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GIS-Based Solid Waste Identification and Optimized Route Planning for Collection and Dumping in Quetta City

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ABSTRACT

Solid waste management is one of the major issues in developing countries facing rapid urbanization. This research focuses on the identification, analysis, and optimization of waste collection and disposal routes, aiming to revolutionize the city's waste management system. By leveraging advanced spatial analysis techniques, this work seeks to address the pressing challenges of urban waste handling and contribute to sustainable urban development. The opening section highlights the issues confronting cities underscoring the importance of implementing an organized waste management system in Quetta. The rising population numbers and swift urban development amplify the need, for waste disposal solutions. To tackle this challenge GIS technology plays a role in this research by mapping analyzing and streamlining waste collection and disposal routes. The methodology focuses on utilizing GIS-based analysis to pinpoint areas producing significant solid waste and determining the most effective routes for collection and disposal. Optimistic collection timetables and routing strategies are developed by incorporating data on population density, waste generation rates, and geographical features. Furthermore, the research explores how this new waste management approach could impact both the economy and the environment. It considers aspects, like cost effectiveness reducing carbon emissions by improving transportation efficiency, and the possible positive effects on the city and its residents. The study emphasizes the importance of using GIS technology to transform waste management practices in optimizing collection and disposal routes for solid waste management in Quetta City. Additionally, the study points out the potential for enhancements in waste collection effectiveness, resource distribution, and environmental sustainability by implementing these optimized routes and strategies.

Keywords: *Geographic Information Systems (GIS), Remote Sensing (RS), Solid waste management, urbanization, Quetta.*

1. INTRODUCTION

The use of Geographic Information Systems (GIS) and sensing technologies to improve waste management routes has become increasingly popular for its ability to boost effectiveness and sustainability (Ajie & Igbokwe, 2023). Solid waste management, in areas is a pressing issue in developing nations facing rapid urbanization that strains the existing infrastructure (Ghose et al., 2006). The push, for waste management solutions has driven the adoption of geographic information system (GIS) and remote sensing (RS) tools to tackle challenges from waste creation to disposal. In the past poor waste management practices have resulted in health and economic issues (Gurjar & Gaur, 2022). City managers are grappling with challenges such as finding spots for transfer stations optimizing waste collection routes promoting efficient waste segregation strategically placing collection bins determining ideal locations, for metal recovery and recycling facilities, and choosing suitable landfill sites. Remote sensing (RS) and geographic information systems (GIS) provide a set of tools including methods, like evaluating multiple criteria tagging geographical data creating virtual boundaries, analyzing grouping data into clusters, etc. For instance, the use of multiple criteria analysis helps in pinpointing areas for waste disposal sites and transfer stations while cluster analysis assists in determining the locations, for material recovery and recycling facilities (Gurjar & Gaur, 2022).

Geographic information systems (GIS) and remote sensing (RS) are crucial, across industries, such as planning and environmental management. Waste management benefits greatly from GIS technology boosting efficiency cutting costs and streamlining waste collection and disposal processes. Urban areas grapple with waste management issues due to population growth. Increased solid waste generation. The cities face challenges, like waste collection, ineffective routing, and improper disposal methods leading to health risks. GIS-based techniques play an important role in identifying waste and routes for the transformation of waste away from urban areas.

Globally different studies have used geographic information system (GIS) and remote sensing (RS) for solid waste management. (Uslu et al., 2024) has analyzed (GIS) and Discrete Event Simulation (DES) for the enhancement of waste management processes. The study investigates the comparison, between these two methods in optimizing waste management systems based on bin locations. The study findings hold value for waste management professionals and policymakers by offering insights into cost reduction potential, carbon emission mitigation strategies, and overall efficiency enhancement, in waste management practices. (Fatima et al., 2023) has utilized GIS technology for efficient municipal solid waste collection and transportation route optimization. The study underscores the significance of choosing routes to reduce time and costs linked to waste management. This study also pointed out the travel paths for waste disposal ultimately enhancing the overall effectiveness of waste management systems. A study was conducted by (Ajie & Igbokwe, 2023) to enhance the solid waste collection routes in Port Harcourt Metropolitan City, Rivers State, Nigeria through RS and GIS. The research process involved gathering data, on road networks and spatial information about approved locations for waste collection using ArcGIS 10.8.2 software. The study also emphasized the potential for cost savings and improved waste management practices. (Ghose et al., 2006) has introduced a routing model based on Geographic Information System (GIS) to streamline the collection and transportation of waste efficiently in Asansol Municipality, West Bengal, India. By considering factors like population density, waste generation rates, road networks, and vehicle types used for collection the model aims to identify cost-practical routes, for transporting waste to designated landfills. (Gurjar & Gaur, 2022) has analyzed how RS and GIS technologies are being used in managing solid waste effectively.

