Integrated Approach to Waste Management in Banepa Municipality: Combining Geographic Information System, Analytical Hierarchy Process, and Network Analysis for Landfill Site Selection and Route Optimization

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Key words: spatial planning, vehicle routing, network analysis, geographic information system, waste management, landfill site

SUMMARY

Rapid urbanisation and population growth in addition to the lack of a landfill site within the municipal boundaries have caused the garbage trucks to travel longer distances to dump waste, causing an increase in fuel consumption, and consecutively deteriorating the environment. This research addresses prevailing waste management issues of Banepa municipality by improving collection routes and timetables to avoid environmental problems and save monetary expenses also proposes an integrated approach to optimise the location of waste disposal sites and garbage truck routes to reach these using the Geographic Information System (GIS), Analytical Hierarchical Process (AHP), and Network Analysis. The optimal location for the landfill site was identified using AHP and GIS, considering various criteria, and the area needed for the next 15 years. For identifying suitable bin locations within the municipality, Network Analysis location-allocation problem, and vector analysis were used. 1436 waste bins of varying capacities were determined and allocated to each building within the municipality based on the population and waste generated. Based on vehicle capacity and bin size, 19 efficient routes were obtained using the Vehicle Routing Problem (VRP) initially and were later revised using the Travelling Salesman Problem (TSP), and efficient routes were identified by specifying 17 service areas for Banepa Municipality. To assess the usability of the obtained results, the optimized routes were compared to the present garbage truck's route from the municipality to the transfer station, i.e., Bhaktapur. It was found that the proposed route reduced the total traveling distance of the trucks by 213 Km which corresponds to 33% and the total traveling time was reduced by 30%. The result suggests that, upon following the proposed route the petroleum costs of garbage trucks could be reduced by 24% compared to the present price. Hence, the findings of this study highlight the important benefits of integrating GIS, AHP, and network analysis for optimal routes and garbage bin allocation for waste management, which leads to reduced greenhouse gas emissions and operation costs aiding sustainable and efficient waste management practices.

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1. INTRODUCTION

One of the major necessities and challenges of increasing urbanisation is managing Solid Waste. The cost of transportation for the collected waste alone accounts for more than half of the total costs associated with Integrated Solid Waste Management (ISWM) in major developed cities. However, in developing countries it accounts for approximately 85% of total costs, therefore, raising operational costs and effectively lowering profits(Sanjeevi & Shahabudeen, 2016). In Nepal, solid waste management has become a major challenge even in urban areas. Thus, it is necessary to manage and engineer landfills for the disposal of solid waste. To guarantee adherence to federal requirements, landfills are situated, planned, run, and closely watched(*Basic Information about Landfills | US EPA*, n.d.).

Therefore, with proper planning and optimal geospatial analysis, these problems can be minimized if not eliminated. Software tools like ArcGIS along with the hierarchical model in integration to the network analysis principles, are to be used to generate the optimal route for the selection of the proper route and Landfill site for the disposal of the collected solid wastes to retain the sustainable development goals. The application of Geographic Information Systems (GIS) has revolutionized the way route planning and optimization are approached, including transportation. Network analysis, a key component of GIS, for solving real-time transportation problems involving complex algorithms for calculating optimal routes based on a range of factors, has become a valuable tool for transportation planning and origin/destination studies. Similarly, AHP is the structured and organized way to model the current decision and is composed of an objective, a collection of choices or alternatives for achieving the objective, and a collection of elements or standards that connect the choices to the objective.

This report majorly focuses on determining a suitable landfill site area within Banepa Municipality based on various criteria along with the placement of bins of varying capacity along the road within Banepa Municipality based on walking distance from settlement finally being able to analyse and optimize the garbage truck routes to enhance collection efficiency and thereby reduce operational costs.

