ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

IMPROVING HOUSEHOLD SOLID WASTE LOGISTICS SYSTEMS OF ADDIS ABABA; THE CASE OF BOLE SUB CITY

A Thesis in Road and Transport Engineering

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in

Road and Transport engineering

The undersigned have examined the thesis entitled '**Improving solid waste logistics systems of Addis Ababa; the case of Bole sub-city'** presented by **Nuhamin Demeke**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I certify that research work titled "Improving solid waste logistics systems of Addis Ababa; the case of Bole sub-city" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly referred.

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ABSTRACT

According to the United Nations Overview of Addis Ababa City Solid Waste Management System (2010), it is estimated that only 65% of the waste generated in the city is collected, with the rest being deposited in open sites, drainage channels, and rivers. And also due to lack of awareness and willingness to sort wastes at household levels it makes the waste management practice poor. As Bole is one of the sub-cities among the 10 sub-cities, the waste collection and transportation is not efficient.

Therefore, in order to improve the waste collection efficiency, properly designed and optimized waste collection routing system is very crucial for minimizing operating cost and to reduce littering of uncollected solid wastes from roadsides and open areas.

This paper deals with, assessing the current waste logistics practice in Bole sub-city and improving the waste logistics system by applying Geographical Information systems as a decision support tool for the optimization of waste collection and transportation for improving waste collection efficiency. From the study, it was found that the waste logistics practice of sorting, recycling, composting are practiced with a little extent measuring below 50%. The study also optimized the total collection distance by comparing two scenarios with the current collection route. The scenarios were: optimization without transfer station and with the introduction of transfer station locations 1 and 2. From the analysis, 79.1 %, 86% and 82.4% benefit of the optimized route distance and 54.8%,68.3% and 58.5% benefit of total travel time without the application of transfer station and with the application of transfer station location 1 and 2 respectively were obtained.

The major conclusion of this study is the waste management of the sub-city suffers from a poor waste logistics practice and an inefficient waste collection and transport system. Though the results from this study are encouraging enough to further expand the scope to cover all sub-cities in Addis Ababa, in order to improve the waste logistics practice in the sub-city, a lot of effort is needed to create an awareness on reverse logistics to the public and an efficient waste logistics practice has to be introduced to tackle the problem.

Keywords: solid waste management, reverse logistics, GIS, optimization

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Abbreviations

GIS- Geographic information system

GPS- Global positioning system

EPA- Environmental protection Agency

MSW- Municipal solid waste

RL- Reverse logistics

SWM- Solid waste management

VRP- Vehicle routing problem

1. INTRODUCTION

1.1 Background of the study

Due to the improved lifestyle of people around the world, the rate of waste generation is rising rapidly. World Bank reported that 2.01 billion tonnes of solid waste is generated in 2016 with a per capita waste generation rate of 0.74 kilograms per day and projected to increase by 70% from 2016 and expected to level in 2050 to 3.4 billion tonnes. Developing countries compared to developed countries struggle more with managing wastes properly. According to the World Bank, in low-income countries, 99% of waste is being disposed of in unregulated dumps and burned in the open air. Building sustainable and livable cities require a properly designed waste management system. Effective waste management can take up 20%-50% of municipal budget (World Bank: A global review of solid waste management, 2019).

Poorly managed waste contaminates the surrounding water and air causing serious health problems on peoples and also animals. It can also affect the nation's economy by diminishing tourism.

Waste handling is one of the greatest challenges facing humankind in modern times in spite of the numerous technological advancements that the world has experienced in recent times (Lawrence Kwami Aziale and Ellen Asafo-Adjei, 2013). The issue of waste management is a problem that our country Ethiopia specifically the capital city, Addis Ababa, is confronting now with detrimental effects on health, Aesthetics and the environment indirectly affecting the nation's economy. The problem is a major and keen concern for the city as it is the capital of the country and also a seat for the African Union and other international organizations.

Waste transport and logistics activities have a wide range of negative social and environmental impacts in urban areas including noise pollution, air pollution, contribution to traffic congestion, involvement in traffic accidents, and the deposit of dirt and waste on the road network (Michael Browne and Julian Allen, 2007).

