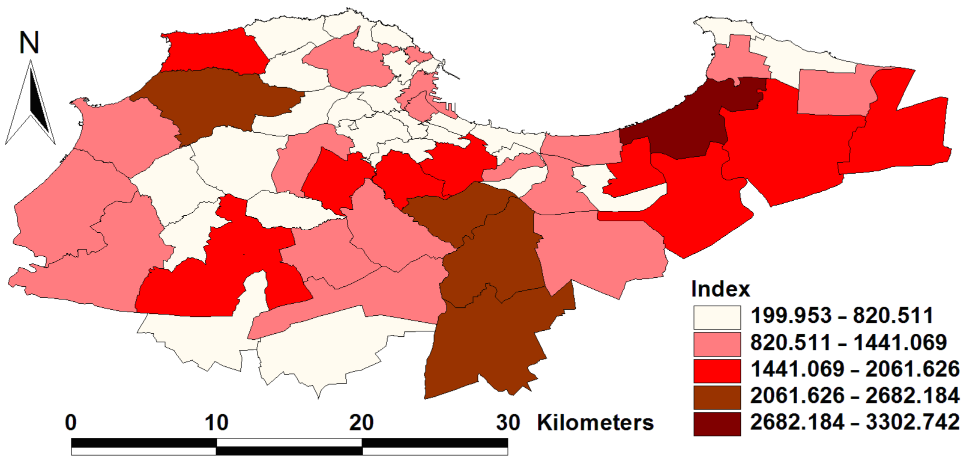

Figure 7. Spatial distribution of the aggregated index across the study area. The distribution is based on creating five equal intervals for aggregated index, built using the four principal components explaining over 90% of the total variation (in terms of the extraction sums of squared loadings—Table 3) weighted by the percentage of variation explained (Table 3).

4. Discussion

The results of multiple regression analysis indicate that waste management is influenced by drivers related to the size of the settlement, specifically area (p = 0.0006) and population (p = 0.0028). Waste management is also influenced by the characteristics of WM companies, represented by the number of collection routes (p < 0.0001) and number of employees (p = 0.0026). None of the sociodemographic variables such as the level of education (people with at least college level, active population) or employment rate were found to significantly influence the production of waste. Similar to other studies, population and size of urban area are found to be key drivers in the waste generation rates [30,34].

The spatial distributions are influenced by the geographic and sociodemographic characteristics of Algeria, and the influence is seen at all territorial levels: wilayas within the country, communes within the wilayas. The size of communes increases from north to south (see Figure 5), because in Algeria, the north corresponds to the Mediterranean shore, which offers, due to its climate, better living conditions and is more populated. The south corresponds to the desert areas and is less populated. As a result, the size balances the communes in terms of population (see Figure 3), i.e., communes are larger in less populous areas. The same geographical settings affect the spatial distribution of education; the north concentrates large cities with strong universities, while the southern areas offer fewer educational opportunities.

This paper reveals the importance of urban district-level variation in terms of waste production, waste bin coverage, and sociodemographic features, as in other studies [31]. At the microlevel, house size, districts, and employment category were found key drivers in waste generation for the Accra region of Ghana [32] and family size in Robe town, Ethiopia [39].

Therefore, other factors could be further examined in future research such as household/family size. The employment category seems not to play a significant role in explaining waste production in Algiers city. Furthermore, spatial analysis using GIS tools provides better monitoring alternatives of waste indicators to improve the collection efficiency. This is important to prevent illegal disposal activities in emerging cities [40].

Compared to other African countries, Algeria is better covered by basic public utilities in both urban and rural regions [5,41]. The population of Algiers city and wilaya is connected to waste collection services, but a traditional waste management system based on mixed waste collection and landfill of waste prevails in the capital city. The household waste collected by two main waste operators (NETCOM and EXTRANET) is disposed of in two different conventional landfill sites (CET HAMICI and CET of Corso). However, the issue of uncontrolled household waste disposal practices is not solved, contributing to environmental pollution [42]. The illegal dumping of household waste remains a significant environmental threat in African cities [39].