2. LITERATURE REVIEW

The integration of GIS (Geographical Information System) and AHP is a powerful tool to solve the site selection problem and has been integrated into the studies to find the optimal site for the Landfill site (Uyan, 2014). Many prior projects had been run and studied using this tool, some instances of which have been included. AHP, a method of MCDA (Multi-Criteria Decision Analysis) has been applied to determine the potential Landfill site at Butwal sub-metropolitan city with criteria: slope, road, river, built-up, land use land cover (Banstola et al., n.d.). Similar research has been conducted in Devchuli municipality with additional criteria such as geological formation and population density (Paudel et al., 2021) and in Kanchanpur district (Subedi Sushil et al., 2023). A similar study was done in Asansol Municipality Corporation (AMC) of West Bengal State (India) where a GIS routing model was developed that considers population density, waste generation capacity, road network, storage bins, and collection vehicles to determine the most cost-effective and efficient routes for transporting solid waste to landfills (Ghose et al., n.d.). A study done in El Bousten district, commune of Sfax, Tunisia conducted by R. Sallem and M. Jamel Rouis showed that there was a 25.83% decrease in route and a 21.5% reduction in collecting time in addition to 26.3% fuel consumption reductions and 40% reduction in number of workers which demonstrate that the collection and transportation system, and consequently, the economic and environmental expenses of the model, tend to show notable improvements when based on a GIS (Sallem et al., n.d.). Waste collection and transport alone account for approximately 50-70% of the total cost of the system. The optimum location and number of transfer stations are required for an economical and efficient collection system (Rathore et al., n.d.). Typically, collection costs represent 80-90% and 50-80% of the municipal solid waste management budget in low-income and middle-income countries, respectively (Das et al., n.d.).

3. METHOD AND RESULTS

3.1 Study Area

The study area is located 25 km east of Kathmandu, the Nepali capital, at an altitude of 1463 m above sea level. The Banepa municipality (27°38′ N 85°31′ E) is a small and ancient region of Kavrepalanchowk district.

3.2 Analytical Hierarchy Process for Landfill Site Selection

AHP is a multi-objective multi-criterion decision-making approach that allows the user to arrive at a scale rather than a set of possible solutions (Saaty, 1990). It aids decision-makers in evaluating which solution best meets their objectives and comprehension of the problem. This method is often used in suitability assessments. The procedure is carried out in several steps, including establishing a comparative judgment matrix, calculating priority vectors, calculating the consolidated Result, and creating a table of comprehensive criterion comparisons. Consistency ratio can be checked as indicated by Eq. 1 This step is used to identify any irregularities in the weighting of each criterion. The CR consistency is a mathematical indicator of the judgment regarding a random decision calculated using Eq. 1.

$$CR = \frac{CI}{RI} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

RI is the random consistency index, and CI is the consistency index expressed as Eq. 2.

$$CI = \frac{(\lambda max - 1)}{n - 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where λ_{max} is the largest or principal Eigenvalue of the matrix is calculated from the matrix and n is the order of the matrix. According to Saaty, the consistency ratio must be ≤ 10% or an imprecision of less than 10%. The principle involves comparing the judgment to the random weighting of the elements.

The criteria that were considered based on the reviewed literature for the selection of landfill sites are described below. The criteria were reclassified into 5 rankings i.e. 5- Highly Suitable, 4- Suitable, 3- Moderately Suitable, 2- Less Suitable, and 1- Restricted.

- Road Network: Construction costs for new roads between settlements and potential landfills consider their proximity to existing roads (Tercan et al., 2020). The reclassified values for the road network are as follows:<250 m as 5, 250-500 m as 4, 500-750 m as 3, 750-1,000 m as 2, and >1,000 m as 1.
- Water Bodies: The wastewater spread to soil, surface, and groundwater is a common issue in irregular landfills, causing negative environmental effects so landfill sites should be far from water sources (Tercan et al., 2020). The reclassified values for water bodies are as follows:<500 m as 1, 500-1000 m as 2, 1000-1500 m as 3, 1500-2,000 m as 4, and >2,000 m as 5.
- Settlement Area: Installing a landfill near residential areas may harm the environment by releasing odours, dust, and noise. So, the farther the landfill site from the settlement the better it becomes(Uyan, 2014). The reclassified values for settlement areas are as follows:<250 m as 1, 250-500 m as 2, 500-750 m as 3, 750-1,000 m as 4, and >1,000 m as 5.
- Slope: The slope of the land surface affects construction costs, with steep slopes resulting in higher excavation costs (Wang et al., 2009). So, the lower the slope higher the suitability. The reclassified values for slope are as follows:<5° as 5, 5°-10° as 4, 10°-15°as 3,15°-30° as, and 30° as 5.
- Aspect: Even though the landfill sites are located away from the settlements, the prevailing wind directions in the study area must be considered to avoid affecting the fragrance of the settlements(Tercan et al., 2020). By considering the wind direction in the Banepa municipality flat surface is considered highly suitable (5) for the landfill site, North East, South East, and East are considered moderately suitable (3), South West, North West, and West are considered less suitable (2) while the south and north aspects are restricted (1).
- Soil: Sites should be located in silt and clay soils, which limit leachate and gas movement. A landfill built on a permeable formation like gravel, sand, or fractured bedrock can have a significant impact on groundwater quality (Walsh Patrick &

O'Leary Philip, n.d.). The soil with less permeability is considered highly suitable whereas soil with more permeability is restricted. Three types of soil were present in Banepa Municipality i.e. Chromic Cambisols as 5, Eutric Cambisols as 4, and Flurial non-Calcareous as 2.