Dogan and Sulman, 2003; Ghose et al., 2006; Nguyen and Wilson, 2010, cited by Zdena Zsigraiova et al., 2013, defined municipal solid waste (MSW) collection and transportation as a waste management activity that contributes substantially to hazardous environmental impact due to fuel consumption and consequent pollutant emissions, and can absorb a considerable share of the total system budget.

Though our country Ethiopia adopted a solid waste proclamation, Proclamation No.513/2007, in terms of implementation and delivering an improved service to the community, it is still backward in terms of operational efficiency.

1.2 Statement of the problem

Rapid urbanization has resulted in Solid waste collection which has become a more complex and serious issue in our country, especially in Addis Ababa in terms of operating cost, service quality and environmental issues. In our country, Ethiopia, open dumping and open burning are very common resulting in a very serious environmental problem. Although there is an effort made by private sectors contracted by the municipal body, to collect and clean the designated areas for waste disposal, in our daily life we still witness uncontrolled dumping and not very well maintained collection spots, talking specifically for the household areas of the capital city.

According to the United Nations Overview of Addis Ababa City Solid Waste Management System (2010), it is estimated that only 65% of the waste generated in the city is collected, with the rest being deposited in open sites, drainage channels, and rivers. And also due to lack of awareness and willingness to sort wastes at household levels it makes the waste management practice poor.

A study conducted by Nigatu Regassa et al. (2011) in two sub-cities specifically in Bole and Akaki Kality sub-city revealed that the reasons for low performance of SWM in the city includes: inaccessibility of the city due to the geographical and urban structure, lack of properly designed collection route system and time schedule, inadequate and malfunctioning operation equipment, open burning of garbage, poor condition of the final dump site, littering of the corner around the skips which encouraged illegal dumping are the technical problem identified. Insufficient funds, as well as lack of promotion on-waste reduction: recycling, absence of cost recovery, the practice of energy options, waste separation and composting, are among the financial challenge.

According to a report by ARTELIA on their final report on solid waste management strategy and institutional report of Addis Ababa city, the maximum potential of waste recycling could be around 15% by weight at the source. But the recyclable materials would be unclean and contaminated by organic waste due to mixed collection. This, in turn, requires washing and drying before being recycled. This could potentially affect the amount of material to be recycled reducing the potentially recyclable materials to less than 8% without informal picking according to their report. This has an implication that the reverse logistics aspect of the waste management still requires studies in more depth in order to improve the waste logistics systems. Furthermore, there has been no sufficient studies carried out to improve the waste logistics system, which is the collection and transport of waste, by applying Geographic information system (GIS).

It is therefore, hopped that this research study on improving the waste logistics Practice of Bole sub-city will contribute towards providing an insight on the role reverse logistics in waste management system and how GIS can be used as a decision support tool for optimization of waste collection distance. Due to time and budget constraints, the study was carried on one of the sub-cities of Addis Ababa after randomly selecting. As this is a case study and confined to only studying Bole sub-city Waste logistics practice, it is important considering to further carry out the study on other sub-cities and the city as a whole for achieving a better result.

1.3 Objectives

The main objective of the thesis was to assess solid waste collection methods to improve the efficiency of waste collection and transportation using route optimization techniques in order to minimize collection distance.

The Specific objectives were to:

(1) Map out solid waste collection Points including loading and unloading stops

(2) Carry out an assessment on the current waste logistics system in Bole sub-city including waste generation and collection.

(3) Perform optimization analysis for the collection route to the landfill and proposed transfer station.

Scope and limitation of the study.

The scope of this research is bound to improving solid waste logistics systems of Addis Ababa city in the case of Bole sub-city. Due to time and budget constraints, the study covers only Bole sub-city among the 10 sub-cities after selecting randomly. The research covers the waste generation, waste collection, and transportation system of Municipal solid waste in the sub-city. The study doesn't cover other waste (commercial waste, industrial waste, liquid or gaseous waste) logistic systems.

Mapping out of the solid waste was carried out using document analysis and interviews with governmental officials and other stakeholders rather than direct quantification and field surveys. In spite of the fact that mapping out of solid waste requires a large amount of budget and human resources, it was not feasible to carry out solid waste quantification and characterization by oneself. Despite this, the data used were recent and reliable.

