An Efficient Framework to Sustainable Management of Refuse Collection and Evacuation in a Developing City

[1]M. A. Shuaibu, [2]A. A. Musa and [2]T. O. Idowu

[1]Department of Surveying and Geoinformatics,
Abubakar Tafawa Balewa University, Bauchi, Nigeria.

[2]Department of Surveying and Geoinformatics,
Modibbo Adama University of Technology, Yola, Nigeria.

Abstract

The study developed a framework for sustainable management of refuse collection and evacuation in Bauchi city through spatial modeling. Coordinates of dump sites and sample households from the study area were obtained by Global Positioning System (GPS) while road network was obtained by digitizing satellite image of the area and both were used in this research. Thus, digital map of dump sites, sampled households and roads about the area were produced. Using the "Network Analyst Tool (NAT)" of ArcGIS 10.2 functionalities for service areas, closest facilities and best routes, a model was then developed to encourage efficient and sustainable refuse collection and evacuation in the area. The model developed has 22 dump sites, 15 closest facilities and 3 trucks routes. The service areas around each dump site are in three buffer zones covering distances of 200m, 350m and 500m respectively while the longest and shortest distances of 1499.46m and 156m in the closest facilities for the households were confirmed. Also, three trucks with truck3 having the longest distance was discovered while truck1 has the least distance for refuse evacuation in the area. These were discovered based on service areas, closest facility and best routes and hence the model will improve the general situation of refuse disposal in the area. Moreover, it will specifically ensure efficiency and sustainability in the management of refuse collection and evacuation of the area. Therefore, spatial modeling through NAT looks more appropriate as panacea for inefficient and unsustainable management of refuse collection and evacuation of a developing Bauchi metropolis. Thus, the model is recommended to be used as an efficient framework for sustainable management of refuse collection and evacuation in similar developing cities.

Keywords: Closest facilities, modeling, network analyst, route optimization, service areas.

Introduction

In this study, the need for spatial modeling of metropolitanrefusecollection and evacuationin a developing cityhas been highlighted and carried out. This need agrees with ever increasing concern by environmentalist that method for the management of metropolitan refuse collection and evacuationis inefficient and unsustainable in developing cities (Musa, 2012; Ayo, 2011; Rabia, 2011). This is in spite of the combined efforts by the United Nations (UN) as contained in the Rio Agenda 21 of 1992 (UN, 1992), the Federal Government of Nigeria(FGN) (Decree 58 of 1988), the private sectors as well as the new millennium development goals (MDGs) for sustainable management, however no significant improvement was seen in the area of refuse collection and evacuation from households, dump site sand land fillsat management level in developing cities. Consequently in Nigerian cities, for example, refuse is often found jumbled on urban neighborhoods (Musa, 2012;Ayo and Ibrahim, 2011;Rabia, 2011; Imam et al., 2008;Walling et al., 2004; Dauda and Osita, 2003; Ogu, 2000). Apart from the ugly scenes induced by this scenario in many and varied vicinities, it also continues to introduce new health risks to man and the environment from insects and rodents (Ayo, 2011) such as the zikka and lassa diseases from mosquitoes and rats respectively that are currently receiving attention globally.

The alarming rate at which heaps of refuse are seen from the nooks and crannies of Bauchi metropolis particularly motivated for study. The situation in the area is even worse in that indiscriminate dumping of refuse is noticed in public places like schools, hospitals, tarred roads, markets, recreational areas, drainages, farms and a host of others; thereby resulting to a number of environmental nuisances leading to deterioration of health. The persistent refuse problems often seen are that classes at some primary schools have been vacated due to the impact of unpleasant smell from the refuse dumped around the schools. Several roads are partially blocked in the metropolis with refuse causing accidents. Similarly, uncompleted buildings and vacant plots are not left out as most of them have been turned to refuse dumping grounds. Cases of floods are yearly experience during raining season at many locations because the drainages are blocked by refuse. More so, well water in areas close to dump sites is no longer drinkable in the study area with reported cases of cholera due to contamination by the refuse via seepage (Bogoro, 2013). These have made refuse collection and evacuation problems unresolved and reoccurring in the study area and this has stimulated interest for the study.

