# Road optimization for waste transportation using GIS: A Case Study for Karteh Solh, Bamyan, Afghanistan

Assistant Professor Mohammad Jawed Nabizada

Head of Geodesy Department, Bamyan University, Bamyan, Afghanistan

E-mail: Jawid.nabizada22@gmail.com, Mobile: (+93) 775693732

*Abstract:* **Solid waste transportation is one of the most important parts of solid waste management system which consume approximately 70-80% of overall cost of solid waste management system. The aim of this study is to develop a GIS based methodological approach to reduce the overall travel distance for transportation of municipal solid waste from residential area to landfill which result less fuel consumption. The shortest collection roads for transportation of municipal solid waste has been created using network analyst extension. All those bins which must visit for clearing purpose divided into clusters based on the capacity of the collection vehicle, the average rate of filling of bins and their proximity distance. Here, it assumed that the filling rate of all bins are equal during the collection period and considered to be 80%. After creating new road for transportation of urban solid waste has been found that the Total annual travelled distance in proposed waste collection system is 30% lesser than the total annual travelled distance covered by waste collection vehicle in current waste collection system.**

*Keywords:* **Urban Solid Waste Management (USWM), Geographic Information System (GIS), Global Positioning System (GPS), network analyst, waste transportation, shortest road.**

## 1. INTRODUCTION

Solid Waste Management (SWM) is a component of multiple activities such as collection, transportation, and disposal of solid waste [1]. On the other hand, it also includes processing and treatment of the solid waste before disposing [2]. The aim of SWM is to create an unpolluted environment for human without annoying natural resource [3]. Solid Waste Management is one of the fundamental and vital services provided by municipal authorities to preserve cities clean and sanitary [4]. However, waste management is a crucial problem as a rise in urbanization and economic development is leading to a big increase in amounts of waste materials. Lack of a proper waste management resulting open dumping, burning, and burying leads to crucial environmental and health problems. In order to reduce the increase in the amount of waste and to reduce the impact of waste on the environment and public health, we need to develop a wide-ranging waste management system. This can be only achieved by joining new technologies. GIS is one of the powerful technologies that have a huge involvement in planning and management of waste. SWM fundamentally involves the collection of waste, transportation of waste and disposal of waste [5].

The overall objective of this research is to set up a GIS-based methodological approach to improve the Solid waste transportation in Karti Solh, Bamyan, Afghanistan.

In Thailand, the waste management system is like this to sort the waste in three types' recyclable, food and toxic waste and dispose them in three different waste bins. Then these wastes are transported with different color trucks. The recyclable waste is transported to sorting plants in order to classify it again to get different recyclable materials. Food waste is transported to composting plants and then disposals are transported to a landfill. And toxic waste will treat by incinerating [6]. Similarly, in many India cities, solid waste is normally disposed of in open dump. That led to an environmental hazard and ecological imbalances [7].

In Afghanistan solid waste especially Urban Solid Waste (USW), is a crucial problem and it became intensive due to the absence of a proper SWM systems in the country. At present all recyclable, reusable and organic waste are collected together and being discarded in very penetrating environmentally places like roadsides, marshy land, public places and water bodies sides which causing many harmful environmental impact such as ground and surface water pollution, atmospheric pollution, air pollution, disease spread, smell bother and visual damage.

**Solid Waste Management using GIS**

GIS tool plays an important role in SWM as many parts of waste management extremely associated with spatial data [8]. Generally, GIS plays a significant role in case of preservation of data to simplify collection operation [9]. These operations including many parts such as allocation of the waste bin, analysing suitable location for the transfer station, planning roads for vehicles in order to deliver waste from community bins to landfill. Moreover, selecting new disposal site and supervision of dump site is also including in these operations. So, GIS is a powerful tool which not only saves the time and decreases the cost but also offers a digital data bank for future monitoring of disposal sites [10].

