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SPATIAL ANALYSIS OF THE DISTRIBUTION OF HOUSEHOLD WASTE CONTAINERS USING GEOGRAPHIC INFORMATION SYSTEMS (GIS). A CASE STUDY OF THE CITY OF AIN EL BEIDA

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ABSTRACT

Urban waste management technology has become one of the most important techniques facing many challenges and concerns in the Algerian city in general and the city of Ain El Beida in particular, due to the quantities of waste produced and constantly increasing, which are due to the increasing population size and consumption rates, which resulted in a set of environmental and health risks and many manifestations of urban degradation due to a lack of appreciation and effectiveness of management, This necessitated study and search for effective solutions with the aim of activating them to improve the process of urban waste management in cities in general. This study aims to clarify how to use geographic information systems (GIS) in the spatial analysis of the distribution of household waste containers in the city of Ain El Beida As a case study and make it more efficient and effective within the urban environment and thus improve its management process. Through this research paper, we have designed interactive maps that provide accurate and comprehensive insights into the distribution of household waste containers in the city of Ain El Beida, which would contribute to directing improvement and effective management efforts with the aim of achieving greater effectiveness and better efficiency in the existing management system. The results also showed that the city's household waste container distribution system was unbalanced as there was a severe shortage of containers, which affected the overall management system.

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1. Introduction.

Cities have recently witnessed rapid growth in population and economic activities, leading to a significant increase in the amount of waste produced daily, which has resulted in enormous pressure on traditional waste management systems, and increases challenges related to the safe and efficient disposal of waste.

There was an urgent need for innovative and effective solutions, hence the importance of research on urban waste management in the Algerian city in general using modern technologies such as geographic information systems (GIS) as a powerful tool to improve urban waste management technology. By collecting, analysing and presenting spatial data in an effective manner, it provides decision-makers, engineers, urban planners and city managers with clear insights into waste distribution and the efficiency of existing systems. in cities, and contribute to the improvement of the management process.

The city of Ain El Beida is one of the Algerian cities facing increasing challenges in waste management, as a result of population growth and rapid urban expansion. And increasingly, we find it an ideal model for applied studies on how to use geographic information systems to improve waste management processes through spatial analysis of container distribution sites, which in turn helps in planning waste collection and transportation routes more efficiently and preserving the environment.

Through this paper, we aim to clarify the possibilities of GIS contributing to the development and use of a database to contribute to optimal and effective management through the application of spatial distribution of household waste containers within urban areas, with a view to enhancing the urban and health environment of the population in general and specifically the city of Ain El Beida as a case of study.

2. Problem Research.

The management of waste in the Algerian city is generally problematic as the quantities of waste raised increase beyond the conventional systems' ability to manage them.

Despite efforts to improve the management process, many cities in general and Ain El Beida in particular still suffer from poor planning and inefficient distribution of infrastructure for this process.

Which can be considered a model for the study as that city that is witnessing rapid urban growth, significant population increase and a significant increase in the amount of waste produced by the population, this prompts us to ask the following question.

How can geographic information systems (GIS) be used in spatial analysis of the distribution of household waste containers in order to improve them and enhance the urban environment for the population in the city Ain El Beida?

3. The importance of research.

The importance of research lies in the following points:

- **Improving the efficiency of waste management:** The research contributes to the development of innovative solutions using geographic information systems (GIS) to improve the efficiency of waste management operations in the city of Ain El Beida, which contributes to reducing costs and improving services.

- **Enhancing the urban environment:** Research helps provide solutions aimed at reducing the negative environmental impacts of poor waste management, enhancing the city's ecology and reducing associated health risks.
- **Possibility of application to other cities:** The results drawn from our research paper can be a generalizable and applicable model, which contributes to enhancing the efficiency of waste.
- **Management in various regions. Supporting decision makers:** The research provides clarity on a powerful tool for urban engineers, architects, urban planners and city managers that contributes to improving waste management strategies and developing plans based on accurate spatial data.
- **Improving the urban environment:** The research contributes to the possibility of improving the urban environment for the residents of the city of Ain El Beida, reducing environmental pollution, and improving the health and well-being of the population by clarifying many recommendations and suggestions.