There seems to be growing concern by environmentalist that no significant improvement is seen in the area of collection and evacuation of refuse at management level in developing cities(Arnold and Justine, 2001;Tchobanoglous*at el*., 1993). This lack of obvious improvement might be due to the lack of clear understanding of the spatial interactions between households and dump sites on one hand and the collection and evacuation practices on the other hand before planning refuse disposal. Therefore, resolving the above issues is important in the modeling foran efficient and sustainable refuse disposal and as a good strategy (Brunner and Fellner,2007)thataddresses the current challenges (Guerrero *et al*., 2013and Solomon, 2009)of refuse collection and evacuation in developing cities (Jonathan, 2013; Nikolas and Vassili, 2008).

The study thrust is to use NAT to resolve the inefficient and unsustainable refuse collection and evacuation of households and dump sites to landfills at management level in the developing city of Bauchi through spatial modeling. This aim was achieved by mapping and optimising dump sites in addressing the challenges of service areas for refuse disposal, closest facilities for refuse collection and best routes for refuse evacuation as objectives of the study.

Study Area

The shaded part of the inset map of Nigeria in figure 1 represents the Bauchi State while the study area is Bauchi metropolis geographically bounded by latitudes10° 19' 55''N and 10° 20' 58''N and longitudes 9° 50' 50''E and 9° 51' 29''E. The area is now the capital of both Bauchi LGA and the Bauchi State and it covers an area of about 3,687km^2. Its population figure, according to the 2006 population census result, stands at four hundred and ninety-three thousand eight hundred and ten (493,810).This area is mountainous that lies in the crystalline uplands of Northern Nigeria and they rose over 600m to 650m above sea level (OnlineNigeria.Com, 2013). In the metropolis, most prominent mountains are the Wambai and Warinje hills located to the northeast of the metropolis, the Jahun and Gudum hills to the south and the Kobi hill that dominates the center of the old walled town. The Bauchi urban area has rivers and watershed with many streams from its uplands characterized by latrite soil and flood plains.

The rivers that drain the urban center are; the Burkumbo River, which drains the eastern part of the metropolis, and Shadawanka River drain the north and northeastern parts. The rivers have numerous headwaters and tributaries within the metropolis. This pattern of drainage has produced productive clay and loam soil from fadama land almost surrounding the metropolis. The Gubi dam lies to the northeast of the metropolis, about six kilometers away and provides a good source of water for urban uses. Agricultural practices for production of both food and cash crops have captured the life of the inhabitants of the city while its climatic condition ranges from hottest in the month of April to coldest in month of December. Mean daily temperature ranges from maximum of about 36.6°C in April to minimum of about 13.3°C in December(Climate-data.org, 2013).There are two major seasons in Bauchi. These are rainy and dry seasons. The rainy season months are May to September, when humidity ranges from about 37% to 68%. The onset of the rains has been often in March and they end virtually October while the dry season starts from November to May