## 2. STUDY AREA

Bamyan is a historical site and one of the thirty-four provinces of Afghanistan which located in the central part of Afghanistan. Geographically Bamyan province located between 34°49′17″ N latitude and 67°49′38″ E longitude. The altitude of Bamyan province is 2600 meters from sea level. The total area of Bamyan province is 18029 square kilometers and the total population is 387,300 people. Bamyan has seven administrative unites Bamyan center, Yakawalang, Waras, Panjab, Shiber, Saighan, Kahmard [11].Karteh Solh is one of the cities of the Bamyan province. Geographically it located between 34°49'58.84" North latitude and 67°47'9.45" East longitude in the center of Bamyan province. It covers an area of 2 square kilometers and its population is approximately 2600 people. A survey which has done by [12] in Kabul pointed that the amount of waste generation in Kabul is 0.4kg/capita/day. According to a sample survey which has done regarding waste generation in Karteh Solh, Bamyan, Afghanistan during this research it found that the waste generation rate is 0.32 kg/capita/day.

## 3. DATA COLLECTION

Data gathering is one the most important part of a research since, it helps for appropriate analysis to get a reliable result. In this study road network of the area and building footprint has been gathered by digitizing the GeoEye satellite image of the study area. The GeoEye satellite image of 2017 of the study area has been received from Digital Globe Foundation. Digital Globe Foundation is an organization which provides freely some high-resolution satellite image for students who are working on their research. GPS survey has been conducted to capture the location of existing waste bins, dump sites and landfill. And also measured the distance between the study area and landfill.

## 4. RESEARCH METHODOLOGY

The aim of this research is to set up a GIS-based methodological approach to improve the Solid waste transportation practices in Karti Solh, Bamyan, Afghanistan, and evaluate the problems which arise due to the improper waste transportation system. Based on the analysis and related literature reviews, a methodology has been proposed to improve the existing waste transportation system. So, methodology conducted to this research can be divided into two different parts. 1) To map out the existing SWMS. 2) Creating new road for waste vehicles to deliver waste from bin to landfill. Moreover, this research is limited to the residential building. So, the methodology for separate objective can summarize as follow.

## 5. METHODOLOGY OF THE FIRST OBJECTIVE

The purpose of the first objective of this research is to analyze and map out the current SWM situation in the research area and evaluate those problems which appear due to improper waste management. Based on the identification of the problem another model was proposed to improve the current situation of SWM system. This study was included argument and a critical analysis of the model. So, this analysis was helped to identify different waste management problems and the ways how GIS was used to deal with waste management in a different situation. Based on the analysis of the existing condition of the waste management, availability of the data in study area another model was proposed. In the proposed model the current problem such as the improper location of the bins, an unaccepted walking distance of the bins, lack of required bins, the frequency of removal of waste from bins to landfill and planning the shortest road for waste transportation was solved. The detailed methodology is shown in fig 1.
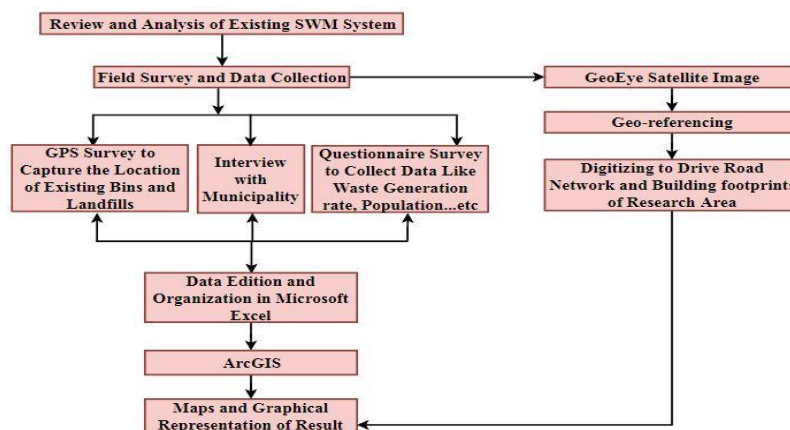
**Fig. 1: GIS Based Methodological Structure for First Objective**