4. Research Methodology.

This study is based on the descriptive analytical approach, which is based on studying the reality of household waste management in the city of Ain El Beida, where this approach aims to analyze the current situation by describing the distribution of waste containers in the city, and deducing spatial differences in their locations and identifying them, through explaining the motives and causes of those differences to provide appropriate suggestions and recommendations.

In addition, a spatial analysis approach using geographic information systems (GIS) has been adopted to analyze the locations of waste containers and identify differences in their spread, such as proximity and geographical distribution tools to improve the efficiency of container distribution and optimal site planning.

The study also included the collection of field data through reconnaissance visits to waste container sites, and as part of the analysis we developed an integrated geographical database. This included digitizing and updating paper maps, processing aerial images, connecting spatial data to text, and we also used spatial analysis techniques to determine the optimal location of waste containers based on functions available in GIS such as Buffer and Directional Distribution.

5. Conceptual framework on the management of household waste.

Urban waste is defined as tailings from various sources within urban areas, including waste from homes, restaurants, hotels, as well as street and road cleaning tailings. It also includes waste from public administrations, shops and public and private institutions, the components of which are similar to household waste. "Substances or objects disposed of or intended to be disposed of or required to be disposed of" While World Bank experts have defined it as "something that has become valuable in usage, if this thing can be rotated so that it can be used or one of its components can be recovered in this case, it is not considered waste." The Algerian legislature, through article 03 of the Law on the Management, Control and Removal of Waste, defined it as "All residues resulting from the process of production, conversion or consumption and, more generally, every substance, product and transporter disposed of or intended to be disposed of by the owner or holder, or required to be disposed of or removed" Domestic waste is "all household waste and similar waste from industrial, commercial, artisanal and other activities, which by nature and components resemble household waste".

The Act also added in paragraph 12 of the same article that the management of waste is "All operations relating to the collection, screening, transport, storage, valuation or removal of wastes, including the control of such operations." It is a study of the process of managing the successive technical phases of waste collection, transport to processing facilities. The latter has a number of valuation and screening methods and a final method of technical burial, treated or not processed in advance, with a view to removing them.

Moreover, the term household waste containers refers to boxes of a certain capacity, where solid household waste is deposited for temporary storage.

They prevent waste from being blown around by the wind. The spread of unpleasant odors through the air is reduced. They limit the access of waste to animals, birds, and insects that transmit infections.

As part of modern waste management, waste containers play an essential role in ensuring optimal collection while preserving the urban environment. They are usually made of plastic and metal,

in different colors and sizes that vary depending on the type of waste and collection methods, and are usually used in residential areas and the urban environment within cities.

5.1. Geographic Information Systems (GIS).

Geographic Information Systems (GIS) technology is one of the most prominent developments in the field of geographic data management and analysis, and contributes to enhancing the capabilities of geographic analysis and research and its application in multiple fields such as urban planning, resource management, and environment.

They are considered integrated systems that allow the input, storage, analysis and output of geographic data, so that these functions are integrated into one program that supports access to a comprehensive database.

This integration allows users to conduct in-depth analyses and understand spatial relationships and patterns accurately, which enhances their ability to make decisions based on reliable and effective geographic information.