There was no quantification and characterization, of municipal solid waste streams generated by different sources, carried out. In addition, the flows of materials collected, transported, recovered and disposed of by the different actors within the WMS wasn't quantified cause it is beyond the scope of this thesis work. The collection and transportation of waste carried out by private companies are also not considered in this study. Because the topic is so broad and requires a study in more depth, it can't be addressed by a single person. It is important to carry out further study by the municipality about waste management and reverse logistics practice in the city as a whole in order to improve the current situation.

Though the efficiency of a waste collection truck can be affected by human factor, road network (Frequent junctions, Traffic lights, Roundabout) and road factors (Traffic lane width, Design speed, Traffic calming device, On-road parking, Vertical alignment), it is not covered in this study due to resources and time limitation but can be suggested for further research. The lack of spatial data was also a limitation of this study not to carry out further analysis.

1.4 Significance of the study

The significance of this research mainly lies in the selected subject; improving solid waste logistics systems, the case study of Bole sub-city. Globally, the relationship between Reverse Logistics and Waste Management has already been an agenda currently. Following this, researches are emerging with regards to improving the logistics systems in the waste sector.

However, in Ethiopia, it seems the research theme has been given limited focus, attention, and resources compared to the magnitude of the problem. The benefits of integrating logistics and waste management haven’t been given much attention.

Even though the entire quantity of waste generated in the sub-city is planned to be brought to the landfill, the waste is not cleared fully. In Addis Ababa, it is very common to see a pile of smelly waste on roadsides polluting the environment. As Bole is one of the sub-cities, the problem is still common. This makes the city as a whole aesthetically unpleasant.

No to date researches in Ethiopia shows the use of spatial modeling tools and GIS for collection and transportation optimization to provide economic and environmental gains by reducing distance and time. This study can shed light on improving the waste logistics systems by using spatial modeling tools in order to improve efficiency in the waste logistics sector.

1.5 Organization of the thesis

This thesis is organized into five parts. The contents of the paperwork are explained briefly below.

- **Introduction**: - In the introduction part, the concept of reverse logistics in relation to waste management was explained. This part also contains the objectives, the scope, and limitation of the study, and the significance of the study. The conceptual workflow of the methodology was also included.
- **Literature review: -** in this section, it was tried to explain what route optimization is. Different reviewed previous research works on route optimization using GIS were explained.

- **Materials and Methods:-** This section explains the methodology followed to achieve the objective of the study.
- **Result and discussion: -** in this section of the paper the results for waste generation, reverse logistics network chain, current waste logistics practice, and different route optimization scenarios were presented using tables, flow chart, and maps respectively and further discussed.
- **Conclusion and recommendation: -** in this section the conclusions based on the results were stated and further areas of research in the subject were recommended.

1.6 Conceptual framework

The conceptual framework which demonstrates the methodology adopted for the improvement of solid waste logistics systems and the application of GIS in the optimization of solid waste collection routes is presented in Figure 3.

The flow of the model indicates the different steps carried in the methodology adopted for the reverse logistics route optimization for solid waste. This model was quite helpful to frame the methodology and the flow of this model also suggested the chapters to be included in this paper. The information of Addis Ababa city and Bole sub-city is available in a different medium. The information from all these mediums has to be brought on a common platform where they can be linked together with each other. As the information is about the same location, they can be correlated. This will form a complete set of data with both spatial and non-spatial information. This would fulfill the basic principle of GIS to relate the information spatially.

There are four main sources of data:

• The maps containing the spatial information:-

• The spatial data, which gives information about the location of different articles. This spatial information was correlated and later incorporated on the maps. The information was about the location of waste bins:-

• The third is the attribute information which contains the non-spatial information giving information about the spatial elements:-

• The other information source was through interviews, questionnaires and online sources. The interview with the municipal official provided information about the existing working pattern of municipal waste management. The questionnaire was for the respective SWM office staff from different woredas in the sub-city and was prepared in the later stages so that the information which was not covered in the above stated.

