14th Annual International Conference on Industrial Engineering and Operations Management Dubai United Arab Emirates (UAE), February 12-14, 2024

Publisher: IEOM Society International, USA DOI: 10.46254/AN14.20240070
Published: February 12, 2024

A GIS-Based Smart Waste Management for Assessing Spatial Distribution of Waste Bins in the City of Bisha, Kingdom of Saudi Arabia

Ghadah M Khushail, Ghaida Fahad Alqarni, Refan M Alshahrani and **Reema M Almotawa**
Undergraduate Student in Mechanical Engineering
Department-Industrial Engineering Program,
College of Engineering, University of Bisha
Bisha 61922, Saudi Arabia
440802539@ub.edu.sa;
440802540@ub.edu.sa, 440802548@ub.edu.sa, 440802553@ub.edu.sa

Khaled Ali Abuhasel
Full Professor in Mechanical Engineering
Department-Industrial Engineering Program,
College of Engineering, University of Bisha,
Bisha 61922, Saudi Arabia
kabuhasel@ub.edu.sa

Abstract

There is a significant increase in solid waste in the city of Bisha, mainly attributed to the rapid population growth characterizing the southern city in the Kingdom of Saudi Arabia. To address the challenge, a smart waste management system based on Geographic Information Systems (GIS) is proposed. The assessment of spatial distribution of waste bins in Bisha, where inefficient waste bin placement had been impacting waste management efficiency was prioritized. A comprehensive analysis of waste bin distribution across the city's neighborhoods, illustrated regions characterized by high population densities and concentrated waste bins placement. Through the application of diverse spatial analysis techniques, it was discovered that there was the clustering of waste bins in specific locations, accompanied by dispersion variations at various distances. The project's found the necessity for improved waste bin placement strategies to enhance waste management efficiency in the city of Bisha. The research offers insights into the spatial patterns of waste bins distribution and presents a data-driven approach to optimize waste collection processes. The approach aligns with the vision of a cleaner and more sustainable environment advocated by international organizations, such as the United Nations Environment Programme (UNEP). By implementing a GIS-based smart waste management system, Bisha can better manage its solid waste in a rapidly evolving urban landscape, reducing environmental impacts and public health risks, and contributing to global sustainability efforts.

Keywords
Smart waste management, GIS-based system, Spatial analysis, environmental safety, Waste collection.

1.Introduction
The city of Bisha, located in the southern Kingdom of Saudi Arabia, is experiencing a sharp increase in its population, leading to an escalation in the generation of solid waste. As the city develops, and is in line with global trends, Bisha

urgently needs to develop a sustainable waste management system that can efficiently deal with the increasing volume of waste. To address these challenges, this research proposal aims to implement a smart system that supports waste management based on geographic information systems in the city of Bisha, seeking to evaluate the spatial distribution of waste bins. The rapid increase in solid waste generation can be attributed to factors such as the continuous economic growth experienced by cities, urbanization, and the continuous industrialization that the world is still experiencing (Danbuzu et al., 2014).
As the generation of waste surges, waste collection has become critical, despite its costs in today's waste management structures. According to Vu et al. (2020), waste collection is said to constitute about 50% of the total costs incurred in waste management endeavors. This issue has necessitated the innovation of a sustainable waste management program to help eliminate the threat that solid waste poses to people and the environment. Over the past few years, there have been extensive studies conducted on technological systems such as the use of vehicle routing systems, network analysis, and GIS to help reduce the expenses of waste collection and make the entire process more effective and efficient (Ramos et al., 2018). In their study, Vu et al. (2020) note that there have been numerous researches on GIS that have provided evidence of the ability of this system to lower the overall costs of solid waste management.

A study conducted by Danbuzu et al. (2014) reflects on how GIS can be effectively utilized in finding the best routes to use while managing solid waste. Danbuzu et al. (2014) indicate that GIS is essential in combining spatial data, that is maps, aerial photographs, and satellite images with non-spatial data, both quantitative and qualitative to help in the collection operations, customer service, analyze optimal locations for transfer stations, plan routes for vehicles that transport waste, which all help in effective disposing of solid waste. Purkayastha et al. (2015) emphasized the significance of improving waste bin placement while reducing open dumping areas as an important step towards a sustainable and green world. In their study, Afzal et al. (2021) assessed the spatial distribution of waste bins in Karachi through GIS techniques. Their results showed that the government did not follow proper criteria for the placement of waste bins in the city.