## 6. METHODOLOGY OF THE THIRD OBJECTIVE

As it found through many research papers that collection and transportation of waste are the costliest part of SWMS because of huge use of machinery, fuel consuming, work intensity and recruitment of workers. The waste collection and transportation in SWM cycle spent 70-80% of total budget [13]; [14]. While this amount of expenditure in modern waste management system can be reduced to 50-70 % [15]. In this research, the network analyst function in ARC GIS software was used to find out shortest collection road for transportation of waste from collection bins to landfill. The procedure of the model can be summarized as shown in fig 2.
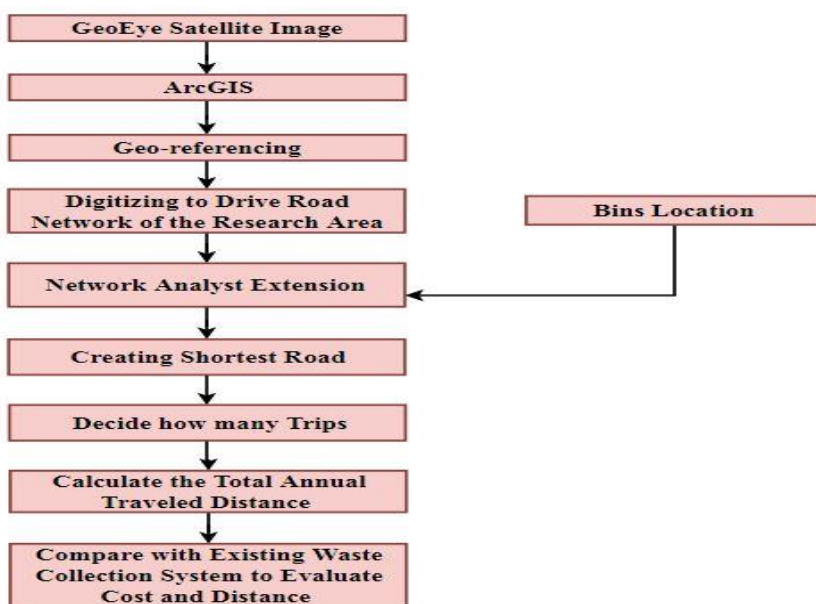


**Fig. 2: GIS Based Methodological Structure for Creating Shortest and Cost-Effective Road**

Network Analyst is an authoritative function in ArcGIS that offers network-based spatial analysis including creating new collection road, travel direction, closest facility, and service area analysis. Network Analyst function can be used to animatedly model truthful network situations, including turn limitations, speed limits, height restrictions, and traffic conditions at different times of the day. The users with Network Analyst extension can do the following tasks: to find out and efficient travel roads, to determine which facility or vehicle is closest, to create a service area around an object and to allocate some new facilities. Here in this research, the network analyst is used to create the best road (shortest road) for transporting the MSW to the landfill and to create a service area around the bins. The network analyst can find out the shortest road based on two factors travel distance and travel time. Here in this research the shortest road created based on travel distance. The network analyst calculates the travel distance according to this formula $D = V * T$ (1)where, D is travel distance, V is the speed limit of roads which is different according th to toe types of roads, T is the travel time. In

order to calculate solve this equation have the value of V and T for each segment of the road. A network service can be defined as an area which include all those available roads that are crossing through that area and have a definite length. The service area around the bins were created according to the convenient distance that was gathered during field survey. Network analyst extension solve all these problems by combining both spatial and non-spatial data.

In this analysis, the collection frequencies are proposed for the collection of mixed wastes based on the size of the bin and amount of generated waste. The number of trips calculated based on the amount of generated waste in the area and capacity of trucks. All the collection bins that should be visited emptied divided into clusters based on the capacity of the waste collection vehicle and their proximity distance, according to this formula $N = \frac{V1*N1}{V}$ (2) where, N- clusters number, V1- bins capacity in $m^3$, N1- the total number of bins in the study area and V- waste vehicle collection capacity. And the total distance has calculated based on this formula D = n*d (3) where D- is the total distance in one year, n- is the number of trip and d- is the round-trip haul distance. Then the total distance traveled by the collection vehicle in the present system was measured by GPS trucking. And finally, the total expenditure has been calculated based on the fuel consumption by this formula $T = P * D$ (4) where T is total annual vehicle running cost, P is vehicle running cost per kilometer and D is annual total traveled distance.