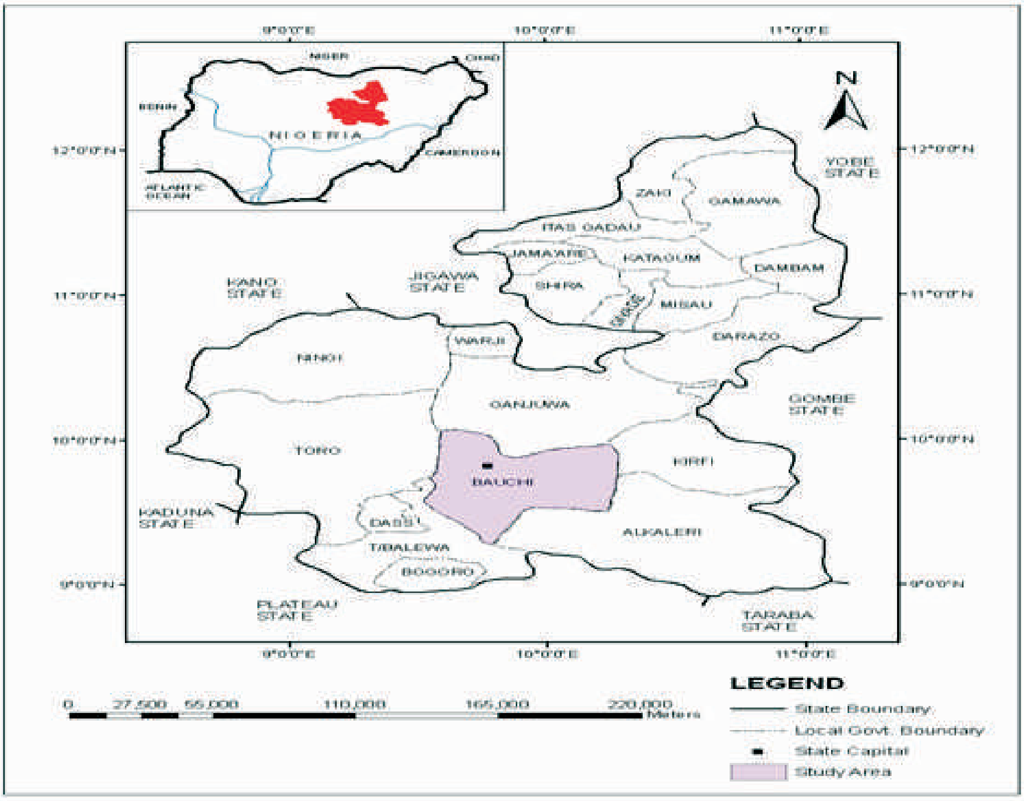

Figure 1: Location map of the study area.
Source: (Bauchi State Ministry of Lands and Housing, 2013).

Modeling for refuse evacuation

In this section, places considered vital in the study area were the dumpsites, transfer stations and landfills. These are places where refuse are seen most of the time. The classification was done to facilitate refuse evacuation and disposal from households to the dumpsites and to landfills respectively (Imam *et al*., 2008; Afon, 2007). This was achieved based on the spatial locations of land fills and transfer stations with preferred trekking distances to dumpsites from households in the study area (Shuaibu, 2015). The optimisation was achieved at 200m, 350m and 500m intervals coverage for the area. This optimisation was spatially determined due to acceptability criterion and service areas coverages as stated earlier in the above and hence locations of some dumpsites were changed while others remained untouched. Others were relocated to optimal locations based on accessibility and suitability of the locations and hence the model using GIS technique (Kang-Tsung, 2012).

Determination of best routes across dumpsites

To achieve the above subject, NAT was utilised. The tool is an extension developed by ESRI to work in ArcGIS 9.1 and above (Matt, 2006). This extension is capable of modeling and solving real world transportation problems using; best route, closest facilities, service areas and origin-destination cost matrix algorithms. The determination was carried out first by importing the satellite (QuickBird) image of the Bauchi metropolis into ArcMap 10.2 environment and georeferenced because it came without spatial reference information. Georeference refers to the definition of location of raster data by means of map coordinates. This enables the creation of feature sources (lines, points and turns) as shape files through digitizing the road network from the satellite image using the editor tool of ArcCatalog and ensuring that topological relationships were established based on polyhedral formula developed by Leonard Euler (1736).

$$v - f + e = 2 \quad (1)$$

Where;

v = number of vertices (nodes)

f = number of faces (directions)

e = number of edges (lines)

Despite the number of polygons, the result will always be two.

The importance of topological relationship is that it focuses on connectivity in a network to ensure that all polygons are closed, lines are connected by nodes and nodes connected to lines. Hence, it enables the determination of errors due to digitisation, routing in a network and reduce lines redundancy by allowing neighboring polygons to share lines in between. Fields such as length and cost with their respective geometry and time values were then added to the network in ArcMap. Also, attributes table that carries vital route information such as road addresses and others were created through add field to the route network. Hence, the road network database was created. Furthermore, the creation of new network data set then followed immediately from the ArcCatalog with participating nodes and junctions. The procedure of finding best routes and service areas were based on the distance criterion which considers only routes where dumpsites are located while traffic is excluded and cost criterion that considers the runtime of the vehicle to locate and load waste at each stop.