Further, while conducting a study on Ejisu Municipality, Fuseini et al. (2021) noted that despite efforts that have been made to try and contain the solid waste menace, little progress has been achieved. The challenges encountered are attributed to the inadequacy of collection bins in the municipality. As a solution, Fuseini et al. (2021) indicate that the stakeholders involved must assess the spatial distribution of the waste bins that have already been provided, using an accurate technique of the GIS methodology, which was hitherto not employed in earlier assessments of communal waste bin utilization. As such, by using this technology, garbage collection firms can effectively use the small spaces that are within cities to get rid of solid waste. With this being the case, it is essential to conduct an in-depth study on a GIS-based smart waste management system that can help assess the spatial distribution of waste bins, to better understand how solid waste can be managed effectively in a much more complex society.

1.1 Objectives of Study

The main aim of this study is to develop a smart waste management system based on GIS Analysis to assess spatial distribution of waste bins points in Bisha.

The research objectives include the following:
1. To assess the spatial distribution of waste bins points in Bisha using GIS Analysis.
2. To evaluate the effectiveness of the GIS-based system in improving waste management efficiency.

1.2 Problem Statement

The United Nations Environment Programme (UNEP) envisions a world with a safe environment for all, including efficient and effective waste management systems. UNEP identifies as the people's partner for the planet and has waste management as one of its main focus areas between 2022 and 2025 to enhance climatic stability and create a future that is free from pollution (UNEP, 2022). The mission and vision of UNEP are in alignment with the Sustainable Development Goals (SDGs), specifically the 11th on sustainability of communities and cities and the 12th one of findings ways to maintain sustainable production and consumption patterns. Waste management takes center stage in the efforts towards attaining the global SDGs (Rodić & Wilson, 2017).

However, despite international efforts and commitments, waste management remains a significant challenge worldwide. Globally, experts explain that about 2 billion tons of solidified waste are produced each year, with projections indicating an increase to 3 billion tonnes in the next 17 years (World Bank, 2022). In the Middle East region, including Saudi Arabia, waste management practices face growing challenges as a result of their fast-paced patterns of development, population, and urbanization (Hussein, Uren, Rekik, & Hammami, 2022). It's worth noting that in 2016, the Middle Eastern region exhibited the lowest waste production, totaling approximately 129 million tonnes. However, this trend is anticipated to shift significantly in the coming years. Projections indicate that the Middle Eastern region, along with South Asia and Sub-Saharan Africa, will experience the most substantial increase in waste production over the next 17 years (World Bank, 2022). In Saudi Arabia, particularly in the city of Bisha, inadequate waste management has severe consequences, including environmental degradation, public health risks, and financial burdens (Ali, 2019). The inefficient collection routes and suboptimal spatial distribution of waste bins exacerbate the problem.

Recognizing the urgency of addressing issues of managing waste, smart waste management systems have been recommended as a viable solution (Farooq et al., 2022). It is on this basis that this study seeks to implement a GIS-based smart waste management approach in the city of Bisha, Kingdom of Saudi Arabia. This project is intended to assess the spatial distribution of waste bins and contribute to more sustainable and environmentally friendly waste management practices, thereby aligning with the UNEP's mission and vision for a safer and cleaner global environment (UNEP, 2022).

1.3 Area of Study

The research examines Bisha City as a field of study, an urban city nestled in the Asir province within the northwestern reaches of the Asir region as shown in Figure (1). Located between latitudes 0′19◦ and 51′20◦ N, and longitudes 50′41◦ and 5′43◦, Bisha City is situated roughly 260 kilometers to the north of Abha. It shares its northern borders with the Makkah Al-Mukarramah region, while to the south, is the center of Khaybar in Khamis Mushait Governorate. To the east, Bisha City's limits extend to the districts of Tathleeth, Jash, and Al-Sabikha in the Tathleeth Governorate, and to the west, it adjoins the Al-Baha region, along with the governorates of Balqarn and Al-Namas. Geographically, the city spans 185 kilometers from north to south, with its width varying from east to west. The narrowest width, around 48 kilometers, is found in the southern region, while the widest, approximately 120 kilometers, is in the northern area. Bisha City covers a total area of 659 square kilometers, and as of 2022, it was home to a population of 248,452 people, It also contains 25 neighborhoods, including Al-Khuzama, Al-Naseem, Al-Fahd, Al-Nakhil and Al-Rabwa etc.

Its significance predominantly revolves around its milestone, the King Fahd bin Abdulaziz Dam, strategically erected in Wadi Bisha, positioned 35 kilometers southwest of the city. Ranking as the second-largest dam in the Middle East, it impressively spans 507 meters in length and soars to a height of 113 meters, remarkably, it hosts the largest artificial freshwater lake in the Kingdom, spanning 30 square kilometers and featuring a remarkable storage capacity of 352 million cubic meters of fresh water. Bisha is a highly important agricultural region due to its fertile soil and its various valleys as it is famous for date palm cultivation.