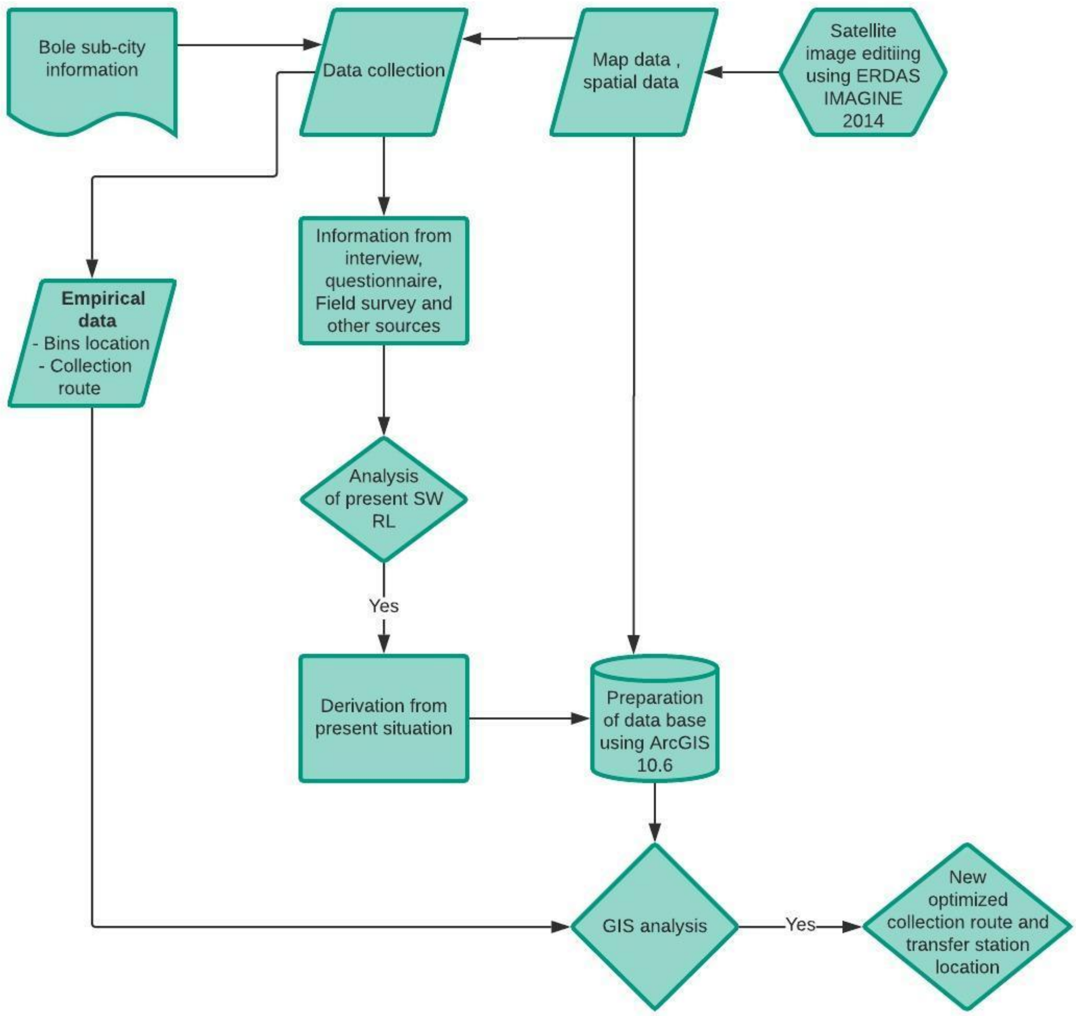


Figure 1. Conceptual frame workflow of the methodology

2. LITERATURE REVIEW

2.1 What is Logistics?

According to The Council of Logistics Management definition cited by Güldem Elmas and Fevzi Erdoğmuş (2013), Logistics is the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements.