Determination of service areas of the dumpsites

The major dumpsites of the study area were checked to find out if they could serve all the existing households. This was achieved first by activating the network dataset which enables the use of the network analyst window. Locations of the dumpsites were loaded into ArcMap as stops, and analysis setting from service area event was then carried out. Polygons indicating the service areas of each dumpsite were fixed and generated in three different levels at interval of 200m, 350m and 500m respectively. Some dumpsites positions were relocated to other points to provide sufficient coverage in terms of service areas. This was achieved using p-median model in changing the locations of the facilities to desired points as suggested by Ritesh *et al.* (2008) and Suman (2012).

Determination of closest facilities

The closest facility functionality in the

NAT was used in the search carried out to identify dumpsites close to households in question. The procedures started by loading the twenty-two dumpsites of the area as stops while the eighteen schools considered as representatives of households were loaded as incidences.

Hence the search was carried and closest dumpsites to each school were determined.

Results and Discussion

In the study, service areas, best routes and closest facilities were used to develop the efficient framework for sustainable refuse collection and evacuation. The model links up households to dumpsites thence trucks to landfill and can guarantee safe refuse disposal and be sustainable.

Service areas of dumpsites

Figure 2 depicts the service areas of dumpsites of the study area. The service areas are in three categories of coloured polygons at distances of 200m, 350m and 500m respectively. The distances radiate away from each major dumpsite towards the households. These polygons cover buffers within which a household will bring refuse to dumpsite. Also, the service area indicates the attitudes of residence towards waste disposal. The zones within which the service areas covered in the metropolis pointed out that the dumpsites locations were optimal for refuse collection. Musa (2012) in a separate study determined

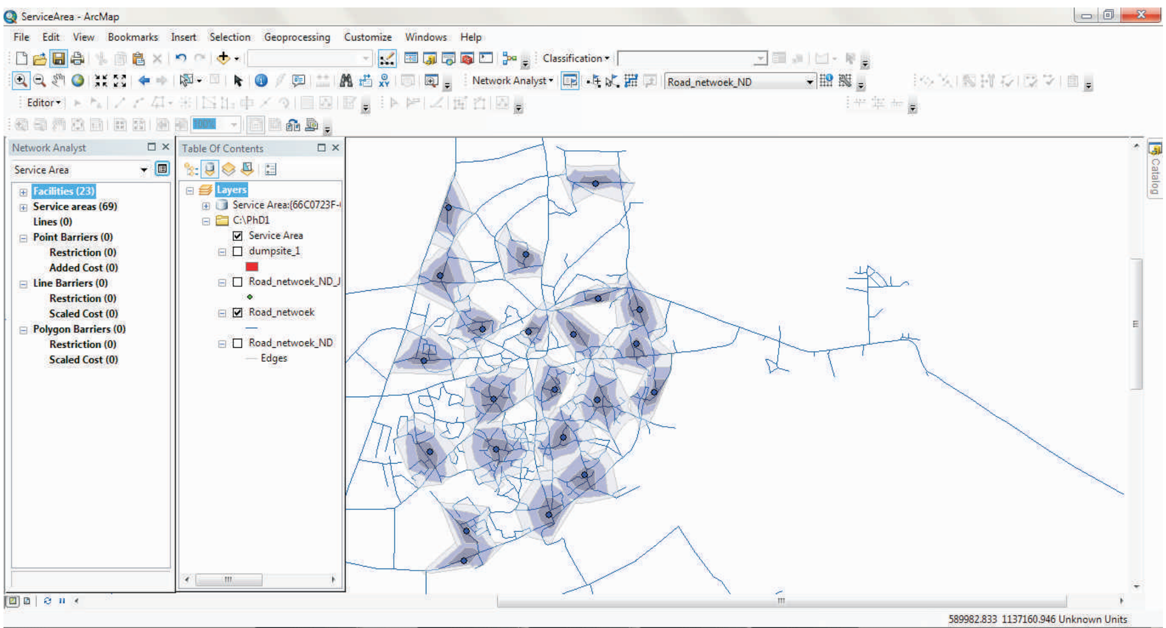

Figure 2: Service areas for refuse disposal in the Bauchi metropolis

optimal bins and their service areas for refuse collection from households to the dumpsites in Jimeta metropolis. He further suggested that if bins will be optimally located with service areas, issues of improper refuse collection in Jimeta will be minimal. This concord the recommendations that optimal dumpsites are needed without which efficient refuse collection from households to dumpsites and evacuation to landfill will be problematic (Ayo, 2011).