Figure 1. The location of the city of Bisha in the Kingdom of Saudi Arabia in 2023

1.4 Hypotheses of the study

To achieve the primary objective of the research, the following hypotheses were developed:
Hypothesis 1. There is a strong relationship between population distribution and the number of waste bins in the city of Bisha.
Hypothesis 2. The distribution of waste bins in the city of Bisha is subject to specific standards.

2.Methodology

The researcher utilized Geographic Information System (GIS) as a tool for generating maps and conducting spatial analysis. This was accomplished using a software program known as "Arc GIS 10.8," with the aim of elucidating the spatial arrangement of the phenomenon under investigation. The accomplishment of this step involved the establishment of a geo-database through the utilization of a software application known as "Arc Catalogue" which consists of a collection of feature classes containing data on various aspects of urban areas. This allows researchers to perform spatial statistical analyses, density analyses, pattern analyses, proximity analyses, and spatial interpolation analyses.

The study relied on field work to determine the distribution locations of various types of waste bins through a GPS device (Global Positioning Systems).

To achieve the research objectives, the study is structured into two primary parts.

- The spatial distribution of waste bins in the city of Bisha.
- Spatial statistical analysis of the distribution of waste bins using geographic information systems
-

2.1 Data Collection

Data used in this research have been collected from various sources such as research studies, surveys, government databases, public records, private companies, academic institutions. The accessibility of the data depends on its source and any restrictions or permissions associated with it. The availability of the data on which an operation is performed depends on various factors. It can be determined by the source of the data, whether it is publicly available or proprietary. Additionally, the data's accessibility may depend on any legal or privacy restrictions that apply to it. In some cases, the data may be readily available and easily accessible, such as public datasets or open-source databases. These types of data are typically freely available for anyone to use. However, there may be situations where the data is not readily available or requires specific permissions or licenses to access. This can be the case with proprietary datasets owned by companies or organizations that restrict access to their data. Furthermore, certain types of sensitive data, such as personal information or classified government data, may have strict regulations and restrictions on their availability and usage.

3. Results & Discussion

3.1 Spatial distribution of waste bins in the city of Bisha

The city of Bisha is divided into 25 neighborhoods. The distribution of waste bins varies across these neighborhoods. By analyzing Figure (2), the following results can be recorded:

- The number of waste bins in the city of Bisha reached 1,325 different bins, about half of which are a 200-liter waste barrel, while 2-yard bins constitute about 30%, and large-sized bins that reach 4 yards constitute about 20%.
- Al-Khuzama neighborhood leads the city's neighborhoods as it contains 11.2% of the total waste bins, followed by Al-Fahd neighborhood with 9.5% of the total bins, and thus the two occupy more than a fifth of the total bins in the city, and the reason for this is due to the concentration of population there and the high population density therein, as They account for more than a quarter of the city's population, which numbered just over 240,000 people.

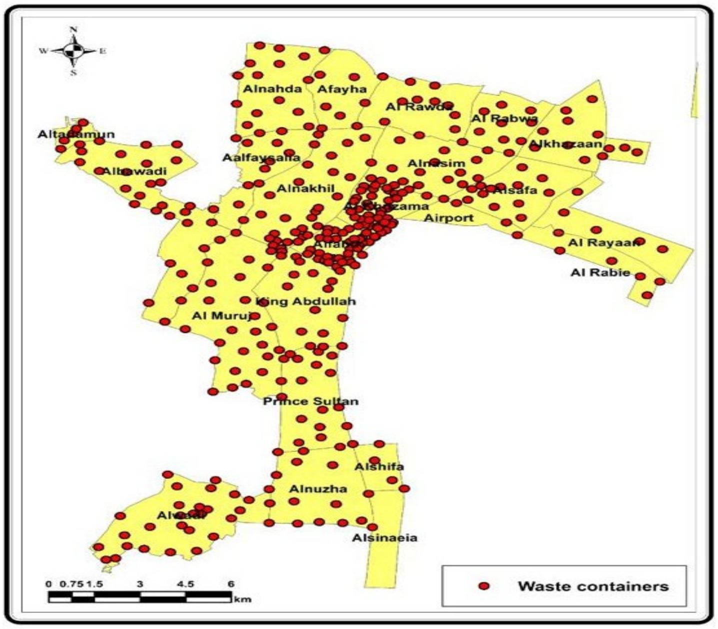

Figure 2. Distribution of waste bins according to the neighborhoods of the city of Bisha in 2023

- The King Abdullah, Prince Sultan, and Nakheel neighborhoods account for about 20% of the total waste bins in the city, and the matter is also related to the concentration of population, and thus approximately 40% of the bins are distributed among five neighborhoods in the city.
- About 60% of the waste bins are distributed among 20 neighborhoods, and its decrease is observed to reach its lowest in the Alsinaeia, Shifa, and outlying neighborhoods. This is explained by the decrease in population density in those neighborhoods and the shrinkage of the built-up mass therein.