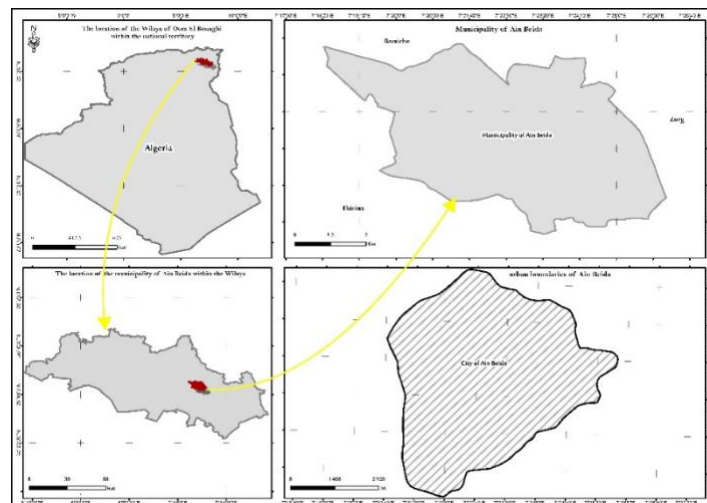
5.2. The importance of GIS applications in our research study.

The importance of GIS in the overall management of urban solid waste is its "ability to handle data and spatial information. The system stores and processes data quickly and accurately and identifies the best locations for transport stations, planning routes towards collection stations and then to disposal centres. In addition to identifying new and appropriate landfill sites and observing current ones, it is not only time-saving and cost-reducing, but also includes future monitoring of waste problems ", in this context we explain through our research study how offers (GIS) Innovative contribution to spatial analysis of the distribution and improvement of household waste container sites sites in Ain El Beida City with a view to achieving greater effectiveness and efficiency in the city's existing management system.

6. Presentation of the field of study.

Ain El Beida city is characterized by the importance of the geographical location within the region of Algeria's Upper Eastern Plains on an area of 52 km² and an altitude of 900 m to 1035 m south at the confluence of two main pillars of national roads, namely, National Route No. 10 between Constantine and the States of Constantine, Tibsa and National Road 80, the link between Khanshila and Qalaa states, and the city is about 150 km from the Tunisian border.

Its urban texture is situated on a variety of terrain that includes many plains, hills and valleys.



Map 1. Showing the location of Ain El Beida city.

Source: Authors, treatment based on administrative division and google earth images (2024).

7. Evolution of the amount of waste in the city of Ain El Beida from 2014 to 2023.

By analyzing the data of the amount of waste generated in the city of Ain El Beida in the last ten years from 2014 to 2024, we find that it is witnessing a significant increase due to the increase in population during this period, where we find that the population increased from 134,955 people in 2014 to 170,224 people in 2023 with an estimated population density of 3274 people/km², where the amount of waste generated per day went from 67.47 tons in 2014 to 75.92 tons in 2024 with a volume of 253.12 m³, showing an increase of 12.52%. 47 tons in 2014 to 75.92 tons in 2024 with a volume of 253.12 m³, showing an increase of 12.52% during this period. And an increase in the rate of waste production per capita from 0.5 kg/day to nearly 1 kg/day. On the other hand, the amount of waste generated annually increased from 24,629.28 tons in 2014 to 27,706.28 tons in 2024 with a volume of 92,389.95 m³, an increase of -12.49%, which puts tremendous pressure on household waste collection infrastructure in particular and management in general.

8. The reality of the spatial distribution of household waste containers in the urban sectors of Ain El Beida city.

The distribution of waste containers in the city of Ain El Beida witnesses a remarkable disparity between the various sectors of the city, which reflects the great and increasing challenges that the city faces in the process of managing household waste, specifically at the stage of collection. This reflects the great and increasing challenges that the city faces in the process of managing household waste, specifically during the collection phase. The field investigation showed that the number of containers in the city of Ain El Beida amounted to 139 containers distributed across 11 urban sectors in addition to the industrial activities area, which is considered insufficient to accommodate the volume of waste. Where it is concentrated in sectors characterized by high population density, such as the first sector, which includes 35 containers, to find the fifth sector with 34 containers, then the second sector with 31 containers, while we find medium-density sectors such as the ninth sector, which includes 20 containers, followed by the fourth sector, which contains 13 containers, while the third sector includes 11 containers, then the eleventh sector contains 10 containers. In less densely populated sectors, the number of containers is 10, such as Sixth sector with 8 containers, Sector Seven with 5 containers, and Sector 8 with 5 containers. We also found that each of the peripheral sectors of Tenth sector and the industrial zone is a single container. Shown in the photos (01-02-03-04). Through the field investigation, we have found 36 collection points for household waste within the urban area of the city, which are considered random without containers, and which we call "black points", where waste accumulates continuously. As shown by map (02) and photos No. (05-06-07-08).