## 7. RESULT AND DISCUSSIONS

**Current MSW Collection System of Study Area**

Presently, the most common method of waste collection which practice in the study area is a door to door method but, the side street also practices. Currently, totally there are 23 official bins (18 bins with 0.45 cubic meter volume, 4 open official dump sites and 1 concrete bin with 6.5 cubic meter volume). On the other hand, there are 3 more nonofficial open dump sites. The current dustbins are not allocated properly over the entire area. Furthermore, there is no any scientific method followed to allocate the bins. Due to improperly distribution of dustbins in the study area, there is an inconvenience distance for the households to throw their MSW into collection bins in the study area. Eventually, this leads to more dumping of MSW besides roads, drainage, and any other sensitive areas.

In the remaining part of the study area, the door to door method practice. In this method, the waste collection vehicle has installed a bell, during the collection time the bell rings in order to transfer their message to the households to bring their waste. Fig 3 shows the current waste collection of the study area.
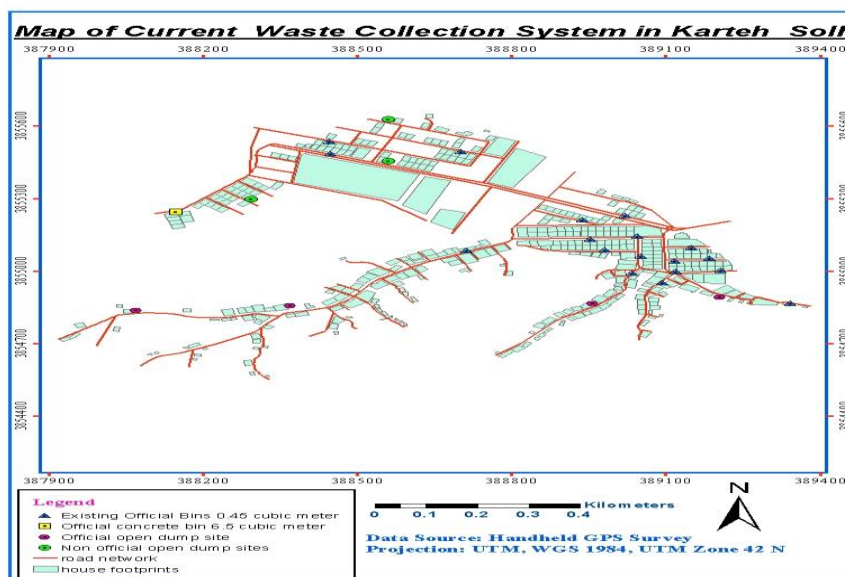


**Fig. 3: Current MSW Collection System of Study Area**

**Frequency of Households Waste Collection by Municipality**

During the questionnaire survey, it found that municipality collects the 92.34% waste of householder in study area twice a week. On the other hand, there were 7.66% of householders which were not satisfied with municipality service.