3.2 Spatial statistical analysis of the distribution of waste bins using geographic information systems

A waste container in Bisha City refers to a receptacle or bin specifically designated for the disposal of waste, such as household garbage or recyclable materials. These containers are strategically placed in public areas, residential neighborhoods, or commercial zones to facilitate proper waste management and disposal practices within the city. The containers are typically part of a broader waste management system implemented by local authorities to maintain cleanliness and environmental sustainability. Waste containers in Bisha City serve as crucial components of the city's waste management infrastructure. They are designed to efficiently collect and contain various types of waste, promoting organized disposal and reducing the impact on the environment. The placement and distribution of these containers are determined by local authorities based on population density, public spaces, and other relevant factors. Residents and businesses are encouraged to responsibly use these containers to contribute to a cleaner and healthier urban environment.

Geographic Information Systems (GIS) contribute to reaching accurate and rapid statistical results for the distribution of phenomena, including waste bins, by building a spatial and descriptive database from which it is possible to extract connections between waste bins on the one hand, and the geographical phenomena surrounding them and influencing them on the other hand, in addition to identifying Their patterns and characteristics, in a way that traditional methods cannot, through spatial statistical analysis methods, which measure the spatial relationship between phenomena based on measuring location, shape, dimensions, and areas. Spatial analysis tools are numerous, and we will apply analyzes of them: measuring geographical distribution, density, patterns.

3.2.1 Measuring Geographic Distributions

It reveals the characteristics of the spatial organization of waste bins, the extent of their concentration or dispersion, and their directions. Therefore, they are also known as spatial measures of dispersion and spread, and include the following methods (Figure 3):

Mean Center: The mean center in GIS (Geographic Information System) refers to the average geographical location of a set of points or features on a map. It is calculated by determining the center point based on the spatial coordinates (latitude and longitude) of the features. The mean center provides a central reference point that represents the spatial distribution of the data set. This concept is commonly used in spatial analysis and can be valuable for understanding the overall geographic tendency of a set of locations**.** The location that is considered a geographical average of the locations of waste bins is determined, and it is calculated from the Spatial Statistics Tools box, including the Measuring Geographic Distributions group in the Arc GIS 10 program. By applying it, it was found that the spatial average of the distribution of waste bins is located in the south of Al-Fahd neighborhood (Figure 3 This is explained by its location in the city center, the concentration of population there, in addition to the fact that it contains a large percentage of waste bins.

Central Feature: In GIS (Geographic Information System), central features refer to key components or functionalities that play a central role in the system. Some central features include: Spatial Data: The core element of GIS, spatial data represents the geographic features and attributes that are analyzed and visualized on maps. Data Analysis: GIS allows for various spatial analyses, such as overlay operations, buffering, and proximity analysis, enabling users to derive meaningful insights from spatial data. Mapping: GIS facilitates the creation, display, and analysis of maps, helping users visualize spatial patterns and relationships. Data Layers: GIS organizes spatial data into layers, allowing users to manage and analyze different types of information independently. Geocoding: The process of assigning geographic coordinates (latitude and longitude) to locations, allowing non-spatial data to be placed on a map. Remote Sensing Integration: GIS often integrates data from remote sensing technologies like satellites or aerial imagery to enhance spatial analysis and mapping. Spatial Querying: Users can perform queries based on spatial relationships, enabling them to extract specific information from a spatial dataset. Geodatabases: These are specialized databases designed to store, manage, and retrieve spatial data efficiently. Cartography: The science and art of mapmaking are integral to GIS, ensuring effective communication of spatial information. Geospatial Analysis: GIS supports advanced analyses such as spatial statistics, modeling, and decision-making, contributing to informed spatial planning and management. These central features collectively make GIS a powerful tool for understanding and interpreting geographic information in diverse applications, from urban planning to environmental management**.** The existing waste bins that are located as close as possible to the previously extracted spatial average are identified, and it is calculated from the Spatial Statistics Tools toolbox, including the Measuring Geographic Distributions group in the Arc GIS program. By applying it, it turns out that the waste bins that are the center of the spatial distribution are located in the north of Al-Fahd neighborhood, the distance between them does not exceed 1.7 km.