In Pakistan (Aslam et al., 2022) carried out a research project that centered on pinpointing and prioritizing locations, for managing solid waste (MSW) in Faisalabad, Pakistan through the integration of RS and GIS techniques. Some studies have been conducted in Quetta such as (Khan Bazai et al., 2023; Muhammad et al., 2024), investigating solid waste management problems in Quetta City, Balochistan. The study delves into the public health repercussions of waste management practices highlighting the pressing need for sustainable solutions to tackle these issues. This study aims to assess solid waste management sites in Quetta City using geographic information system (GIS) and remote sensing (RS). The outcomes of this research are vital for educating decision-makers, local authorities, and stakeholders about the necessity for waste management practices in Quetta.

2. MATERIALS AND METHODS

2.1 Study Area

Quetta is the capital and largest city in terms of population in Balochistan province with an absolute location of 29°48' to 30°27' north latitudes and 66°14' to 67°18' east longitude (Figure 1) (Ullah et al., 2024; Ullah, et al., 2025). According to the 2023 census, 2.59 million people were living in the district with a population density of 752.97 people per square kilometer (Pakistan Bureau of Statistics, 2024). Quetta covers an area of 3,447 km^2 with an average elevation of 1,680 meters (Ullah et al., 2025). Quetta Valley is a mountainous region, bounded in the south by Mustung and Chaghi districts, in the north by Pishin, in the east by Sibi, and in the west by Afghanistan through the Durand Line. The district is facing several issues such as water scarcity, urbanization, solid waste management, overpopulation, natural disasters (floods), etc. Quetta like any other is experiencing significant challenges in solid waste management due to rapid urbanization and population growth. The improper disposal of waste, lack of efficient collection systems, and unregulated dumping sites contribute to environmental pollution and health risks. Many areas within the city face issues such as overflowing waste containers, irregular waste collection, and inadequate landfill management.