Table 1. Different Logistics types and their description (Kinobe, J. R, 2015)

Logistics types	Description
Airfreight logistics	Mainly relevant to high value and precious goods and perishable products that need to reach their destinations quickly. The services of air freight transportation are always high compared to other modes of transportation.
. City logistic	City logistics refers to logistic activities by organizations and companies in urban centers. It is characterized by high traffic, advanced information system, co-operative freight transport, and public and private logistics terminals. However, city logistics is affected by problems such as increased traffic activities, congestions, noise, emissions, and traffic accidents (E. Taniguchi, R.G. Thompson,2002)
Construction logistic	This focuses on the efficient transportation of materials to the construction site to reduce transport movements, reduce stock holding, efficiency use of on-site labor, and generate less waste. This, on the other hand, will reduce construction time, improve quality, reduce risks to health and safety and also protect the environment.
Green logistics	Green logistics refers to minimizing the ecological impact of logistics, for example, reducing the energy usage of logistics activities and reducing the usage of materials. Green logistics is an increasing new emerging field that is spreading from the traditional forward logistic channel perspective [19, 20]. Green logistics is getting more attention from the supply chain management attributed to the deteriorating environment brought about by the increasing level of energy and pollution released into the ecosystems, high generation of waste and diminishing raw materials.
Lean logistics	Aims at eliminating waste (inventory) which affects the progress of work in process inventories and in turn will decrease process and cycle times and ultimately increase supply chain velocity and flow. When undertaken, lean logistics will improve inventory accuracy because storage space will be better utilized, products

	will be handled, moved, counted less and less damaged.
Manufacturing logistics	This refers to techniques that are developed by most firms in the supply chain aimed at efficiency and effectiveness, for instance, JIT (just in time) ideology.
Maritime logistics	Mainly associated with container shipping and involves an integration of maritime operations and supply chain management to meet the needs of regional, national, and international shipping. It is characterized by a high carrying capacity.
Organization logistics	This is concerned with the entire management of firms or organizations both internal and external throughout the supply network, with a primary focus on the capacity of people to learn and share knowledge and information.
Retail logistics	Retail logistics gained recognition after the rise of supply chain management. This was through the addition of value to products through manufacturing, branding, packaging, display at the store, and at each stage cost is added in terms of production cost, branding cost and overall logistics cost.
Reverse logistics	It is the process of planning, implementing and controlling the efficient cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal.
Rural logistics	Refers to logistic activities that occur in the rural areas and spread to city centers aiming for a market for supplying agricultural products.

In spite of the fact that the scope of logistics becoming broad, the logistics discipline has generally focused on transportation, warehousing, inventory management, and so on, from the perspective of forwarding distribution, i.e., producer-to-consumer movement of products.

Logistics has two areas of knowledge, which are forward logistics and reverse logistics, of great interest that grows continuously, but still, have a lack of research concerning its interrelations. Logistics activities are quite complex and have high uncertainty. By treating the information, especially through the creation of knowledge, plays a key role in value creation. Well interpreted information can be translated into knowledge, which in reverse logistics enables effective and efficient decision making processes of organizational change, based on the evaluation and integration of reverse flows of information into knowledge processes of a business.

Because of environmentalism, the concept of "reverse" distribution, that is, consumer-to-producer movements have become more prevalent. The relation of reverse logistics and waste management is further explained later on in this paper.

2.1.1 Reverse logistics

2.1.1.1 *Introduction to RL*

According to the European Working Group on Reverse Logistics (2004) cited in PricewaterhouseCoopers first Reverse Logistics report in the Consumer Electronic industry, Reverse Logistics is the process of planning, implementing, and controlling flows of raw materials, in-process inventory, and finished goods, from a manufacturing, distribution or use point to a point of recovery or point of proper disposal.

According to Reverse Logistics Association (RLA), cited by Güldem Elmas and Fevzi Erdoğmuş (2011), reverse logistics is defined as all activity associated with a product or service after the point of sale where by the ultimate goal is to optimize or make more efficient aftermarket activity, thus saving money and environmental resources. More precisely, reverse logistics is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal.

Reverse logistics is a relatively new phenomenon in the research area mainly referring to damaged goods that should be returned to the manufacturers or distributors. According to Cassiano Finkler et.al (2017), the benefits of effective implementation of Reverse Logistics can be understood:

a) To add value to the corporate image in society

b) To reduce liabilities, environmental impact and use of virgin raw materials through the reuse and recycling of returned products

c) To generate value through the reduction, reuse, and recycling of materials and products, and the reduction of costs with waste treatment and final product disposal

d) To optimize processes with the control of residues and generated information

According to Stock (1998, p. 20), the term Reverse Logistics is used to refer to “the role of logistics in product returns, source reduction, recycling, material substitution, reuse of materials, waste disposal, and refurbishing, repair and remanufacturing”. The author also stresses on waste disposal.