Standard Distance: In GIS (Geographic Information System), "standard distance" typically refers to the standard deviation distance or standard distance ellipse. It is a statistical measure used to quantify the dispersion or spread of point data in a spatial dataset. The standard distance is calculated based on the spatial distribution of points and provides a measure of how tightly or loosely clustered the points are around their mean center. A smaller standard distance indicates a more concentrated distribution, while a larger standard distance suggests a more dispersed pattern. The standard distance is often used in spatial statistics and analysis to understand the spatial variation or clustering of features, especially in point pattern analysis. It helps researchers and analysts gain insights into the geographic patterns and relationships within a dataset. To measure the extent to which waste bins are spaced or spatially concentrated, the standard distance value is used to draw a circle called the Circle Standard, through which one can know the extent to which the spatial dimension of the phenomenon is concentrated or dispersed. The center of this circle is the spatial average, and the larger the standard distance value, the larger the size. The standard circle whenever this indicates an increase in the spread and spatial dispersion of the phenomenon and vice versa, that is, the radius of the standard circle determines the area where most of the components of the phenomenon under study are concentrated. The options in the Arc GIS program allow defining three measurements for the Circle Size, the first of which determines the concentration of 68% of the phenomenon's components, the second of which determines the concentration of 95% of the phenomenon's components, and the third of which determines the concentration of 99% of the phenomenon's components. The first was applied in this study. Applying this method to the distribution of waste bins in the neighborhoods of the city of Bisha showed that the standard distance is 63,638 meters, which is the radius of the standard circle, and 702 bins are located within it, constituting 53% of its total in the city, hence the lack of appropriate distribution of waste bins, and their tendency toward dispersion. Because it is assumed that a circle with a radius of one standard distance includes 68% of the phenomenon if the distribution is appropriate. Otherwise, the distribution is affected by other factors.

3.2.2 Directional Distribution

It is known as the Standard Deviation Ellipse, and the distribution pattern of geographic phenomena (points) can be inferred from it, and whether it has a specific direction or not? This is done by obtaining an oval shape that expresses the characteristics of the directional distribution, where the center of this shape is applied to the middle center point, and its largest axis measures the value of the direction taken by most of the components of the phenomenon. Applying the distributional direction to the waste bins in the city of Bisha resulted in the following results:

- The standard distance value in the direction of the X axis (half of the major axis of the oval) = 46024 meters.
- The value of the standard distance in the direction of the Y axis (half the minor axis of the oval) = 77338 meters.
- The value of the angle (skew) of the distribution (the angle of inclination of the major axis measured from the north direction) = 19.7, meaning that the distribution of waste bins takes an oval shape extending from the northeast to the southwest, and the reason for this is the location of the city of Bisha on flat land in the same direction.

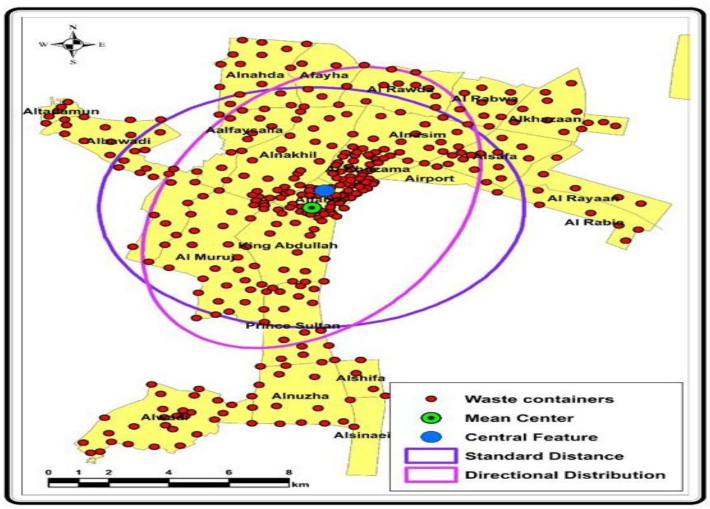

Figure 3. Results of applying analyzes measuring the geographic distribution of waste bins in the city of Baish in 2023

4.Analyzing Patterns

These analyzes reveal the patterns of distribution of waste bins, and whether they have a specific pattern, and therefore there are factors influencing their formation. Therefore, our interest in knowing the pattern will lead us to search for the factors leading to its formation, or is their distribution random, and we will discuss these analyzes as follows: (Figure 4):