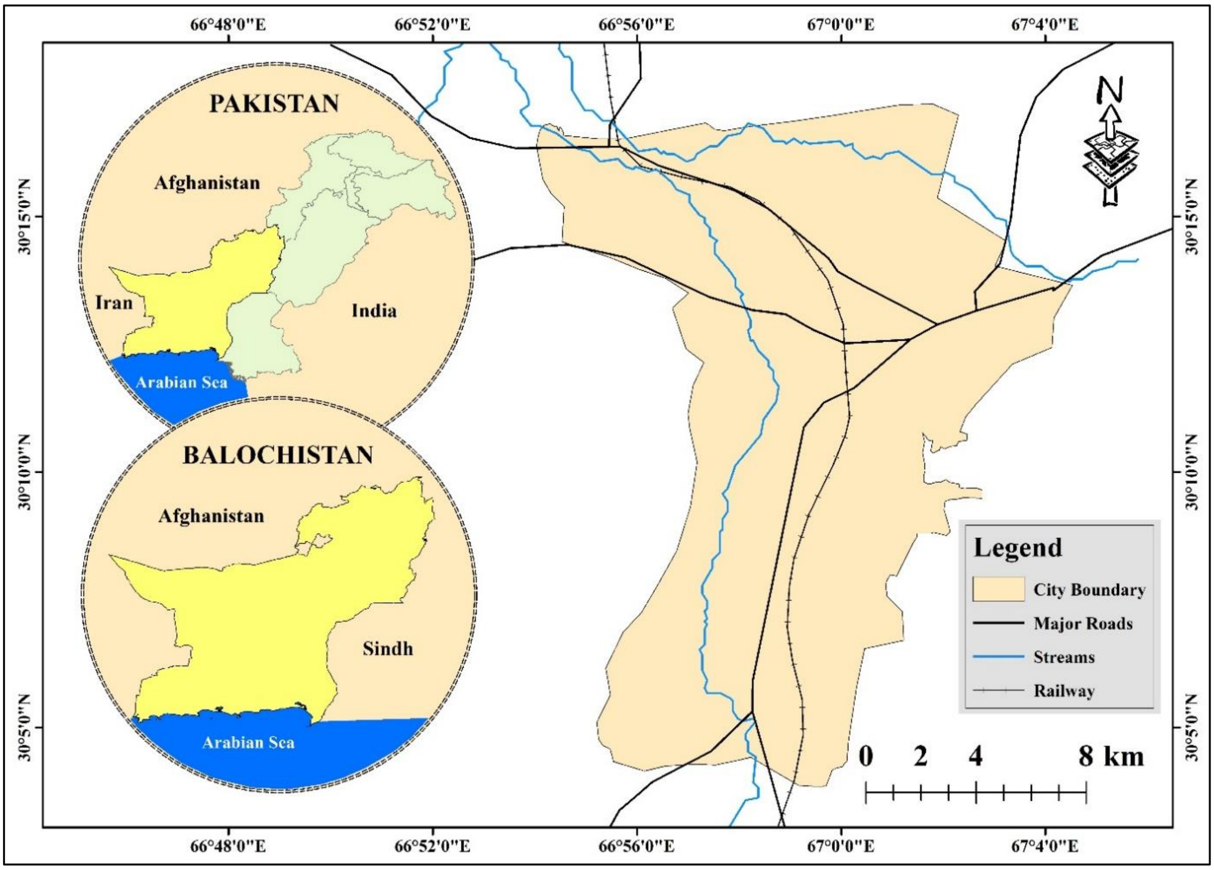

Figure 1. Study area map of the present study work.

A GIS-based approach can help identify the solid waste hotspots, and the optimized collection routes, and enhance the efficiency of waste management by reducing transportation costs and minimizing environmental impacts. Implementing an optimized waste collection and dumping system is crucial for ensuring a cleaner and more sustainable urban environment in the city of Quetta.

2.2 Methodology

This section describes in its following subsections how the issue of improving waste management in Quetta City is tackled while using GIS-based identification and route planning. Furthermore, it explains in detail the procedures for collecting, processing, and analyzing the data in the research study.

2.3The Conceptual Framework of Design and Procedure

To summarize as well as briefly depict the whole system of the employed procedure in one shot as a precursor to the formal explanation of the methodology, the following conceptual framework is given in the form of a flow-chart for easy understanding of the integrated and interconnected phases and stages of the whole process (Figure 2).