- Weighted Centre: To determine the economic feasibility of a landfill site, it's important to consider its proximity to waste production sources. Locating landfills near waste production centers can reduce transportation costs(Wang et al., 2009). The reclassified values for weighted centers are as follows:<2000 m as 5, 2000-2500 m as 4, 2500-3500 m as 3, 3500-5,000 m as 2, and >5,000 m as 1.
- Population Density: Landfilling sites near homes, hotels, restaurants, industries, hospitals, markets, bus stops, and communities may be hazardous to human health, so low-population density areas are preferred while high-population density areas are ranked lower (Kapilan & Elangovan, 2018). The reclassified values for population density are as follows:286-330 as 5, 330-562 as 4, 562-1445 as 3, 1445-4188 as 2, and >4188 as 1.
- Cultural and Tourism Places: Landfill sites cause visual and odour pollution, negatively impacting tourism and cultural sites. So, should be located as far as possible(Tercan et al., 2020). The reclassified values for Cultural and Tourism Places are as follows:<500 m as 1, 500-750 m as 2, 750-1000 m as 3, 1000-1,250 m as 4, and >1,250 m as 5.
- Land Use Land Cover: Certain lands, such as protected areas, dense forests, residential areas, and water bodies, cannot be used for landfill sites. A land use map has been created using the Google Earth Engine. Images were classified using the maximum likelihood supervised classification method (Karimi et al., 2019). The reclassified values for LULC are as follows: Bare Ground as 5, Crops as 4, Trees as 3, Built up as 2, and Water as 1.

Criteria selected were ranked with the Saaty scale as shown in Table 1 for comparison based on the different research papers. Then the matrix was made and the weightage of each criterion was determined. The Consistency Ratio of the matrix obtained was 0.0097 i.e.<0.01 so, the matrix was valid for further use.

Table 1: The foundation scale(Saaty, 1990)

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement strongly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another

7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rationales	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Table 2: Comparison matrix of criteria

	WB	SA	LULC	CT	WC	SL	RN	S	A	PD
WB	1	3	3	2	5	4	5	4	6	5
SA	1/3	1	5	1	6	3	6	5	4	2
LULC	1/3	1/5	1	1/2	3	2	3	4	5	3
CT	1/2	1	2	1	4	3	5	6	4	3
WC	1/5	1/6	1/3	1/4	1	1/3	2	4	2	3
SL	1/4	1/3	1/2	1/3	3	1	3	2	1/2	2
RN	1/5	1/6	1/3	1/5	1/2	1/3	1	2	2	3
S	1/4	1/5	1/4	1/6	1/4	1/2	1/2	1	2	1/2
A	1/6	1/4	1/5	1/4	1/2	2	1/2	1/2	1	1/2
PD	1/5	1/2	1/3	1/3	1/3	1/2	1/3	2	2	1

Where WB = Water Bodies, SA = Settlement Area, LULC = Land Use Land Cover, CT = Cultural and Tourism places, WC = Weighted Centre, SL = Soil, RN = Road Network, S = Slope, A = Aspect and PD = Population Density

The required Landfill area was also calculated using population data and waste generation per capita per day. The daily solid waste generation is 0.32 kg/capita/day (Development Bank, 2013) and the average density of municipal solid waste is 311.73 kg/m3(Palanivel & Sulaiman, 2014). The population of Banepa Municipality is 67,690 with growth rate of 0.015 as per census report 2021. Then the population was forecasted for 15 years and the average population was considered. The study used population data, waste generation per capacity, and waste average density to calculate the required land area of 21,406.624 m^2 with height of 10m over 15 years.