4.1 Nearest Neighbor Analysis

Through it, it is possible to know the pattern of distribution of waste bins in the city of Bisha, and whether their distribution takes a consistent, random, or concentrated pattern, as it is calculated based on the distances separating the location of each bin from the other locations closest to it, then the average distance between these points is calculated, then dividing the average Calculated on the expected average of the total distances between all locations. If the resulting distance is less than the expected average of the random distribution, the distribution of bins in that case takes a clustered form. If it is larger, it takes a dispersed distribution, and its value ranges between (zero and 2.15). If the result ranges from zero to one, the distribution is close. If the result is one, the distribution is random. The distribution is divergent or dispersed, if it ranges. The formula for finding nearest neighbor analysis can be computed as follow:

$$NNA = \frac{\overline{D}(O)}{\sqrt[0.5]{\frac{A}{N}}}$$

Where, $\overline{D}(O)$ represents the observed nearest neighbor distance. The A represents area under study, while N represents total number of points in the area. The result is between one correct, 2.25, and the results of its application (Figure 4-A) revealed a value of (0.233), while the value of the standard Z Score was (-49.4), which is less than the critical value range (the Critical Value range ranges (-2.58, + 2.58), If the Z Score value associated with the standard deviation from the mean falls outside the critical value range, then we accept the alternative hypothesis that the distribution takes a non-random pattern, and vice versa). As for the probability value, it was recorded (0.0000), which means that the distribution of waste bins in the city Bisha takes a clustered pattern, with a very high confidence level of 99%, and a very weak probability of no more than 1% that the distribution pattern tends to be random or regular.

4.2 K Function Analysis

It is known as the “K function” through which the distribution of waste bins can be determined, and whether it represents a statistically significant gathering or dispersion across a range of distances. The “K function” indicates the average values of the distance separating each bin from the rest of the bins within a specific distance, and the result is compared to the average The expected distance between the same bins within the same distance in the case of a random distribution, and the actual and potential “K function” are represented graphically on the vertical axis, while the distance values are represented on the horizontal axis, In order to identify the significance of the resulting statistical model, a specific confidence level is determined when comparing the distribution of actual and theoretical values, and the upper and lower confidence limits are determined to be represented graphically. They originally represent the confidence limits for a random distribution, and then if the curve of the actual values exceeds the upper limit of the confidence level, the cluster with Statistical significance at this distance indicates the concentration of the elements of the phenomenon, while if the curve of the actual values exceeds the minimum level of confidence, the dispersion is statistically significant at this distance and indicates the dispersion of the elements of the phenomenon, while increasing the gap between the actual and theoretical “K function” values indicates a concentration Elements of the phenomenon.

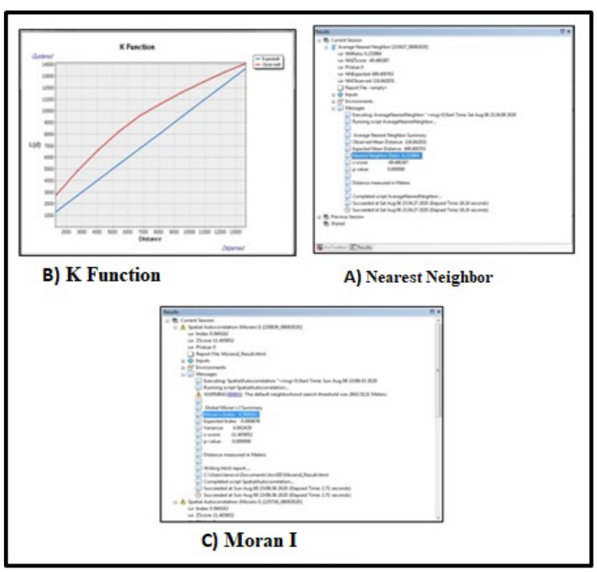

Figure 4. Results of applying analyzes of waste bins patterns in the city of Bisha in 2023

The results (Figure 4-B) showed that the curve of the observed “K function” value is higher than the expected “K function” value curve, and therefore the distribution pattern of waste bins takes a clustered shape, with a slight variation at some distances, which is a result that is consistent with the result of the analysis Neighborhood, this is due to the concentration of waste bins in specific locations, previously mentioned, with a very high level of confidence as a result of the actual "K function" curve being far from the curve of the upper limits of confidence. The K-Function can be described by the following equation:

$$KF = \sqrt{\frac{AoS \sum_{i=1}^{n} \sum_{j=1, j \neq n}^{n} k_{i,j}}{\pi n^2 - \pi n}}$$

Where n represetns the total number of features, AoS is the area of study and $k_{i,j}$ is the wieght.

4.3 Moran I Analysis

It is known as autocorrelation or spatial correlation analysis, and it determines the pattern of spread of a phenomenon spatially by studying the symmetry in the distribution of the phenomenon's components spatially, and the extent of autocorrelation between them. It differs from nearest neighbor analysis in that it depends on entering another value that is taken as a criterion in calculating the spatial correlation, such as the number of populations, Moran's index values range between (-1, + 1). If the value is close to (-1), it means a dispersed or divergent distribution, while if it is close to (+1), it means a clustered or convergent distribution. Finally, if the value is close to Zero means that the distribution is random.