We find that this unplanned variation in the distribution of containers and the acute shortage of containers contributed to the decline in the effectiveness of the collection system in the city of Ain el-Baida and faced many challenges in the process of managing household waste, which led to the accumulation of waste in the streets and across sectors and increased health and environmental risks:

- Accumulation of waste in the streets and across sectors and increased health and environmental risks.
- Increased burdens on waste collection teams.
- Deterioration of the general appearance of the city.



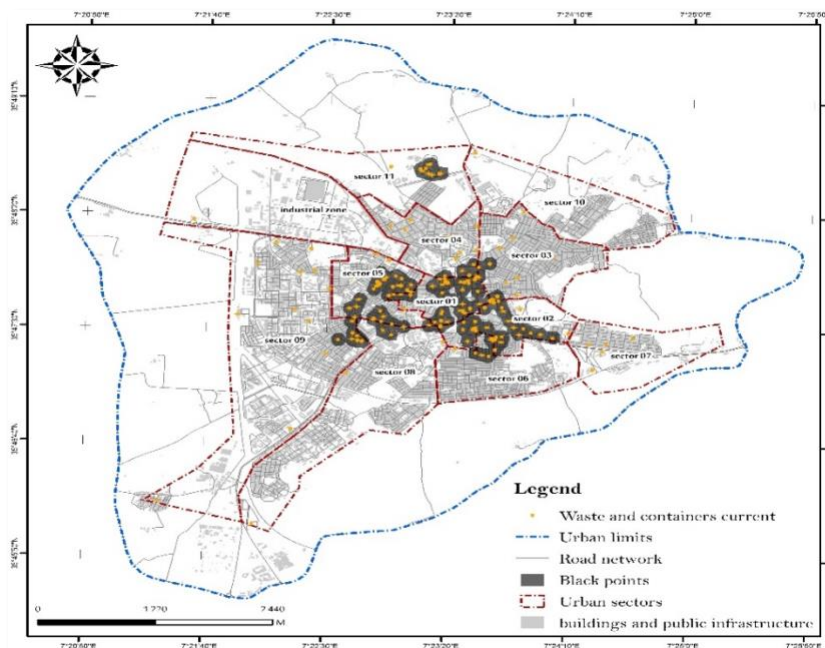
Photos (1-2-3-4) of the containers located at the level of the first sector of Ain El Beida city center.

Source: Authors , September (2024).



Photo (5-6-7-8) Some of the random collection points of household waste spread in Ain El Beida city.

Source: Authors, September (2024).



Map 2. Distribution of household waste containers and black spots in the urban sectors of Ain El Beida city.

Source: Authors, treatment based on field output (2024).