Carter and Ellram (1998) stated that more holistic view of Reverse Logistics includes the reduction of materials in the forward system in such a way that fewer materials flow back, reuse of materials is possible and recycling is facilitated. According to Benjamin et al. (2012), reverse logistics focuses on four main activities: reuse, Product update, material recovery, and waste management. According to Souza Fonseca (2009), cited by Regiane P. Andrade et al. 2013, reverse logistics can be seen in two major areas: economic and social. The first, due to financial gains the company can reduce its costs reusing materials that would otherwise be discarded. The social aspect considers the gains obtained by the Company to dispose of less waste in landfills through the practice of recycling, thus reducing the chances of soil and groundwater contamination.

According to Guarnieri (2013) cited by Annelise Nairne Schamne and Andre Nagalli (2016), a reverse logistics process is a great opportunity to develop the systemization of waste streams, goods, and waste products inside or outside the supply chain. Furthermore, the reverse logistics system consists of an organizational tool in order to make all stages technically and economically feasible and contribute to the promotion of sustainability, minimizing environmental impacts.

Reverse logistics reduces the amount of waste, deposited in the environment (the materials
are reused instead of consuming new resources) by reducing dependence on landfills and energy (Janusz Grabara et.al, 2014).

Leite (2003) asserts that, as cited by Karina TS Dias and Sergio S Braga Junior (2016), as the area of business logistics that is used to plan, operate, and control the flow and logistics information corresponding to the return of after-sales and post-consumer goods to the production cycle through reverse distribution channels, which adds value of various kinds, such as economic, ecological, legal aspects, logistic, and related to corporate image, among others, reverse has been recognized.

2.1.1.2 *The difference between forward logistics and reverse logistics*

Forward logistics is an active process, where firms plan, produce and supply distributors with products based upon forecasts. Whereas, reverse logistics is a reactive process with more unpredictable factors, which is usually initiated by end-user (M. M. Veiga, 2013).

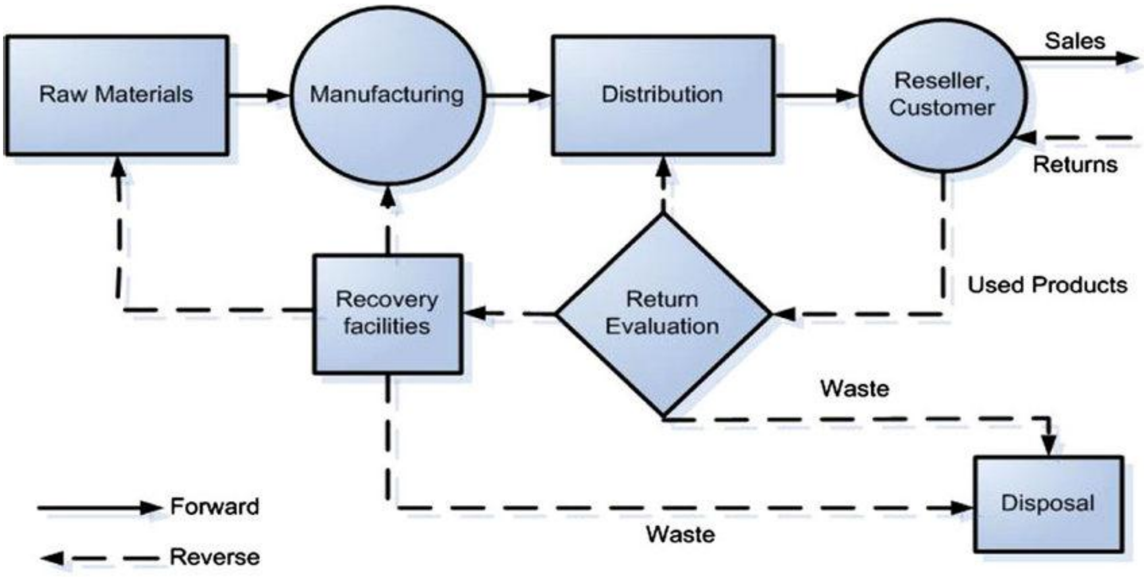


Figure 2. A generic form of forward/reverse logistics (Tonanont et al., 2008).