According to the results of applying Moran's guide (Figure 4-C), the distribution of waste bins in the city of Bisha takes a clustered pattern, as its value reached (+ 0.56). This was confirmed by the Z Score value of (11.40), as it falls outside the Critical Value range. (-2.58, + 2.58), with a confidence level of 99%, hence the number of waste bins increases in places with high population density.

$$\mathrm{z} = \frac{\mathrm{X} - \mu}{\sigma}$$

The X represents the data value, while $\mu, \ \sigma$ represents mean and standard deviation respectively.
The Moran's I spatial correlation can be computed as follows:

$$MI = \frac{n}{W_0} \frac{\sum_i^n \sum_j^n w_{i,j} z_i z_j}{\sum_{i=1}^n z_i^2}$$

Where z_i is used to represent the deviation of a given attribute for a particular feature from its mean, and $w_{i,j}$ is the spatial weight between two features i and j from total features n. We can represent the aggregate weight W_0 by

$$W_0 = \sum_j^n w_{i,j}$$

The formula for finding Z_I score can be described by the following equations.

$$Z_I = \frac{I - E(I)}{\sqrt{V(I)}}$$

$$E(I) = \frac{-1}{(n-1)}$$

$$V(I) = E[I^2] - E[I]^2$$

5. Conclusion

In conclusion, the current spatial distribution of waste bins in the city of Bisha is suboptimal and tends to cluster in areas with higher population density. Geographical distributions revealed that the waste bins were not evenly distributed throughout the city. Standard distance analysis indicated that a significant portion of the bins were located within a relatively small area, highlighting the need for a more balanced distribution. Directional distribution analysis showed that the distribution pattern of waste bins in the city had an oval shape, with the major axis extending from the northeast to the southwest, influenced by the city's flat topography. To achieve more efficient and sustainable waste management, it is essential to develop strategies that result in a more even distribution of waste bins across the city. The proposed smart waste management system based on GIS analysis provides a valuable tool for city planners and waste management authorities to optimize waste bins placement and collection routes, ultimately contributing to a cleaner and more environmentally friendly Bisha. The research aimed to develop a smart waste management system based on GIS analysis to assess the spatial distribution of waste bins in Bisha. By implementing the recommended changes in waste bins distribution and collection routes, Bisha can take a step closer to achieving its waste management goals and aligning with international efforts to create a cleaner and more sustainable environment.

The GIS-based smart waste management system in the City of Bisha, Saudi Arabia, effectively assesses the spatial distribution of waste bins. Results indicate optimized placement for efficient waste collection, minimizing environmental impact. Discussion should delve into the system's benefits, challenges, and potential improvements to enhance urban sustainability. The system likely contributes to improved waste collection logistics, reduced operational costs, and enhanced overall cleanliness. Discussion should explore any observed variations in waste generation patterns across different city zones and propose strategies for dynamic bin allocation based on real-time data. Additionally, community engagement and technology scalability could be key points for discussion to ensure the long-term success of the GIS-based smart waste management initiative. Moreover, the study may discuss the integration of sensor technology for real-time fill level monitoring in waste bins, addressing issues such as overflow prevention and timely collections. Evaluating the economic viability and social acceptance of the system could provide insights into its sustainability and widespread adoption. Furthermore, comparisons with traditional waste management methods could highlight the tangible advantages of the GIS-based approach in terms of resource efficiency and environmental impact

References

Afzal, A., Afsar, S., Lahori, A. H., and Kausar, A. Assessment of Spatial Distribution of Waste Bins in Karachi through GIS Techniques. *International Journal of Economic and Environmental Geology*, vol. 12, no. 1, pp. 9–13 June 2021, https://doi.org/10.46660/ijeeg.vol12.iss1.2021.551.

Ali, E. E., Seedahmed, A. I., Abuhasil, K. I, and Abdallah, K. A., Design and Utilization of a Pyrolysis Unit to Convert Plastic Waste into Fuels (Bisha-Kingdom of Saudi Arabia - as a case study). *PontE International Journal of Science and Research*, vol. 75, no. 4, p. 11, 2019.

Danbuzu, L. A. S., Tanko, A., Ibrahim, U. A., and Ahmed, M., Spatial Distribution of Solid Waste Collection Points Using GIS Approach in Urban Katsina, Katsina State, Nigeria. *Semantic Scholar*, 2014, www.semanticscholar.org/paper/Spatial-Distribution-of-Solid-Waste-Collection-GIS-Danbuzu-Tanko/591d13ff887ffb8d6672940326d6bb479bfea3d2.

Farooq, M., Cheng, J., Khan, N. U., Saufi, R. A., Kanwal, N., and Bazkiaei, H. A., Sustainable Waste Management Companies with Innovative Smart Solutions: A Systematic Review and Conceptual Model. *Sustainability*, vol. 14, no. 20, p. 13146, Jan. 2022.