**Creating New Road for Collection of MSW Using Network Analyst Function**

The shortest collection roads for the collection of MSW was created using network analyst extension. All those bins which must visit for clearing purpose divided into clusters based on the capacity of the collection vehicle, the average rate of filling of bins and their proximity distance. Here, it assumed that the filling rate of all bins are equal during the collection period and considered to be 80%. The number of clusters has been calculated using equation (2) page (4). After, solving the equation (2) found that there is need of five clusters which every cluster covers nine collection bins. Then, for every cluster of bins, a new collection road has been created which shown in fig. 4-fig.8. It is worth mentioning that cluster method was applied in order to calculate the required number of trips, required number of trucks to schedule the collection time for every truck and to decrease the total traveled distance. If, we create one collection road for all collection bins, then every truck should follow same collection road, but if we create separate collection road for each cluster the truck will follow that collection road which cover a cluster of bins. Moreover, the order was assigned to the network analyst function to display the travel distance in the meter. In addition, network analyst has the capability to reorder the assigned order of Stop to create the shortest road. It is worth mentioning that, if we order like the collection bins should be visit based on our priority. Our priority means if we do not tick the reorder option the software will create the road according to first and end stops. Here, we can order the software based on our priority which one should be first Stop, which one should be second Stop, and which one should be last Stop. Then, the software will create the road base on our priority, it means that during the waste collection the waste collector should visit the bins according to our order. On the other hand, if we tick the reorder option software will number the Stops based on software choice. On the other hand, if we tick the reorder option the software will create the shortest path based on software choice. In addition, in special cases where some phenomenon causes traffic problems such as traffic accident, bridge destruction, road slipping and blocking road by falling a tree network analyst is able to find the shortest road by avoiding these kinds of barriers to solve the traffic problems. It means that network analyst can find the shortest road through another path. So, with the help of network analyst function, the shortest road which was created found to be cost effective and less time consuming when compared to the current run roads which shown in TABLE Ⅰ. The collection arrangement of the vehicle such as the number of trips, number of bins covered in each trip, the quantity of waste collected and traveled distance in every trip are shown in TABLE Ⅱ. The road which obtained through network analyst its total traveled distance which covers all the collection bins for collection frequency of twice a week is 64.78 km, and the total round-trip haul distance during MSW collection from the study area is 129.56 km. The total annual optimized distance covered by collection vehicle calculated by equation (3) page (4) is 67371.2 km. Furthermore, the total annual distance which traveled by waste collection vehicle in both SWMS is shown in fig 9.
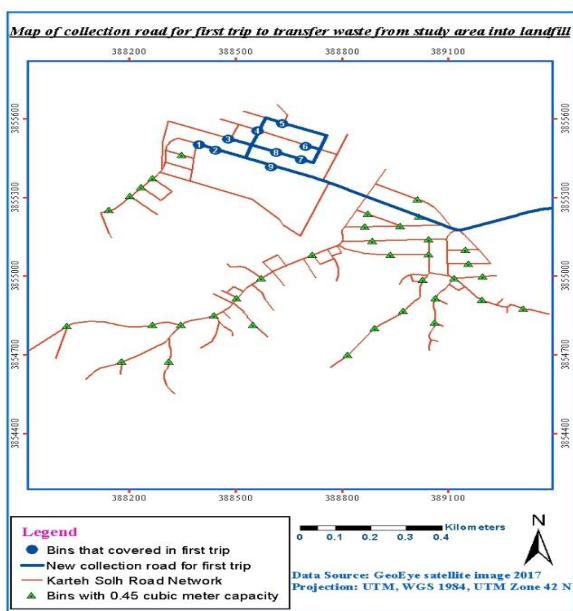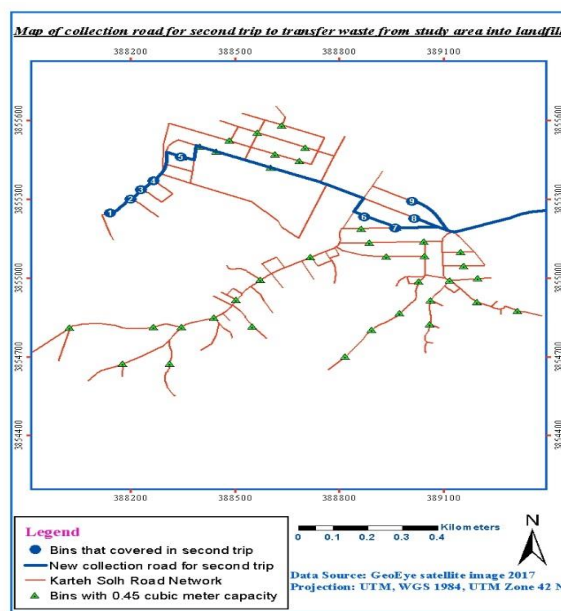