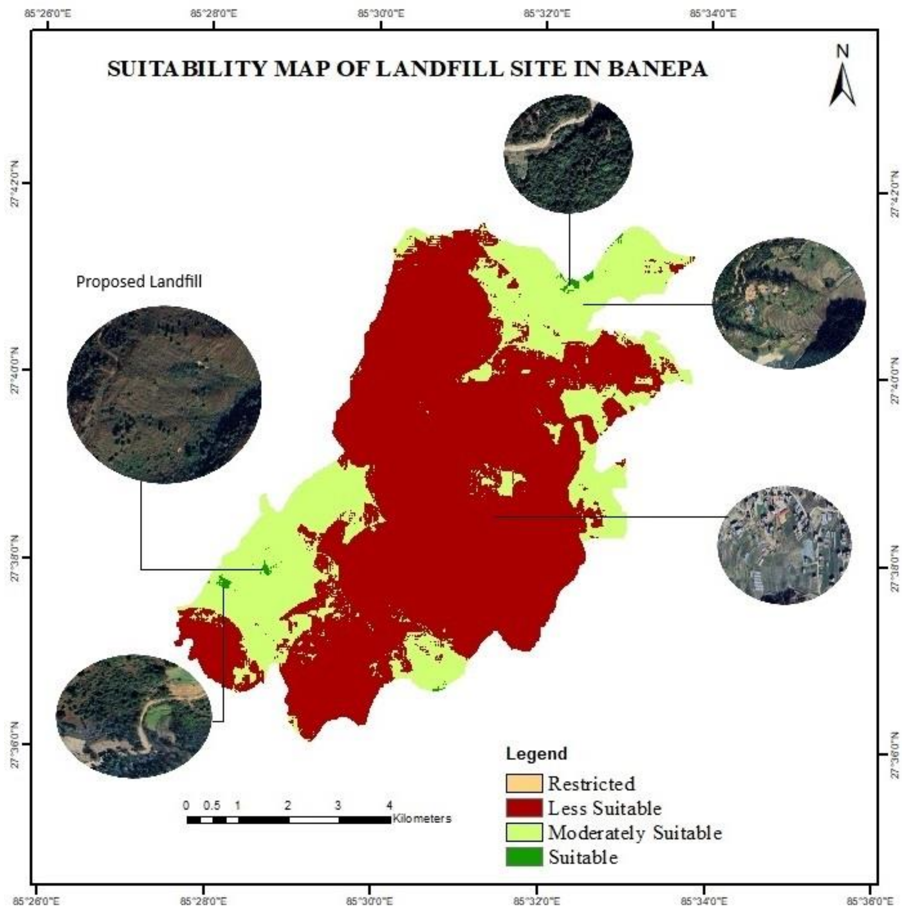

Figure 1: Suitability Map of Landfill Site in Banepa

3.3 Network Analysis

Network analysis is a GIS operation that analyses geographic or real-world networks. Network analysis looks at the properties of natural and man-made networks to understand edge-node topology to mimic real-world information networks. Objects navigate the network by following edges, and junctions occur when two or more edges intersect. Junctions and edges can have impedance, which increases the cost of network traffic. A road network may include speed limits and junctions that prevent left turns. There are two types of networks: directed (only one direction of travel) and undirected (any direction of travel). A network can be described as "a set of linear features through which resources flow." "Nodes (the endpoints of lines) are used as origins and destinations", as well as "links (lines) traverse from one node to the other". "In network analysis, we focus on the characteristics of links rather than nodes' properties." Lines must meet certain criteria, such as length, direction, connectivity, and pattern(Parihar Mehra Seema, n.d.).

3.3.1 Location Allocation for Bins

Location allocation analysis is an extension of a network analysis tool which, as the name implies, is a two-part problem that involves both the location of facilities and the allocation of demand points to those facilities. Given facilities that provide goods and services and demand points that consume them, the goal of location-allocation is to locate the facilities in the most efficient way to supply the demand points. Initially, all location-allocation analyses may solve the same problem, but the best location varies depending on the type of facility (*Location-Allocation Analysis—ArcMap | Documentation*, n.d.).

Before Performing the network analysis to find the optimal route, several bins were located on the side of the road. The bins were located with the integration of the Location Allocation Problem and Vector Analysis. At first, the candidate bins were selected at intervals of 30 m along the road. Then a buffer of 50m, 100m, 200 m, and 250m around the road was created. At first, the building that lies inside a 50m buffer was selected and bins for those building the bins were selected by location-allocation problem. Again, for the distance of 50-100 m from the road the building was selected, and bins were located. In this way, the bins for the building up to 250 m were located and buildings that lie outside 250m remain unlocated. Few bins were located to only one house due to less density of households in that place. A total of 1436 bins were located. The object ID of the dustbin, the object ID of the building, and the object ID of the line that connects the building and the dustbin were known. Then with these IDs, they were joined in the database and the capacity of each bin was calculated. The capacity of each bin differs from place to place. The number of bins along with their size are tabulated below.