9. Spatial analysis of urban waste container distribution locations in Ain El Beida city.

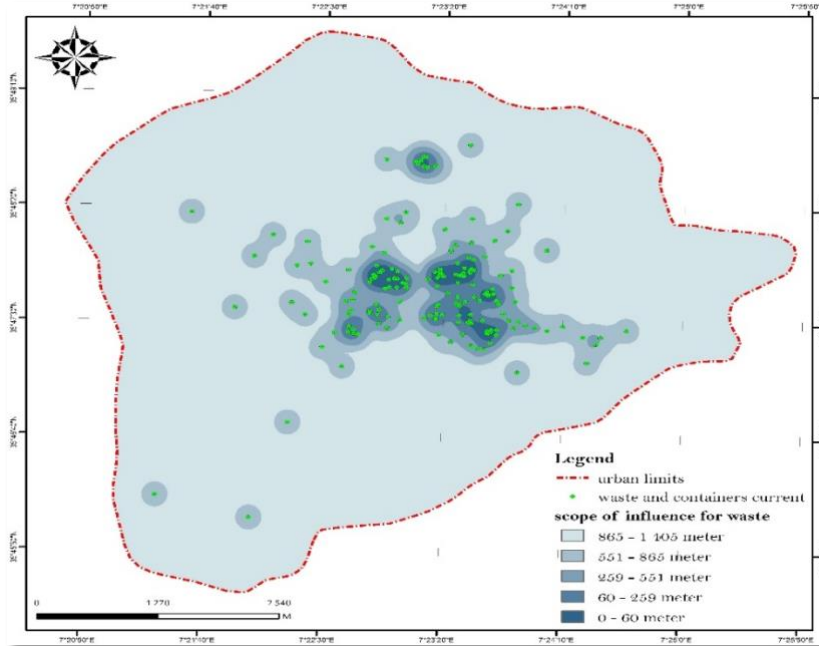
Spatial analysis of waste distribution in the city of Ain El Beida is a pivotal step in understanding the spatial patterns that affect waste management in the city.

Through the use of Geographic Information Systems (GIS) tools, the location of containers and their coverage of different neighborhoods can be determined, as well as understanding the relationship between population density and the amount of waste produced in the city.

The analysis shows that densely populated neighborhoods suffer from a lack of container distribution, which leads to the accumulation of waste in some areas, especially in the centers. As shown

in Map (03), it provides a clear picture of the spatial disparities in container distribution and its impact on collection areas using buffer zones.

By illustrating the distribution of containers and the extent of each container's influence, the light blue shaded areas represent small ranges of containers, while dark blue represents larger ranges with more waste accumulation. It can also be seen that the central areas are dominated by garbage with large areas of influence, while the outer areas show less influence of containers and garbage. This indicates that the central areas are not receiving an effective service from the outer areas. In addition, the distance between containers in peripheral areas increases the likelihood of uncontrolled waste accumulation, as residents need to walk farther distances to reach the containers.



*Map 3. Area of influence of container distribution in Ain El Beida city.
Source : Authors, treatment based on field output (2024).*

10. Using the nearest neighbor to analyze distribution patterns.

The Average Nearest Neighbor method is an important tool in analyzing spatial patterns using geographic information systems (GIS), and it helps measure the extent of the distribution of spatial elements such as waste containers in a particular city.

This method is based on calculating the distance between each spatial element and its nearest neighbor, and then comparing this distance with the expected distance in the case of a random distribution, as this comparison shows whether the distribution is regular, clustered, or random. In our research study, we analyzed the distribution of waste containers in the city of Ain El Beida, where this tool was used to determine whether the containers are evenly distributed to meet the needs of the population or whether there are clusters in certain locations and their absence in others, as shown in the following figure:

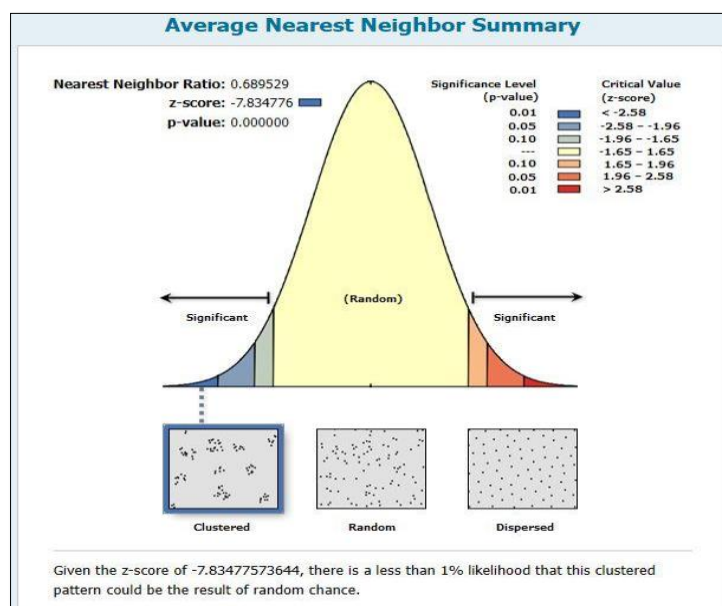


Figure 1. Spatial Spread of Waste Containers in Ain El Beida City – Average Nearest Neighbor.