Best route for refuse evacuation

Figure 3 shows the truck routes with database for refuse disposal in the Bauchi metropolis. The result indicates that the truck routes were best categorised into three routine category of the truck1 has color red with up to seven stops. The origin starts at Games Village and covered all the stops from origin at Wunti through the transfer station at Ibrahim Bako Housing Estate Junction. Also, the evacuation process will be completed by truck 3. These three trucks will ensure efficient refuse evacuation in the area. Musa (2012) determined best route for refuse evacuation in Jimeta and reported that best route facilitates quick refuse evacuation; reduce transportation cost and wear and tear of machines in refuse disposal. This agrees with the findings that optimized routes are required to reduce cost in sustainable management ofrefuse disposal and as well for ensuring city life quality (Apaydin and Gonullu, 2008).

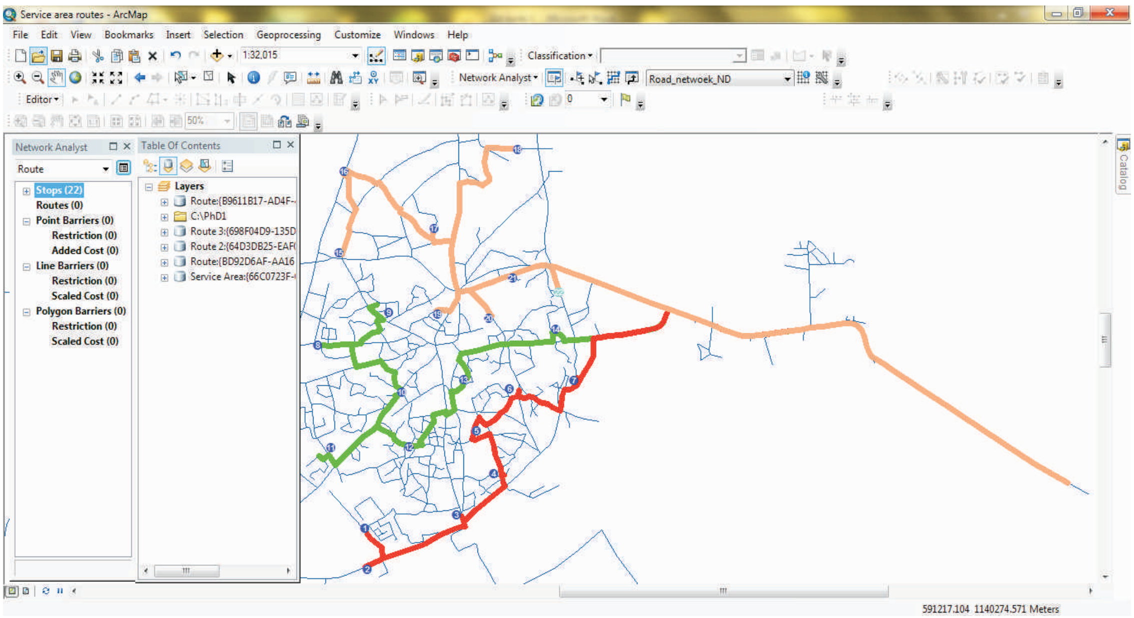

Figure 3: Best routes for refuse disposal in the Bauchi metropolis

Closest facility

Figure 4 depicts lines with color green as the searched closest facility of the study area. The results indicate that eighteen schools (in square blocks) as representative of the households in terms of refuse generation were used to test how far refuse from households are collected to the dumpsites (in round dots). The dumpsites are twenty-two in number but only fifteen attracted the eighteen refuse generators used in this study. The longest distances of 1499.46m and 1146.62m from the closest facility study were between Special School and Saadu Zungur Primary School to the dumpsite at Wunti respectively while the shortest distance of 156m was between Unguwar Borno Primary School to the dumpsite at Jahun. Others that followed were: Government Secondary School Kofar Idi and Federal Government Girls College to the dumpsite at Kofar Wambai with distances of 1115.28m and 826.28m respectively, Federal Lowcost Secondary School with distance of 1049.44m to the dumpsite at Jahun, Jahun Primary School with distance of 767.49m to dumpsite at Jahun, Zannuwa Primary School and Comprehensive Secondary School with distances of 767.40m and 429.49m respectively to the one at IBB Square, Shekal Primary School with distance of 581.45m to the dumpsite at Gombe road near the Health Clinic, Digan Yaya Primary School with