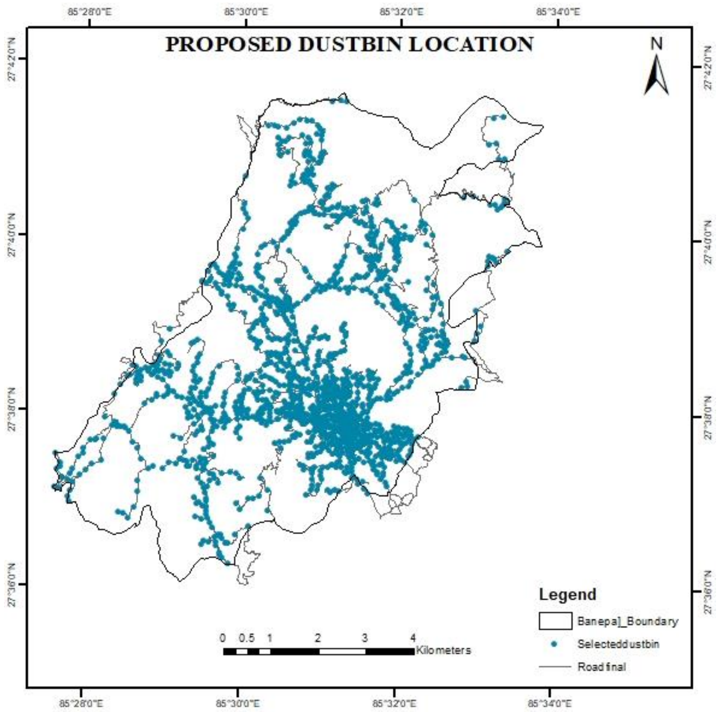

Figure 2: Proposed Dustbin Location

Table 3: Volume and Number of allocated dustbins

Number of Dustbin	Range of Volume of Dustbin (in litre)
312	0 - 50
419	50 - 100
575	100 - 250
202	250 - 500
35	500 - 1000
2	1000 - 2000

3.3.2 Network Analysis for Garbage Truck

Several organisations service orders using a fleet of vehicles. The vehicle routing problem (VRP) is used to determine the route for the large fleet of vehicles by determining which orders (homes, restaurants, or inspection sites) should be serviced by each route (truck or inspector), as well as the order of visits. The primary goal is to best service the orders while minimizing the overall operating costs for the fleet of vehicles(*Location-Allocation Analysis—ArcMap | Documentation*, n.d.).
The allocated dustbin was used as the order and the suitable landfill site was used as the depot for the network analysis. Then VRP analysis was used for 19 vehicles and 19 routes were determined.

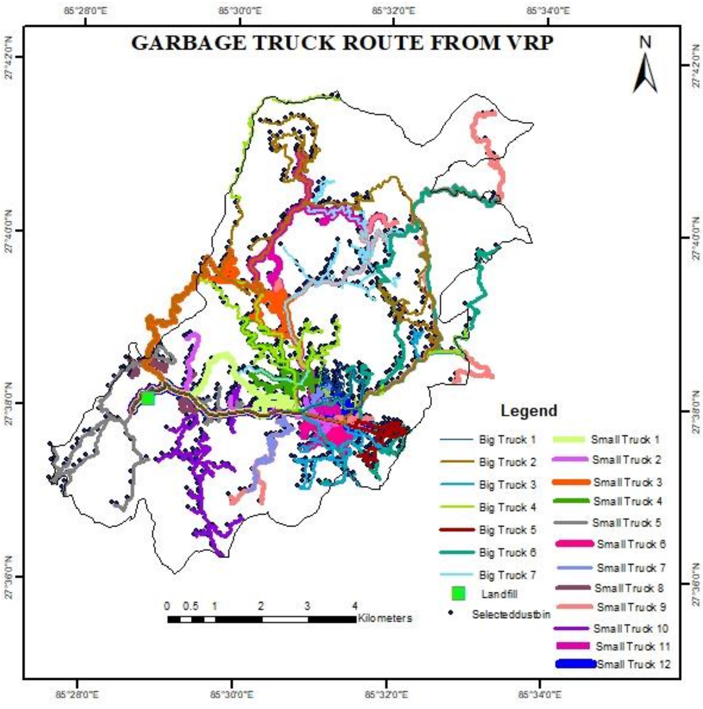

Figure 3: Garbage Truck Route from Vehicle Routing Problem

The Travelling Salesman Problem (TSP) is a traditional algorithmic problem in computer science and operations research that focuses on optimization. It seeks the shortest possible route, visiting each point in a set of locations only once. The TSP problem is widely applicable in the logistics industry, particularly in route planning and optimization for delivery services, solving algorithms contributes to reduced travel costs and time(*Algorithms for the Travelling Salesman Problem*, n.d.). While TSP finds the best route for a single vehicle, VRP solver finds the best route for a multiple fleet of vehicles.