**Fig. 4: New Collection Road for First Trip**      **Fig. 5: New Collection Road for Second Trip**
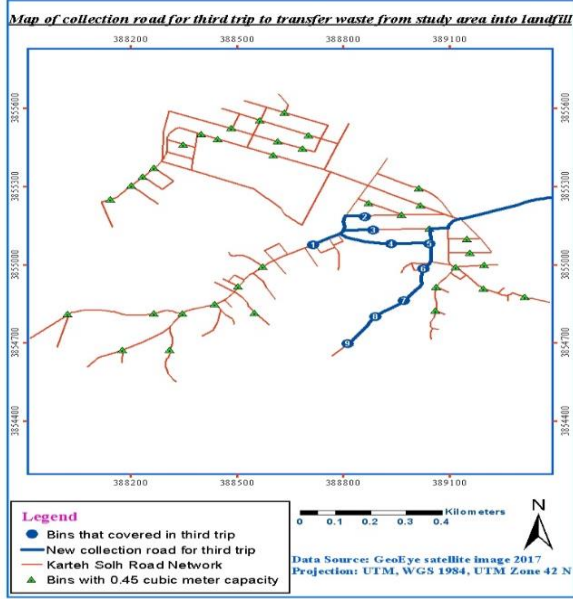
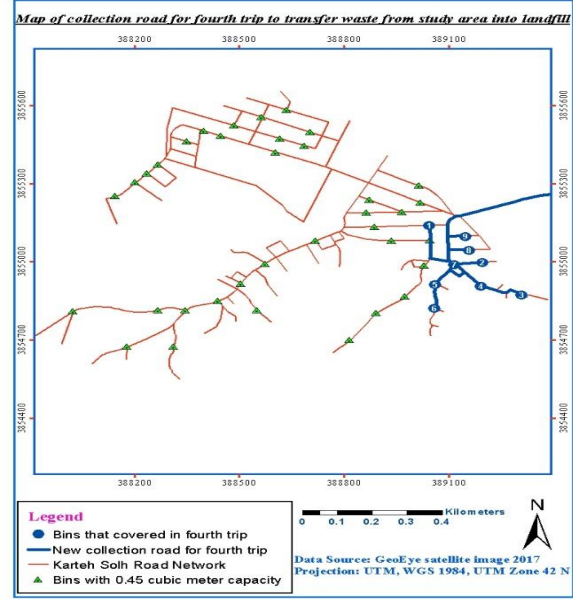**Fig. 6: New Collection Road for Third Trip**

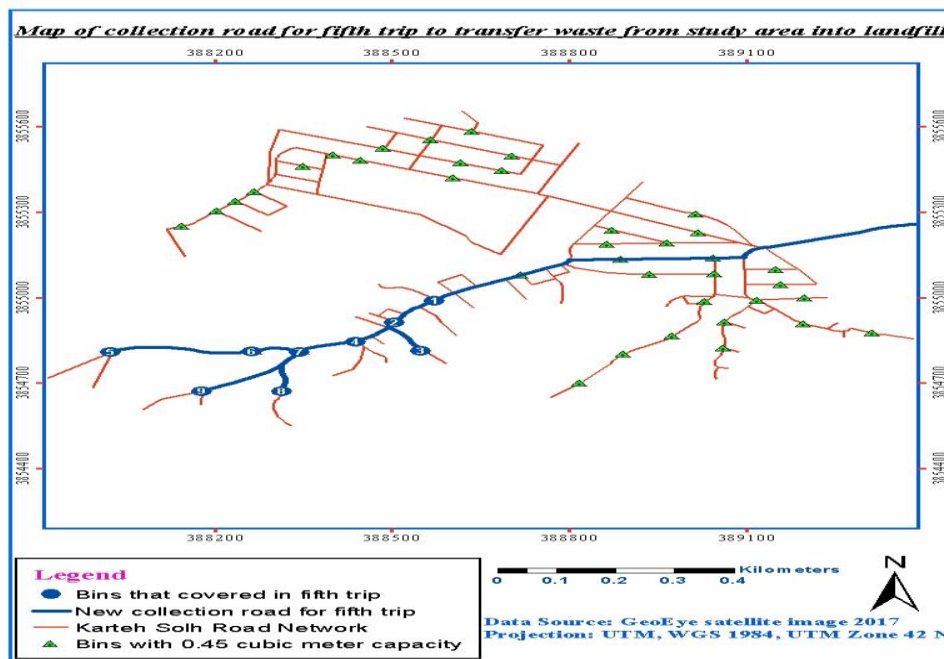**Fig. 7: New Collection Road for Fourth Trip**



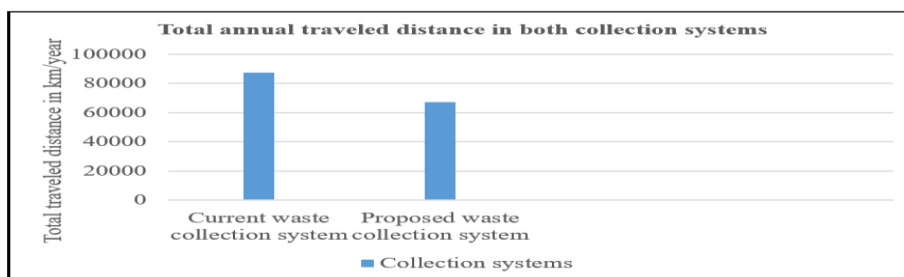**Fig. 8 New Collection Road for Fifth Trip**