distance of 415.57m to the dumpsite at Ibo Quarters, Juniour Secondary School Wayan Makafi with distance of 373.89m to the dumpsite at DutsenTanshi, Kofar Dumi Primary School with of 318.58m to the dumpsite at Karofin Madaki, Bakaro Primary School with of 276.29m to the dumpsite at Gwangwangwan, NRC Training School with a distance of 251.30m to the dumpsite at Federal Lowcost, Nasarwa Primary School with distance of 211.20m to the dumpsite at Gwallaga and finally Kobi Primary School with of 199.09m at Kobi Play ground.

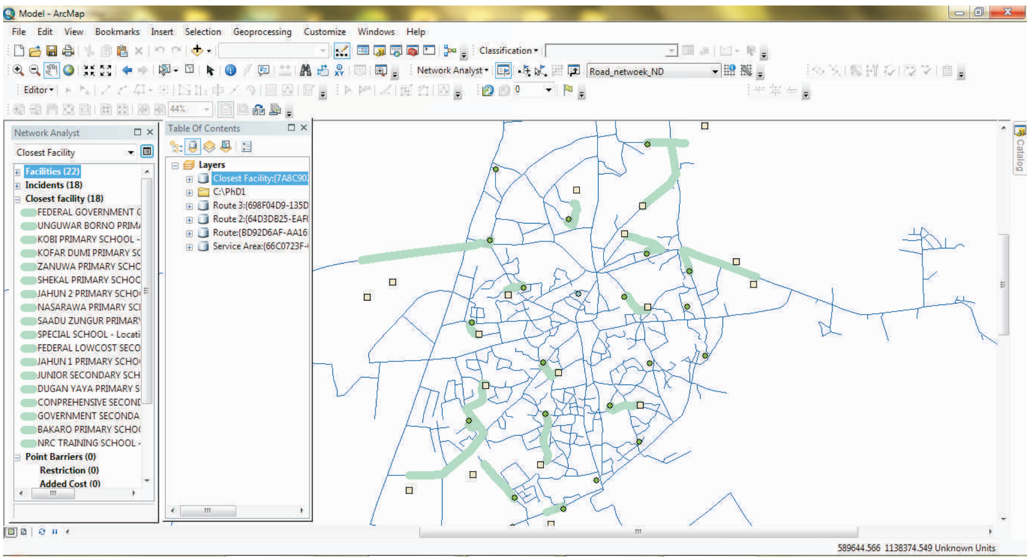

Figure 4: Closest facilities for households refusecollection in the Bauchi metropolis

Model for effective and efficient refuse disposal

The map presented in Figure 5 is the model for effective and efficient refuse disposal of the Bauchi metropolis. The model consisted of basically four major items; the households, the dumpsites, the landfills and the trucks. The square boxes with color sahara sand in the model represent sample refuse generators. The rounded small points in macaw green represent the dumpsites in the model. The transfer station is a rounded point with number 8 written on top while the landfill is closely rectangular in shape with a rounded point 9 written on top and all are located towards the eastern part of the model. The three trucks routes with color red, green and orange completed the major components of the model.

The model was designed to deal with refuse disposal elements. Therefore, three phases of refuse disposal process were considered and are; refuse disposal from households to dumpsites thence transfer station thence landfill. Effective refuse disposal from households was insured by the use of closest facility in the model. Each household can be guided as to where refuse from that household should be disposed at the nearest dumpsite. Likewise the service areas in the model show number of households within each optimal dumpsite and insuring that the whole study area was covered spatially with the available dumpsites for households refuse disposal. More so, the three routes in the model provided good ground for not only making efficient refuse disposal but also for sustainability from dumpsites to landfill. Shou-Min and Jau-min (1994) determined best routes in Teipi cityfor refuse and this concord Musa (2012) for the best route with service areas in Jimeta city for proper refuse disposal.