The urban waste generation rate is estimated to be at 0.8 kg.inhab.day-1 compared to 0.6 kg.inhab.day-1 in rural areas at the country level, while the recycling rate is around 7%, composting 1%, and the rest of municipal waste flow is disposed of in sanitary landfills or dumpsites [43]. The waste generation rate varies among regions of Algeria with significant disparities between north and south regions, but the highest waste generation rate is around 0.95 kg.inhab.day-1 in Algiers [20]. Across estimation of household waste generated by Algiers city is around 500,000 tons per semester, approximately 1 million tons per year [44]. Therefore, this study provides a better picture of household waste flows using spatial analysis at the district level. Such spatial analyses at this scale are needed by decision makers aiming to improve the current waste management practices. However, experimental analyses based on field data regarding urban waste generation rates on a per capita basis and municipal waste composition in different districts of Algiers city and wilaya are required to provide a comprehensive baseline of household waste characterization for the study area and model future predictions of waste flows. The frequency of waste collection schemes is a daily regime and in some periods of the year the regime is twice a day (e.g., summer season for coastal communes and the two days of the "Aid el Adha" celebration). During the month of "Ramadan", the waste collection regime becomes nightly. These religious events could significantly increase the urban waste generation rates, putting additional pressure on waste collection schemes [45]. This issue could also be investigated in Algiers city, in comparison with other urban centers of the country.

There are no source-separation collection schemes, but some recyclable waste is recovered from residual waste at the sorting station located near the CET landfill site. Additionally, the informal sector collects some dry recyclable waste (plastics and metals) for recycling purposes. The informal sector plays a critical role in African cities in recovering recyclable waste from dumpsites associated with the underdevelopment of municipal waste management infrastructure [46]. Most private economic agents involved in waste recovery and recycling operations are found in Algiers and Boumerdes according to the National Waste Agency [47]. Metals and scraps of iron are often recovered at the source, and these fractions are less prone to landfilling compared to the organic waste fraction [21].

NETCOM introduced seven separate collection sites for paper/cardboard, glass, organic waste, and bread [48]. Besides waste collection operations, the transportation of household waste seems to have a high ecological footprint, and landfills are not equipped with biogas installations in Algiers [42]. The rate of recycling household waste is unknown, and computation of waste statistics at the city level should be compulsory. At the country level, the latest estimation of the recycling rate was around 9.83% in 2020 [47]. There are no composting facilities in Algiers despite the fact that most residual bins contain organic waste (54.4%), followed by plastics (16.5%) and paper/cardboard (13.4%) [48]. This is in line with the last household waste characterization from April 2018 to March 2019, where the organic fraction represented 63%, followed by plastics (15.2%) [49]. However, this characterization did not include Algiers. Therefore, such studies need to be further developed in the capital city and related wilayas. Preliminary findings suggest that composting facilities fed by source separation of organic waste should be a future investment priority besides material recycling facilities combined with separate collection schemes extended to all districts in the study area. Composting practices are limited across MENA countries despite the high share of organic waste in household waste flows [15].

The recovery of recyclable waste is very low because sorting stations receive mixed household waste instead of clean source-separated recyclable wastes (paper/cardboard, glass, plastic, and metals/aluminum cans). Without proper waste management infrastructure separating clean organic wastes from dry recyclable waste, the target of recycling and composting more than 50% of household and similar waste by 2035, set by the Waste Management Strategy in Algeria [50], will be an impossible target to fulfill based on the current situation in Algeria. In fact, the African Circular Economy Alliance argues the key role of organic waste and plastic packaging diversion from landfills having as members Cote d'Ivoire, Ghana, Nigeria, Rwanda, and South Africa [51]. A similar alliance could be initiated in the MENA region, where Algeria could be part of it or adhere to the existing ACEA to stimulate transition towards a sustainable waste management system by 2035 through international cooperation, exchanging of know-how, and adopting best practices in the region.

5. Conclusions

This study reveals that GIS and spatial statistics at the district level are useful tools for the assessment and monitoring of household waste flow in large urban areas such as North African capital cities. However, this approach depends on the availability and quality of waste statistics provided by waste operators. The results of multiple regression analysis indicate that waste management is influenced by drivers related to the size of the settlement, i.e., area ($p = 0.0006$) and population ($p = 0.0028$), and characteristics of the waste management companies, i.e., number of collection routes ($p < 0.0001$), and number of employees ($p = 0.0026$). Sociodemographic variables such as the level of education and the employment rate were found to have no significant influence on the production of waste. Algiers is still a landfill-based city in the MENA region, where mixed waste collection prevails in all districts. The expansion of source-separated waste collection schemes is compulsory at least for organic waste and dry recyclables (plastic, metal, paper cardboard, and glass) that must be further treated in composting and sorting facilities to increase the household waste diversion from landfills in line with circular economy principles.

From a methodological perspective, our study proved that a combination of multiple regression analysis and principal component analysis is efficient to describe and understand waste production; the first method is useful in detecting the relevant drivers of waste production and the second in contextualizing them spatially. However, the reliability of our methodology depends at large on the availability of waste statistics provided by waste operators, which can constitute an important challenge in North Africa. Future studies can use more relevant variables to start with, if data are available. In this regard, data on more socioeconomic variables could enhance the results of future studies.

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