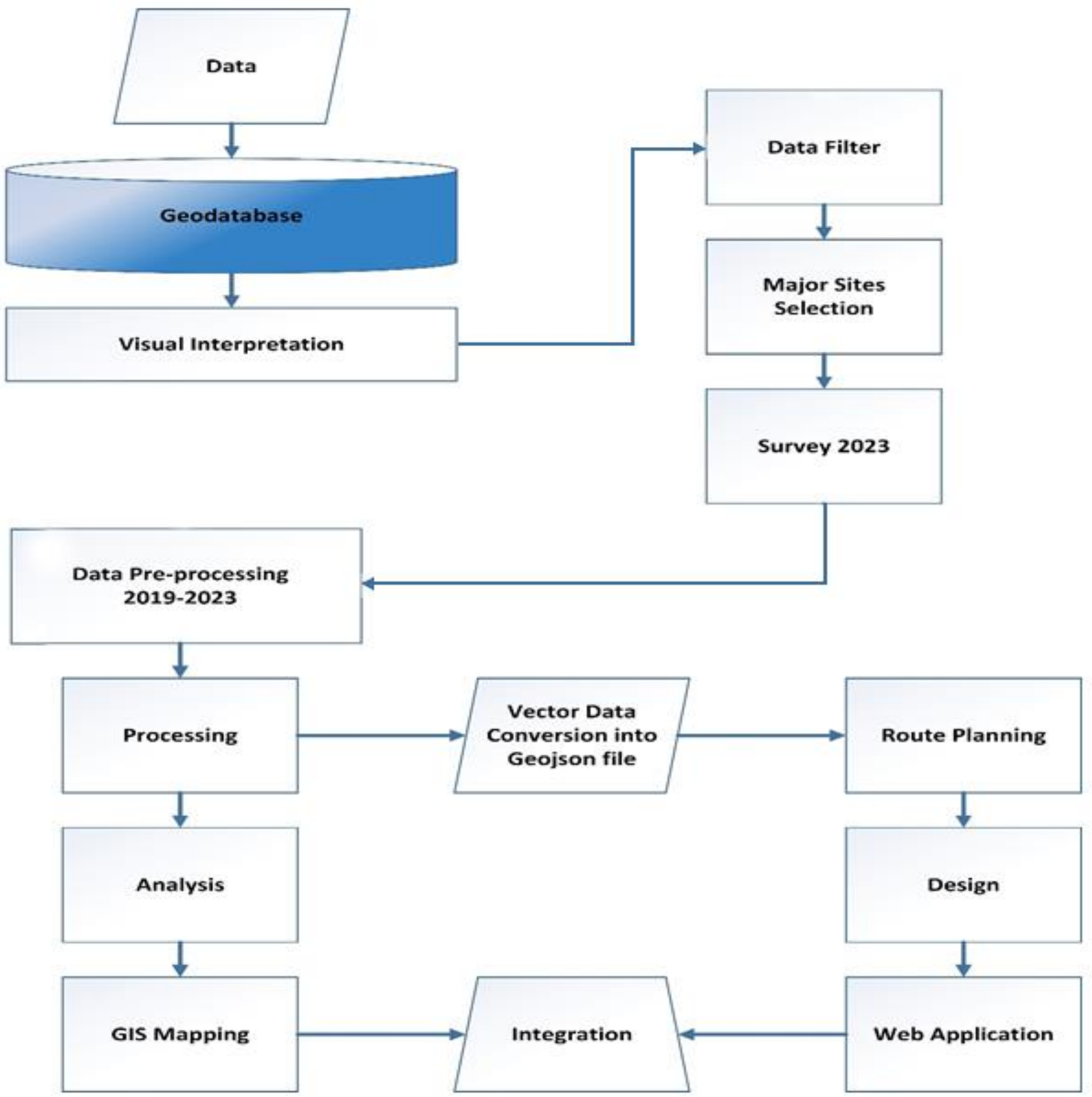

Figure 2. Detailed methodological workflow of the present study.

2.4 Data Collection and Management

In the current study, both primary and secondary data sources were utilized. The primary data were collected through field surveys in the study area. The information for this study was gathered from outlets, such as documents and surveys carried out in the year 2023.In order to cover/ incorporate different aspects of the study, a geodatabase was created so as to store and organize both non-spatial information. This database combines various sets of data, such, as population density, waste generation rates, and road networks which are crucial for conducting thorough GIS analyses.

As an exploratory mechanism before the utilization of formal analysis procedures, the visual analysis methods were applied to examine information, recognizing trends and irregularities in the disposal of waste as well as the routes taken for the waste collection. This initial process helped establish a grasp of how waste is managed within the location of the research area. To narrow down the scope of the data and for the sake of achieving better accuracy, data filtering was performed to guarantee the precision and applicability of the datasets utilized in the analysis. This procedure entailed eliminating anomalies and unimportant data points with a focus, on variables influencing waste management.

2.5Data Processing

After the completion of the initial steps, the data pre-processing procedure was carried out, which included the cleaning and organizing of datasets spanning from 2019 to 2023. This crucial step aimed to maintain uniformity and precision for analysis enabling integration, into the geodatabase. During the data processing stage, we transformed vector data into GeoJSON format, which works well with web apps and GIS tools. This phase also involved mapping out routes and designing them to improve waste collection efficiency.

2.6 Geospatial Analysis

Spatial relationships were assessed using GIS analysis to enhance waste collection routes. The main goal was to reduce travel distances and enhance the effectiveness of waste management processes. GIS mapping methods were used using ArcGIS 10.8.2 to display the routes and key waste locations. This combination offered a depiction of the waste management system aiding in improved decision-making and planning processes.

3. RESULTS

This section showcases the outcomes and discoveries of the approaches employed to enhance waste management in Quetta City. The aim here is to outline the setup, for testing procedures followed, and the results obtained through utilizing GIS and remote sensing tools. The findings encompass the identification and validation of disposal locations, examination of road networks for routing, and integration of these data points into Google Earth Engine for spatial analysis. This segment emphasizes the real-world implications of the study and delves, into how the results support the project's goals of enhancing waste collection effectiveness and sustainability.

3.1 Dumping Sites Marking

A total of 165 dumping sites were first. Labeled throughout Quetta City with the help of Google Earth Pro. A survey of 40 of these sites was kept for additional examination (Table 1).