Source: Authors, treatment based on field output (2024).

By analyzing the distribution pattern of waste containers in the city of Ain El Beida using the nearest neighbor method, statistically significant results emerge that indicate a clearly clustered distribution pattern.

The graph shows that the Z-score value lies in the dark blue area on the left-hand side, confirming the presence of a strong clustering pattern with a statistical significance level of $p < 0.01$. This means that the distribution of waste containers in the city has a significant tendency to cluster in the city center, rather than spreading evenly and randomly across the city. This clustered pattern reveals a marked disparity in the distribution of municipal services related to waste management in Ain El Beida. Containers are heavily concentrated in the city center, while other areas lack a sufficient number of containers. This uneven distribution reflects the fact that the placement of containers did not follow a random or systematic pattern, but rather was subject to specific factors that influenced the choice of locations.

It is the result of several factors, such as the high population density in the city center, the concentration of commercial activities, and the easy accessibility of some areas but not others. It also reflects logistical challenges in waste collection operations, as the containers were concentrated in areas easily accessible by waste collection vehicles.

This analysis reveals the need for a comprehensive review of the waste container distribution strategy in Ain al-Bayda city, as the current clustered pattern is not optimal to fairly and efficiently meet the needs of all the city's residents. It leads to excessive pressure on infrastructure in areas with a high concentration of containers, while causing environmental and health issues in areas that lack a sufficient number of containers.

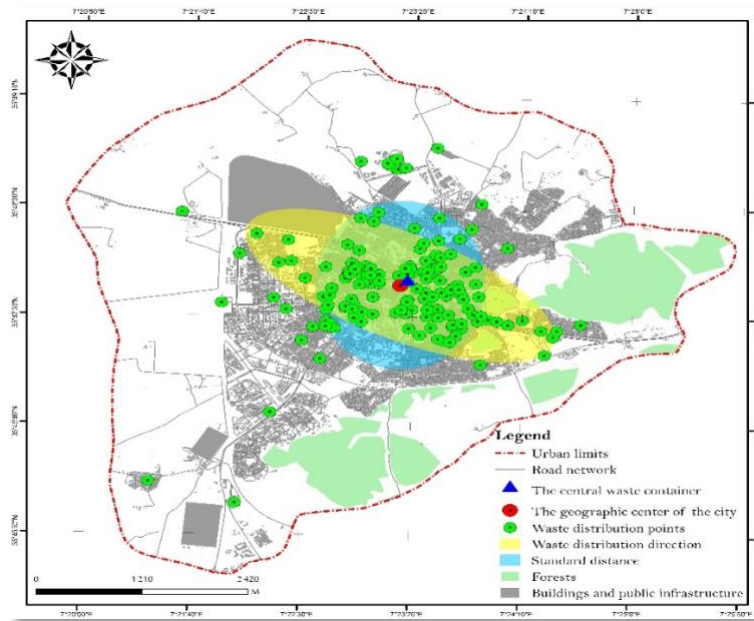
11. Waste distribution trend and standardized distance of containers in the city Ain El Beida.

Studying the waste distribution trend and the standard distance of containers in the city of Ain El Ain El Beida is a vital step to analyze the efficiency of the city's waste management system.

Through this analysis, we can assess how containers are distributed in relation to population density and urban activities, and determine the extent to which the overall coverage of the waste collection system is balanced. As shown in Map (04), the distribution of containers is based on the centers of gravity of waste within the city. The map shows the central area in blue, which is the most dense in the number of containers and waste accumulation, and the colors progress outward to show areas with fewer containers.

The green circles represent the location of containers in different areas. It can be seen that the containers are concentrated in the central area of the city, reflecting the increased amount of waste production in those areas.