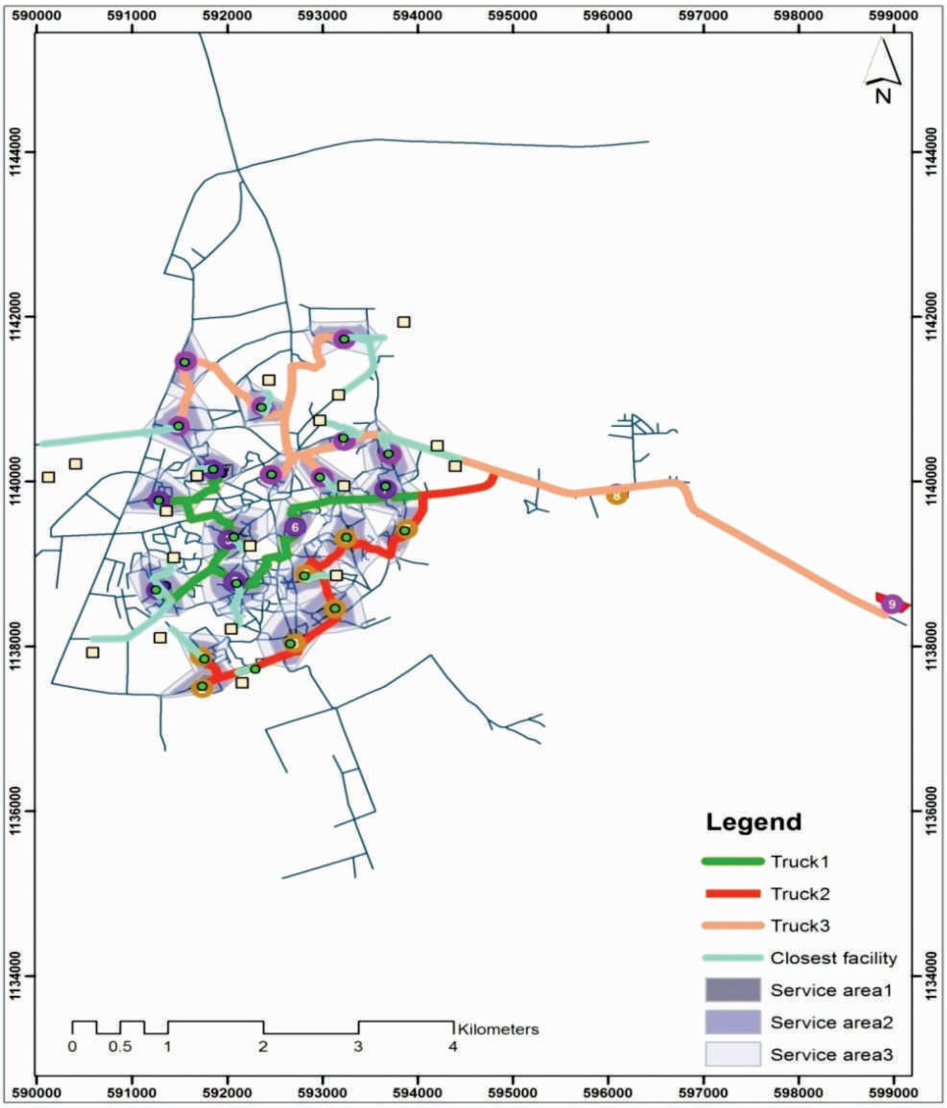

Figure 5: Model for efficient and sustainable refuse disposal of Bauchi metropolis

Conclusion and Recommendations

The NAT proves to be simple and more workable means of designing an efficient framework to sustainable management of refuse collection and evacuation based on service areas, closest facilities and best routes. This was carried out for the Bauchi metropolis. Thus, it is recommended for efficient refuse collection and sustainable evacuation in developing cities.

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