Table 1. Distribution of dumping points in the study area.

Stage	Number of Points
Before Survey	165
After Survey	40

3.1.1 Verification of dumping points

The survey confirmed 40 out of the 165 dumping points initially marked showing that a considerable number of the noted points were either inaccurately labeled or not applicable anymore. This validation step played a role, in guaranteeing the precision and dependability of the data utilized for planning routes.

3.2 Importing Sites to GIS Environment

The confirmed data points were imported into ArcGIS 10.8.2 software allowing for analysis and visualization. This process facilitated analysis and visualization by importing the verified data points (Figure 3).

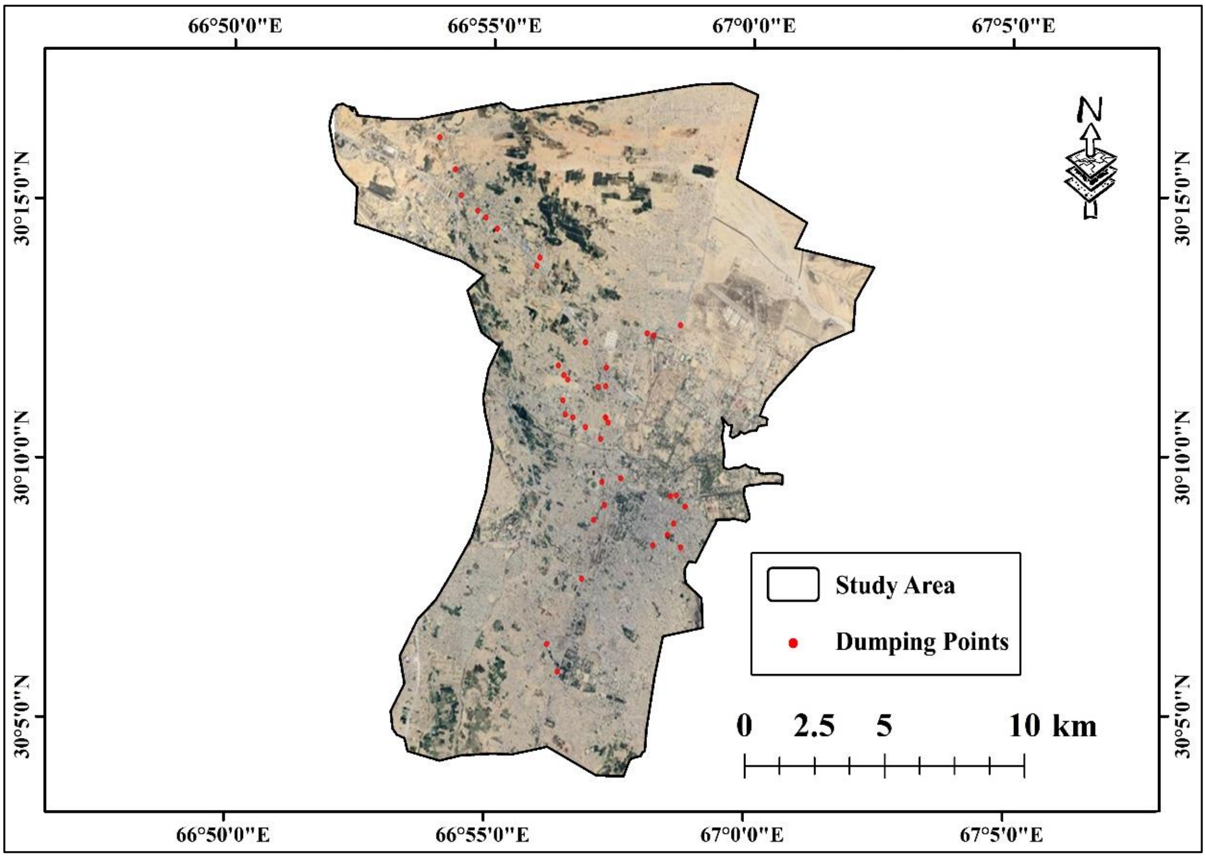

Figure 3. Dumping points visualization in the study area.

3.3 Road Network Analysis

Studying the road layouts was essential, in planning the garbage truck routes considering aspects such, as road conditions, traffic patterns, and accessibility. Road network analysis of the study area is shown in Figure 4.