The standardized distance surrounding the containers stands out as a criterion for determining effective waste distribution. Larger ranges in the outer areas mean a greater spacing of containers, which leads to increased waste accumulation in those areas. From the above, we conclude that the current distribution is completely unbalanced, as containers are concentrated in the central areas, while the peripheral areas lack sufficient coverage. The standard distance indicates that there is a need to reduce the gaps in container coverage in the periphery to minimize the long distances residents have to travel to dispose of their waste.

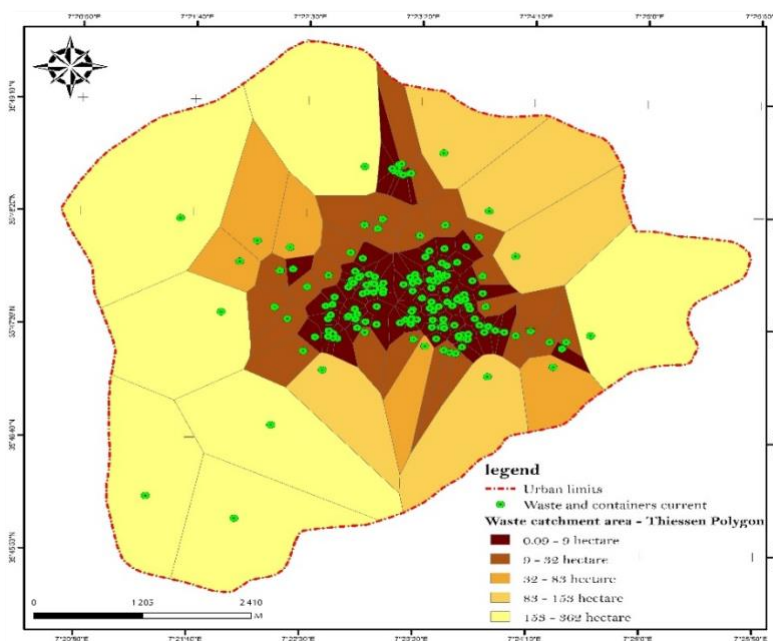


Map 4. Distribution direction and standard distance of containers in Ain El Beida city

Source: Authors, treatment based on field output (2024).

12. Container efficiency using Thessen polygons in Ain El Beida city.

The efficient distribution of containers is an essential part of the management of urban waste in general and domestic in particular, contributing to improved service levels and reducing the impact of waste on the environment and the population's health. A useful tool in this context is Thessen polygons, which provide a geographical model for determining the areas served by each waste container in the city.



Map 5. Estimated Areas of Influence of Containers in Ain El Beida City
-Thiessen polygons-

Source: Authors, treatment based on field output (2024).

Thiessen polygons are used to analyze the distribution of containers by providing an accurate visualization of the geographic area served by each container. In the city of Ain El Baida, the map extracted from Thiessen polygons shows that there is a significant variation in the efficiency of container distribution:

- **High-density areas:** In densely populated central neighborhoods, such as Sector 01 downtown, the Thiessen polygons represent small areas. This indicates that the containers serve narrow spaces, reflecting a denser distribution and enhancing the efficiency of waste collection in these areas. However, this overcrowding is insufficient in the face of increasing demand for waste collection, as the increase in waste volume exceeds the capacity of the containers.
- **Peripheral areas and edges:** In peripheral neighborhoods such as Sector 08 and Sector 09, Thiessen polygons show that containers serve larger areas. This large spacing of containers leads to a lack of service efficiency, as a single container needs to cover large areas, increasing the likelihood of waste accumulation and delays in waste collection.

The results of the Thiessen polygon analysis show that there is significant variation in the distribution of containers across Ain El Beida city. For containers located in the central areas, services are more concentrated but suffer from increased pressure due to the density of waste. In the peripheral areas, containers serving large areas show a lack of efficiency.