Fuseini, A. K. W., Appiah, D. O., Sabi, G. K., and Aidoo, K. M., Analysis of Spatial Distribution of Solid Waste Disposal and Collection Points in Urban Ghana; the Case of Ejisu Municipality. *Semantic Scholar*, 2021, www.semanticscholar.org/paper/Analysis-of-Spatial-Distribution-of-Solid-Waste-and-Fuseini-Appiah/a6ae03b6763b0665b6e559d9334b7edaa868f2a3

Hussein, L., Uren, C., Rekik, F., and Hammami, Z., A Review on Waste Management and Compost Production in the Middle East–North Africa Region. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, vol. 40, no. 8, pp. 1110-1128, Dec. 2021.

Purkayastha, D., Majumder, M., and Chakrabarti, S., Collection and Recycle Bin Location-Allocation Problem in Solid Waste Management: A Review. *Pollution*, vol. 1, no. 2, pp. 175–191, 2015.

Ramos, T. R. P., de Morais, C. S., and Barboa-Povoa, A. P., The Smart Waste Collection Routing Problem: Alternative Operational Management Approaches. *Expert Systems with Applications*, vol. 103, pp. 146–58, Aug. 2018, https://doi.org/10.1016/j.eswa.2018.03.001.

Rodić, L. and Wilson, D., Resolving Governance Issues to Achieve Priority Sustainable Development Goals Related to Solid Waste Management in Developing Countries. *Sustainability*, vol. 9, no. 3, p. 404, Mar. 2017.

UNEP. Medium-Term Strategy 2022—2025. Available: https://wedocs.unep.org/bitstream/handle/20.500.11822/35875/K2100501-e.pdf , Accessed on November 13, 2023.

Vu, H. L., Ng, K. T. W., Fallah, B., Richter, A., and Kabir, G., Interactions of Residential Waste Composition and Collection Truck Compartment Design on GIS Route Optimization. *Waste Management*, vol. 102, pp. 613–23, Feb. 2020. https://doi.org/10.1016/j.wasman.2019.11.028.

World Bank. Trends in Solid Waste Management., Available: https://datatopics.worldbank.org/what-a-waste/trends_in_solid_waste_management.html, Accessed on November 21, 2023.

Biographies

Ghadah M Khushail is an undergraduate student in her final year of Industrial Engineering at the University of Bisha with exceptional academic performance. She actively contributes as a scientific content writer within the Research and Publications section at IEOM UB student chapter and is a member of Sustainable Development Division at IISE. Ghadah holds leadership positions in both the Engineering Club and the Renewable Energy Club at the University of Bisha. She received a cooperative training at Saudi Aramco, the world's leading energy company. Her research interests include optimization, sustainability, environmental health, and risk analysis.

Ghaida Fahad Alqarni is an undergraduate student in her final year of Industrial Engineering at the University of Bisha. She was trained at the Saudi Telecom Company (STC) for two months, and she has held several positions in extracurricular activities, including member of the Planning and Organization Renewable Energy Club. She was a member of research and publication at the IEOM UB student chapter, and she is now a member of Cooperation and Internship. She was also a member of the Quality Department at the Engineering Club. Her research interests include sustainable manufacturing, risk analysis, and smart manufacturing.

Refan M Alshahrani is an undergraduate student in her final year of Industrial Engineering at the University of Bisha, interested in industrial engineering with a focus on quality control, sustainability, and safety. Leader of the research and publication team at UB IEOM, member of the development and follow-up team in the Renewable Energy Club, She was trained at the Saudi Telecom Company (STC), which is the Saudi digital enabler of telecommunications services in the Kingdom of Saudi Arabia. In the transmission department. Her research interests include sustainability, spatial analysis and environmental safety.

Reema M Almotawa is an undergraduate student in her final year of industrial engineering at the University of Bisha. She trained a Saudi Telecom Company (STC) for two months, in transmission department. She is a member of the Social and Technology team at UB IEOM Student Chapter and member of the Planning and organization team at the Renewable Energy Club for Bisha University. Her research interests include sustainability, public service, and risk analysis.

Khaled Ali Abuhasel received the B.Sc. and M.Sc. degrees from the University of Central Florida, Orlando, FL, USA, in 2009 and 2010, respectively, and the Ph.D. degree from New Mexico State University, Las Cruces, NM, USA, in 2012, all in industrial engineering. He is currently a Professor with the Mechanical Engineering Department, University of Bisha, Saudi Arabia. He holds three U.S. patents, and more than 67 publications in journals and proceeding of very reputable conferences. His research interests include optimization, systems engineering, health care systems, intelligent systems, artificial neural network methodologies, and statistical analysis.