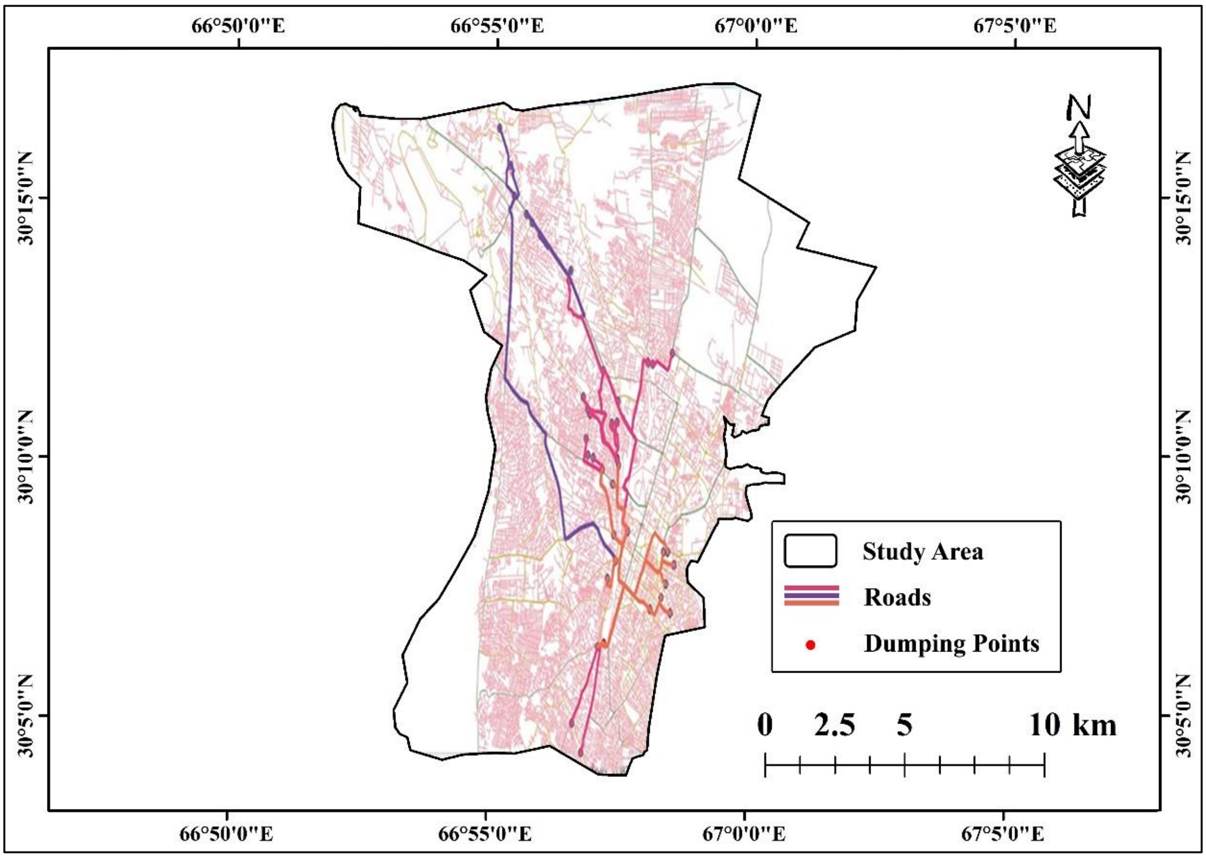

Figure 4. Road network analysis of the study area in the GIS domain.

3.4 Interpretation of Results

The findings, from this research showcase how GIS technologies have a role to play in improving waste management in Quetta City. Pinpointing and confirming dumping sites along, with utilizing route planning help enhance the effectiveness and sustainability of the waste collection process.

3.5 Significance of Findings

These findings are significant as they demonstrate the application of GIS technologies, in addressing waste management challenges. The improved accuracy in identifying disposal sites and optimizing waste collection routes offer advantages such as cost reduction minimizing impacts and enhancing the sustainability of Quetta City's waste management system. This model could be applied in other cities dealing with similar waste management challenges illustrating how GIS technology can improve efficiency and sustainability.