For TSP the whole Banepa municipality was divided into 17 service areas manually according to the dustbin size and the capacity of the garbage truck. Then by using the Travelling Salesman Problem of Network Analysis the route for each service area was computed individually. The routes were computed from two analysis to check which gives better results and results show that the result from TSP gives the better result. The present route was determined by using the handheld GPS following the garbage truck. The comparison of the present route followed by the garbage truck to transfer station and the result from the TSP analysis for 3 days is tabulated below in Table 3.

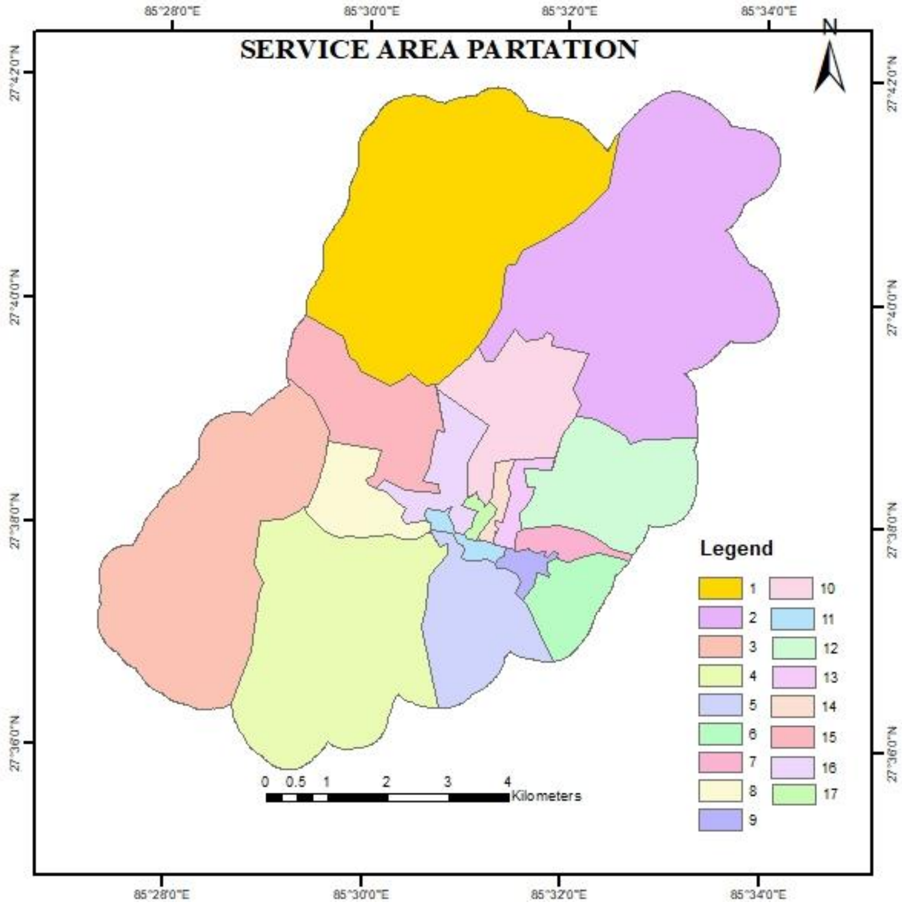

Figure 4: Service Area Partition

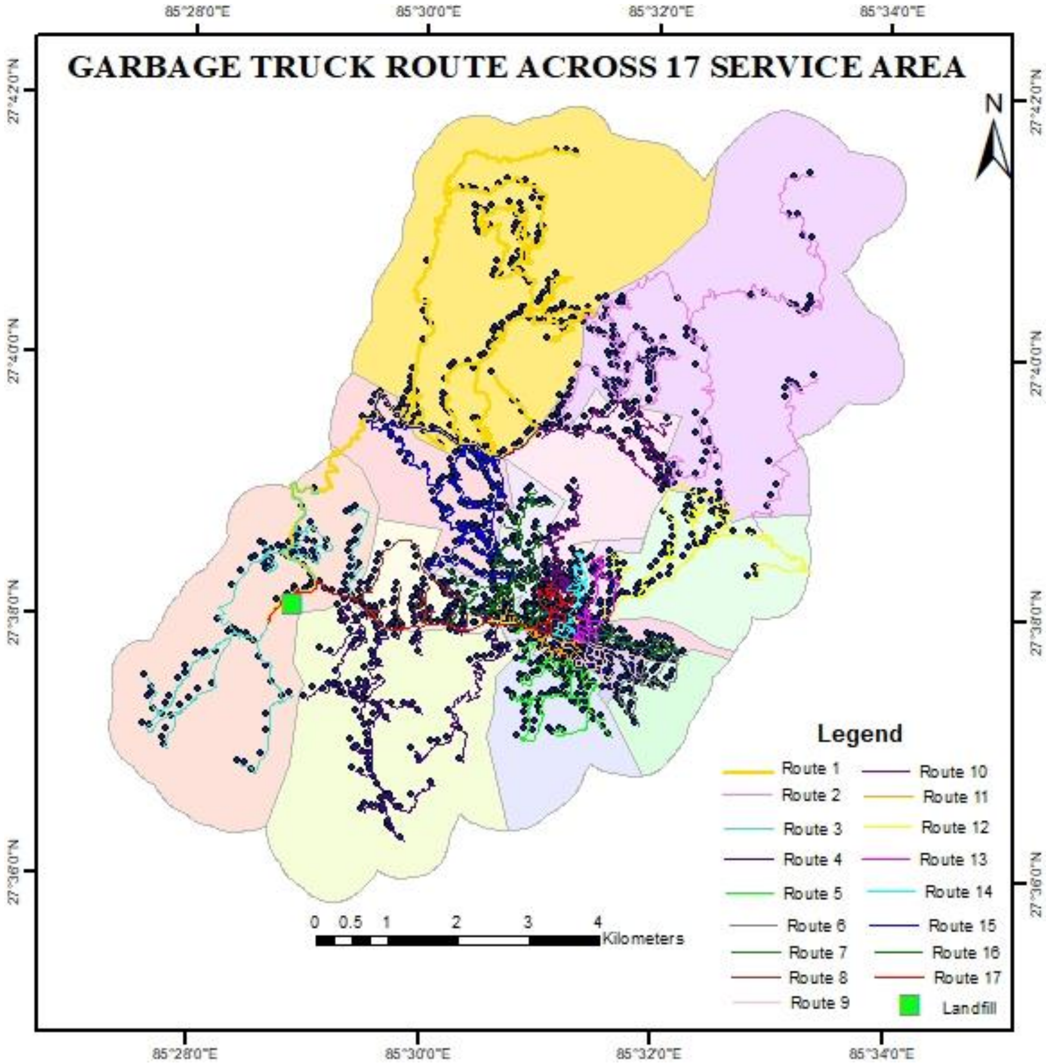

Figure 5: Garbage Truck Route Across 17 Service Area

Table 4: Result

	Present Route	Proposed Route	Total Reduction in Present and Proposed Route	Total Percentage Reduction
Distance (metre)	705334	491527.19	213086.841	30%
Time (minute)	4791	3192.0591	1598.94	31%
Petroleum Cost (Rs)	32149.44	24904.0591	7245.38	23%

4. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the project successfully identified and selected the best landfill site using AHP and verified that the chosen site in basis of the google image and the area required. Furthermore, determining the most efficient routes to the landfill site ensures lower transportation costs and less environmental impact. This comprehensive approach