**Fig. 9: Total Annual Traveled Distance for Collection of MSW in Both Collection Systems in Karteh Solh, Bamyan, Afghanistan**

**TABLE I: Total Annual Vehicle Running Cost in Both Current and Proposed MSWM System**

| No | Waste collection system | Per kilometer vehicle running cost in AF | Total annual traveled distance in km | Total annual vehicle running cost in AF. |
|----|-------------------------|------------------------------------------|--------------------------------------|------------------------------------------|
| 1 | The current waste collection system | 20 | 87582 | 1751640 |
| 2 | Proposed waste collection system | 20 | 67371.2 | 1347424 |

Total annual traveled distance in proposed waste collection system is 30% lesser than the total annual distance covered by waste collection vehicle in current waste collection system due to the optimization of the collection road. In addition, there is 30% save in terms of the total annual vehicle running cost.

**TABLE II: Collection Arrangement of the Vehicles**

| Trips | The capacity of vehicle $(m^3)$ | Bins number which covered in a trip | Estimated waste collected in a bin $(m^3)$ | Traveled distance in meter |
|-------|---------------------------------|-------------------------------------|--------------------------------------------|----------------------------|
| $1^{st}$ trip | $4m^3$ | (1,2,3,4,5,6,7,8,9) | (0.45, 0.45, 0.45, 0.45, 0.45, 0.45, 0.45,0.45,0.45)$m^3$ | 6373 |
| $2^{nd}$ trip | $4m^3$ | (8,9,10,11,12,13,14,15,16,17,18) | (0.45, 0.45, 0.45, 0.45, 0.45, 0.45, 0.45,0.45,0.45)$m^3$ | 6454 |
| $3^{rd}$ trip | $4m^3$ | (19,20,21,22,23,24,25,26,27) | (0.45, 0.45, 0.45, 0.45, 0.45, 0.45, 0.45,0.45,0.45)$m^3$ | 6573 |
| $4^{th}$ trip | $4m^3$ | (28,29,30,31,32,33,34,35,36) | (0.45, 0.45, 0.45, 0.45, 0.45, 0.45, 0.45,0.45,0.45)$m^3$ | 6659 |
| $5^{th}$ trip | $4m^3$ | (37,38,39,40,41,42,43,44,45) | (0.45, 0.45, 0.45, 0.45, 0.45, 0.45, 0.45,0.45,0.45)$m^3$ | 6330 |

Table 4.6 explains that totally there is need of five trips to cover all the bins to collect waste and transfer it to landfill. These five trips can be done by two vehicles or five vehicle belongs to municipality schedule and their machinery. In every trip nine bins with a capacity of $0.45m^3$ will be visited by a collection vehicle with a capacity of $4m^3$. Furthermore, the total traveled distance is different for each trip. The total traveled distance to cover all the bins for collection frequency of twice a week is 64.78 km.

## 8. CONCLUSION

To conclude, the study aim was to create a GIS-based methodological approach to improve the current solid waste transportation system of Karteh Solh, Bamyan, Afghanistan. Moreover, during the research, it became clear that there are many problems with current solid waste transportation system. Resident of some part of this study area had complainant that the municipality do not collect their waste. To analyse the current situation of SWM system in the study area. The questionnaire survey and GPS survey were conducted. After, analysis of questionnaire survey and proximity distance of existing collection bins it was found that the people of research area are not satisfied from current SWM system due to improper distribution of bins, lack of bins along the roads, shortage of sufficient number of bins, undefined collection and transportation roads and lack of a sanitary landfill.