13. Discuss the results of the research study.

The study found that the household waste management system in Ain El Beida city is facing increasing challenges with the rapid population growth and the marked increase in the amount of daily and annual waste.

The main findings indicate a set of challenges and failures in the distribution and efficiency of containers, the most important of which are as follows:

13.1. Analyze the distribution of containers and waste.

- Spatial analysis using GIS revealed significant variation in the distribution of containers across the city.

Densely populated areas suffer from a shortage of containers, leading to the accumulation of waste, while less dense areas suffer from an unbalanced distribution.

- The influence map showed that the central areas have a high concentration of containers, while the peripheral areas lack a sufficient number of household waste containers, and this unbalanced distribution leads to issues that negatively affect the urban environment and the health of the population.

13.2. Analyzing the distribution pattern using the Average Nearest Neighbor method.

- The results of the Average Nearest Neighbor method showed a clustered distribution pattern of containers in the city, where the containers were significantly concentrated in the center, which means an unfair distribution of waste collection services.

13.3. Trend of container distribution and standard distance.

- The container distribution map showed a concentration in central areas and an increase in standard distances in peripheral areas, which increased the likelihood of waste accumulation in peripheral areas due to the distance of the containers.

13.4. Analyzing container efficiency using Thiessen polygons.

- The results of Thiessen polygons revealed a variation in the efficiency of container distribution, where services are more concentrated in centralized areas but suffer from overloading. On the other hand, containers in the peripheral areas show less efficiency due to their spacing.

14. Conclusion.

The study of household waste management in the city of Ain El Beida is an important step in understanding the major challenges faced by the city in light of urbanization and continuous population growth. The remarkable increase in the volume of waste has put pressure on the existing waste management infrastructure, resulting in several issues such as the uneven distribution of containers and the accumulation of waste in some sectors and neighborhoods.

The current situation in the city is unbalanced and inefficient, with some sectors suffering from an acute shortage of containers, despite the efforts made, increasing the potential for environmental pollution and urban degradation.

Through our study, it became clear that improving the household waste management system in Ain el-Baida requires effective interventions through the use of spatial analysis techniques such as Geographic Information Systems (GIS). We were able to analyze the distribution of containers and their associated zones of influence, which provided a deeper insight into the current efficiency of the waste management system. The maps derived from the study provide a clear view of the spatial distribution of waste and containers, and highlight the disparities that exist between different areas of the city.

In light of these facts, adopting the use of modern technology such as Geographic Information Systems (GIS) is a necessary step to improve waste management in the city of Ain El Beida to identify optimal locations, plan waste collection routes more efficiently, reduce costs and identify “black spots” that require immediate interventions, while directing efforts towards areas that need urgent improvements.

The adoption of such modern technologies contributes to enhancing the urban environment for residents, keeping the city clean, and minimizing negative environmental impacts.

Thus, the city of Casablanca emerges as a model for cities that require restructuring their waste management systems through the use of GIS spatial analysis techniques as an essential step towards achieving effective and successful management, by optimizing the spatial distribution of household waste containers, which reflects positively on the effectiveness of management systems and the urban environment in the city.

From the above, we came up with the following suggestions and recommendations:

➤ **Increase the number of containers and distribute them in a balanced manner across the sectors of the city of Ain El Beida :** The need to increase the number of containers and distribute them based on the actual needs and the amount of waste produced in each sector, which contributes to solving the issue of waste accumulation and the emergence of black spots in the urban area within the city, thus improving and optimizing waste management technology.

➤ **Using Geographic Information Systems (GIS) to analyze the location of containers in the Algerian city in general and Ain El Baida in particular:** We believe that it is necessary to improve the current household waste container distribution system by identifying optimal locations using GIS,

which contributes to improving the efficiency of container distribution and reducing the distances that citizens have to travel to dispose of their waste.

➤ **Improve the waste management infrastructure in the city Ain El Beida:** Household waste collection sites should be renovated in accordance with the size of the population and the amount of waste generated to ensure fast and efficient Collection.

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