ensures that landfill site selection and access routes align with long-term waste management objectives while preserving community and ecological integrity. This approach can be applied on various local body within the developing country to ensure the less cost, efficient and standard waste management procedure.

5. REFERENCES

Algorithms for the Travelling Salesman Problem. (n.d.). Retrieved August 30, 2024, from https://www.routific.com/blog/travelling-salesman-problem#

Banstola, P., … K. B.-J. of A., & 2023, undefined. (n.d.). Landfill site selection using GIS and Multicriteria Decision Analysis: A Case Study of Butwal Sub-Metropolitan City. *Thejournalshouse.Com P Banstola, KR Bhusal, S Adhikari Journal of Advanced Research in Geo Sciences & Remote Sensing, 2023•thejournalshouse.Com*. Retrieved August 30, 2024, from http://thejournalshouse.com/index.php/geoscience-remotesensing-earth/article/download/787/862

Basic Information about Landfills | US EPA. (n.d.). Retrieved August 30, 2024, from https://www.epa.gov/landfills/basic-information-about-landfills#

Das, S., Management, B. B.-W., & 2015, undefined. (n.d.). Optimization of municipal solid waste collection and transportation routes. *Elsevier S Das, BK Bhattacharyya Waste Management, 2015•Elsevier*. Retrieved August 30, 2024, from https://www.sciencedirect.com/science/article/pii/S0956053X15004432

Development Bank, A. (2013). *Solid Waste Management in Nepal: Current Status and Policy Recommendations*. www.adb.org