3.6 Relation to Existing Literature

Integration of GIS underscores the advantages of combining GIS with data analysis tools. In both instances, GIS offered insights for planning and decision-making, in waste management (Uslu et al., 2024). (Fatima et al., 2023) have emphasized the advantages of using GIS to enhance waste collection and transportation routes. The results of this study confirm these advantages showing enhancements, in effectiveness and environmental friendliness. Nevertheless, this research also points out obstacles that have been mentioned in studies like the importance of precise initial data and how urban changes affect waste management systems. Another study conducted by Ghose et al. (Ghose et al., 2006) encountered difficulties with the accuracy of dumping locations a challenge. This study also highlights the importance of enhancing both the data collection and validation processes for investigations. This study conducted by (Aslam et al., 2022) highlights the influence of dynamics on waste management. There is a call for exploration into how changes in infrastructure and population dynamics impact waste management systems over time.

3.7 Validity

Several measures were taken to ensure the validity and reliability of the findings. The measures taken to ensure data accuracy, cross-referencing of sources, and the use of reliable tools contribute to the validity of the findings. The study provides valuable insights into the application of GIS technologies in optimizing waste management, although further research with expanded resources and more comprehensive data collection is recommended to build on these findings. The following are some important steps taken for the validation of the present study;

- **Data Validation.** An extensive survey was carried out to confirm the dumping locations.
- **Data Comparison.** Information from a range of sources including on-site surveys, past records, and input from the community was cross-checked to boost the precision and trustworthiness of the data.
- **Utilization of Trusted Tools.** The research made use of GIS and remote sensing tools with a reputation for accuracy in data analysis. These tools played a role in reducing errors and biases during data processing and analysis.
- **Expert Advice.** Regular consultations with authorities and waste management professionals were held throughout the study to validate the discoveries and ensure their alignment, with real-world practicalities.

4. DISCUSSION

Louati and colleagues presented a smart routing algorithm based on heuristics, for the collection of waste (MSW) in their study. Their goal was to improve collection processes and reduce impacts. The research, published in the Journal of Ambient Intelligence and Humanized Computing highlights the impact of MSW on climate change and sustainable development. Using Python scripts within ArcGIS the algorithm focuses on creating collection routes reducing travel distances and optimizing vehicle operation times. The study was validated through a case study in Sfax, Tunisia a city facing challenges and high pollution levels. A specialized optimization model for MSW collection in Sfax was. Tested against real-world scenarios. The evaluation was done using the PROMETHEE method to consider economic factors. This research demonstrates the effectiveness of methods in improving MSW management practices providing insights, for urban areas worldwide dealing with similar issues (Louati et al., 2019).

Singh and Behera conducted a research study that focused on improving transportation routes, for managing waste (MSW) in Kanpur, India. They used Geographic Information System (GIS) tools and techniques to optimize the process. The study, which was published in "Advances in Waste Management" by Springer Nature aimed to address the challenges faced by bodies in handling large amounts of solid waste in Indian megacities. By utilizing optimization techniques and algorithms within the ArcGIS network analyst tool they proposed collection routes. The research considered factors such as waste point locations, existing road networks, planned transport routes, and disposal yard locations as parameters. The study focused on an area in Kanpur with eighteen wards and thirty-three collection points along with two transfer stations for MSW disposal. Their main goal was to reduce the distance traveled for waste collection through GIS-based modeling to enhance efficiency. The findings showed a 27.78 ± 10.2% decrease in haul distances for the chosen network indicating improved efficiency and cost-effectiveness in managing MSW within urban settings. This study adds insights to the existing literature, on enhancing MSW management practices using GIS tools and computational methods emphasizing the significance of strategic route planning to cut costs and lessen environmental impacts associated with waste transport. The results highlight the advantages of using GIS techniques to improve waste management systems, in urban areas such, as Kanpur (Singh & Behera, 2019).

Amal Louati, Le Hoang Son, and Habib Chabchoub introduced a method called Spatial GIS-based Genetic Algorithm (SGA) in their research article published in "Environmental Science and Pollution Research" in July 2018. This approach combines a modified Dijkstra algorithm with a Geographic Information System (GIS) to create optimized routes, for waste collection vehicles. These routes are further improved using a Genetic Algorithm (GA). Their study involved testing this method in Sfax City, Tunisia, where it outperformed routes and the original Dijkstra algorithm. The research emphasizes the effectiveness of integrating GIS and heuristic algorithms to enhance the efficiency of waste management systems (Amal et al., 2018).