In case of waste collection and transportation, as the waste collection is the most expensive part of SWM system and spent 70-80% of the total budget. The goal of this research was to make an effective waste collection system as much as possible. The only solution to accomplish this goal was to optimize the roads using GIS network analyst extension. A GIS optimal routing model based on the parameters such as daily per-capita waste generation, road network and existing collection bins have been developed to create a new shortest road for delivering the solid wastes to the disposal site. The clustering method was applied to calculate the required number of trip, required number of truck and to decrease the total traveled distance. Then, for every cluster of bins, separate collection road has been created. The percentage of total annual

distance which has been saved due to road optimization is 30% and the total cost which has been saved due to road optimization is 404216 AF. Furthermore, optimizations of collection roads reduce the emission due to vehicles running and traffic volume on the roads. Finally, the proposed SWM system can be used as the decision support model by municipal authorities for a proper waste management in any part of the country.

### ACKNOWLEDGEMENT

### REFERENCES

[1] Robinson, W.D. (1986). The Solid Waste Handbook: A Practical Guide, John Wiley and Sons, Chichester.

[2] Velumani, A. (2013). GIS based optimal collection routing model for municipal solid waste : case study in Singanallur , India. International Journal of Engineering and Innovative Technology, 3(5), 1–5.

[3] McDougall, F., White, P., Franke, M., & Hindle, P. (2001). Integrated solid waste management: a life cycle inventory. In P. R. W. Forbes R McDougall & M. F. and P. Hindle (Eds.), Chemistry & … (second edi). Blackwell Science. https://doi.org/10.1007/978-1-4615-2369-7

[4] Shohel, M., Rafizul, I., & Roy, S. (2013). Gis Application for Suitable Location of Waste Bin for Solid Waste Management in Khulna CITY. International Journal of …, 1(1), 26–34. http://www.ijoer.in/IJOER 1.1.2013/4.pdf

[5] Shrivastava, P., Mishra, S., & Katiyar, S. K. (2015). A Review of Solid Waste Management Techniques Using GIS and Other Technologies. In 2015 International Conference on Computational Intelligence and Communication Networks (CICN) (pp. 1456–1459). https://doi.org/10.1109/CICN.2015.281

[6] Illeperuma, I. A. K. S., Samarakoon, L. (2010). Locating Bins using GIS. International Journal of Engineering & Technology IJET-IJENS Vol:10 No:02, (2).

[7] Sharholy, M., Ahmad, K., Mahmood, G., & Trivedi, R. C. (2008). Municipal solid waste management in Indian cities - A review. Waste Management, 28(2), 459–467.

[8] Kallel, A., Serbaji, M. M., & Zairi, M. (2016). Using GIS-Based Tools for the Optimization of Solid Waste Collection and Transport: Case Study of Sfax City, Tunisia. Journal of Engineering (United Kingdom), 2016. https://doi.org/10.1155/2016/4596849

[9] Paul, K., Dutta, A., & Krishna, A. P. (2017). Corporation area. International Journal on Emerging Technologies, 8(1), 511–520.

[10] Oyinloye, M. A. (2013). Using GIS and Remote Sensing in Urban Waste Disposal and Management: A Focus on Owo L.G.A, Ondo State, Nigeria. European International Journal of Science and Technology, 2(7), 106–118.

[11] CSO (Central Statistics Organization). 2013. Socio-Demographic and Economic Survey Bamyan. Retrieved July 12, 2017, from. Retrieved from http://cso.gov.af/Content/files/Afghanistan SDES Bamiyan Final Report - 24 April 2013.pdf

[12] NEPA (National Environmental Protection Agency). (2010). National Waste Management Policy Retrieved July 10, 2017, from http://faolex.fao.org/docs/pdf/afg63169E.pdf

[13] Nithya, R., Velumani, A., & Senthil Kumar, S. R. R. (2012). Optimal location and proximity distance of municipal solid waste collection bin using GIS: A case study of Coimbatore city. WSEAS Transactions on Environment and Development, 8(4), 107–119. https://doi.org/10.11648/j.ajaf.20140206.20

[14] Bhambulkar, A. (2011). Municipal Solid Waste Collection Routes Optimized With ARC GIS Network Analyst. International Journal of Advanced Engineering Sciences and Technologies, 11(1), 202–207.

[15] Sonesson, U. (2000). Modeling of the waste collection a general approach to calculate fuel consumption and time. Waste Management and Research, 18(2), 115–123.