Ghose, M., Dikshit, A., management, S. S.-W., & 2006, undefined. (n.d.). A GIS-based transportation model for solid waste disposal–A case study on Asansol municipality. *Elsevier MK Ghose, AK Dikshit, SK Sharma Waste Management, 2006•Elsevier*. Retrieved August 30, 2024, from https://www.sciencedirect.com/science/article/pii/S0956053X05002849

Kapilan, S., & Elangovan, K. (2018). Potential landfill site selection for solid waste disposal using GIS and multi-criteria decision analysis (MCDA). *Journal of Central South University*, *25*(3), 570–585. https://doi.org/10.1007/S11771-018-3762-3

Karimi, H., Amiri, S., Huang, J., & Karimi, A. (2019). Integrating GIS and multi-criteria decision analysis for landfill site selection, case study: Javan rood County in Iran. *International Journal of Environmental Science and Technology*, *16*(11), 7305–7318. https://doi.org/10.1007/S13762-018-2151-7

Location-allocation analysis—ArcMap | Documentation. (n.d.). Retrieved August 30, 2024, from https://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/location-allocation.htm

Palanivel, T. M., & Sulaiman, H. (2014). Generation and Composition of Municipal Solid Waste (MSW) in Muscat, Sultanate of Oman. *APCBEE Procedia*, *10*, 96–102. https://doi.org/10.1016/J.APCBEE.2014.10.024

Parihar Mehra Seema. (n.d.). *NETWORK ANALYSIS in GIS _07_Network Analysis in GIS LEARNING OBJECTIVES*.

Paudel, A., Sherchan, B., & Adhikari, A. (2021). *Landfill site selection with spatial suitability analysis and multi-criteria decision making in Devchuli municipality*. https://www.academia.edu/download/76477070/V7I4-1906.pdf

Rathore, P., Production, S. S.-J. of C., & 2019, undefined. (n.d.). Modeling transfer station locations considering source separation of solid waste in urban centers: A case study of Bilaspur city, India. *Elsevier P Rathore, SP Sarmah Journal of Cleaner Production, 2019•Elsevier*. Retrieved August 30, 2024, from https://www.sciencedirect.com/science/article/pii/S0959652618335042

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research*, *48*(1), 9–26. https://doi.org/10.1016/0377-2217(90)90057-I

Sallem, R., Environment, M. R.-C. W., & 2017, undefined. (n.d.). Optimization of household waste collection routes using GIS: Case study of El Bousten District, Commune of Sfax, Tunisia. *Cwejournal.Org R Sallem, MJ Rouis Current World Environment, 2017•cwejournal.Org*. Retrieved August 30, 2024, from https://www.cwejournal.org/index.php/vol12no1/optimization-of-household-waste-collection-routes-using-gis-case-study-el-bousten-district-commune-of-sfax-tunisia

Sanjeevi, V., & Shahabudeen, P. (2016). Optimal routing for efficient municipal solid waste transportation by using ArcGIS application in Chennai. *Waste Management and Research*, *34*(1), 11–21. https://doi.org/10.1177/0734242X15607430

Subedi Sushil, Thakulla Ashok, & Chauhan Jenish. (2023, February). *GIS Based MCDA Selection of Waste Management Site in Kanchanpur District, Nepal*. https://www.researchgate.net/publication/368156134_GIS_Based_MCDA_Selection_of_Waste_Management_Site_in_Kanchanpur_District_Nepal

Tercan, E., Dereli, M. A., & Tapkın, S. (2020). A GIS-based multi-criteria evaluation for MSW landfill site selection in Antalya, Burdur, Isparta planning zone in Turkey. *Environmental Earth Sciences*, *79*(10). https://doi.org/10.1007/S12665-020-08974-9

Uyan, M. (2014). MSW landfill site selection by combining AHP with GIS for Konya, Turkey. *Environmental Earth Sciences*, *71*(4), 1629–1639. https://doi.org/10.1007/S12665-013-2567-9

Walsh Patrick, & O'Leary Philip. (n.d.). *Lesson 5: Evaluating a Potential Sanitary Landfill Site*. Retrieved August 30, 2024, from https://www.waste360.com/industry-insights/lesson-5-evaluating-a-potential-sanitary-landfill-site

Wang, G., Qin, L., Li, G., & Chen, L. (2009). Landfill site selection using spatial information technologies and AHP: A case study in Beijing, China. *Journal of Environmental Management*, *90*(8), 2414–2421. https://doi.org/10.1016/J.JENVMAN.2008.12.008

6. BIOGRAPHICAL NOTES

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