Sumathi and colleagues conducted a study focusing on the aspect of selecting landfill sites for managing solid waste efficiently in urban areas, particularly in countries experiencing rapid urban growth, like India. The research highlights the need for waste management practices to address concerns and societal perceptions associated with landfills. Factors such as geology, land usage, water resources, air quality, and groundwater quality play roles, in making decisions. By utilizing Geographic Information Systems (GIS) and multi-criteria decision analysis (MCDA) the study integrates data sources to determine landfill locations based on weighted criteria. The outcomes of this approach demonstrate its potential to improve sustainability and effectiveness in deciding where to place landfills (Sumathi et al., 2008).

4.1 Limitations

- The process of collecting data may lead to a possible inaccuracy, in identifying dumping locations. This issue could have influenced the reliability of analyses and route optimizations.
- Factors such as changes in infrastructure population trends and waste generation patterns were not fully considered, potentially impacting how broadly the findings can be applied. The study was conducted during a timeframe so the results may not capture shifts, in urban dynamics.
- Limited resources constrained the survey and data collection limiting the depth of the study. A broader survey, with a pool, could have yielded more comprehensive data and enhanced the trustworthiness of the conclusions.

5. CONCLUSION

The main goal of this study was to enhance waste management in Quetta City by using GIS technologies. The key findings show that incorporating GIS tools greatly improves the effectiveness and sustainability of waste collection processes. The study successfully confirmed 40, out of the initially identified 165 dumping points underscoring the importance of data collection and verification in waste management planning. Analysis indicates that utilizing GIS for route optimization can significantly reduce travel time and operational expenses aligning with the study objectives. The research aimed to enhance the accuracy of identifying dumping points and optimize waste collection routes. Create a user app for real-time data management. These goals were mostly met. Thorough data verification ensured the reliability of identified dumping points while road network analysis and route optimization notably boosted waste collection efficiency. Additionally, the creation of the Earth Engine Pro application has offered a tool, for accessing real-time data and planning routes to aid in decision-making. The primary objective of the project was to improve waste management in Quetta City through the utilization of GIS technologies. The main findings demonstrate that integrating GIS tools can significantly enhance the efficiency and sustainability of waste collection processes. The study successfully verified 40 out of the 165 dumping points highlighting the importance of data collection and validation in waste management planning. Analysis suggests that utilizing GIS for route optimization can lead to reductions in travel time and operational costs aligning with the study’s goals. The research aimed to improve the accuracy of identifying dumping points and optimizing waste collection routes by developing a user-friendly application for real-time data management. These objectives were largely achieved through data verification ensuring the reliability of identified dumping points while road network analysis and route optimization notably improved waste collection efficiency. Additionally, creating the Earth Engine Pro app provided a resource, for accessing real-time data and planning routes to facilitate decision-making.

4.1 Future Work

While this project has made progress, in improving waste management in Quetta City through the use of GIS technologies there are still areas that require further investigation and enhancement. One important aspect to focus on in research is improving the accuracy of data collection. The current low verification rate of 24.2% indicates the need for methods to identify and confirm dumping locations effectively. Future studies could explore utilizing sensors, machine learning algorithms, and community engagement strategies to enhance data precision and dependability. Another significant area for exploration involves incorporating real-time data into the waste management system. This study predominantly relied on survey data, which may not fully reflect the nature of urban waste generation and disposal processes. By integrating real-time data from devices GPS trackers on waste collection vehicles and smart waste bins a precise and up, to date understanding of waste management requirements can be achieved. Adopting this real-time approach could result in responsive waste collection strategies ultimately boosting efficiency and sustainability efforts. Additionally, future research could explore the socio-economic factors influencing waste management practices. This study focused primarily on spatial and logistical aspects, but understanding the human dimensions of waste generation and disposal is equally important. Investigating how factors such as income levels, education, and community engagement impact waste management can provide deeper insights and inform more holistic solutions. Developing educational programs and community initiatives could complement technological solutions, fostering a more sustainable waste management culture.

Recommendations for future researchers include the importance of interdisciplinary collaboration. Combining expertise in GIS, urban planning, environmental science, and social sciences can yield more comprehensive and effective waste management solutions. Researchers should also consider the scalability of their solutions, ensuring that the methodologies and technologies developed can be adapted to different urban contexts and scales. Finally, engaging with local stakeholders, including government agencies, waste management companies, and community members, is crucial for the successful implementation and sustainability of waste management innovations.

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