The difference between forward and reverse logistics are summarized in Table 2. As presented by Ronald S. Tibben-lembke and Dales S. Rogers (2002).

Table 2. Difference between Forward and reverse logistics

Forward logistics	Reverse logistics
Forecasting relatively straightforward	Forecasting more difficult
One to many transportations	Many to one transportation
Product quality uniform	Product quality, not uniform
Product packaging uniform	Product packaging often damaged
Destination/routing clear	Destination/routing unclear
Standardized channel	Exception driven
Disposition options clear	Disposition not clear
Pricing relatively uniform	Pricing dependent on many factors
Importance of speed recognized	Speed often not considered a priority
Forward distribution costs closely monitored by accounting systems	Reverse costs less directly visible
Inventory management consistent	Inventory management not consistent
Product lifecycle manageable	Product lifecycle issues more complex
Negotiation between parties straightforward	Negotiation complicated by additional considerations
Marketing methods well-known	Marketing complicated by several factors
Real-time information readily available to	Visibility of process less transparent

track product	

2.2 Municipal Solid waste management

United States Environmental protection agency (EPA) defined municipal solid waste (also called trash or garbage) as wastes consisting of everyday items such as product packaging, grass clippings, furniture, clothing, bottles and cans, food scraps, newspapers, appliances, consumer electronics, and batteries and does not include municipal wastewater treatment sludge, industrial process wastes, automobile bodies, combustion ash, or construction and demolition debris. World Bank in one of its urban development series – knowledge papers titled 'what a waste: a global review of solid waste management' stated that the higher the income level and rate of urbanization, the greater the amount of solid waste produced. Recycling, composting and reusing should be the natural alternatives for disposing of waste, as they are associated with lower environmental impacts (M. M. Veiga, 2013).

2.2.1 Logistics Facilities in Solid Waste Management

2.2.1.1 *Primary Storage Facilities*

A variety of facilities are used for primary storage of solid wastes. Standardized containers can be used; the standardization of primary-storage facilities could maximize labor and transport productivity. This is especially true for waste collection methods that rely on the direct handling of primary refuse-storage equipment by municipal workers. No such advantage is derived in the case where municipal workers only handle secondary-storage facilities, such as communal bins. In the separation at source scheme, the householder is either required to place recyclable materials into one container for sorting by the collectors (including informal sectors), or the recyclable materials are placed in separate containers.

2.2.1.2 *Secondary Storage facilities*

Secondary waste storage facilities may be either stationary or portable units. The stationary units are commonly uncovered, and the waste is often scattered around the facility where insects, rodents, and animals are attracted to it. In portable storage facilities, the vehicle deposits an empty container and collects a full one. Vehicle productivity, in general, is maximized in portable units since the time taken to set down an empty container and load a full one is very small (typically one minute), and with appropriate tipping gear fitted to the vehicle, the tipping operation also requires minimal time to complete

2.2.1.3 *Landfill*

The landfill is an ecologically sensitive area where groundwater supplies are threatened because it is located on a wetland. 'Koshe' is an open and unlined landfill with no groundwater protection and limited leachate recovery. The landfill is encircled by settlements and housing, posing a health risk to the people living nearby. The waste pickers at the landfill burn the waste to reduce its capacity. The smell is a nuisance and discomfort to the people because the waste is not segregated. Burning of medical and industrial wastes produces gases that when inhaled can cause health hazards to the surrounding community (Hu *et al*., 2002, Jang *et al*., 2006). The waste is heterogeneous in nature and is not segregated from the household to the disposal site. Waste 18 loaders who perform out the action of picking out recyclable products do sort these unsegregated wastes before it is loaded onto the vehicles, taking up a considerable amount of time (Wilson *et al*., 2009, Wilson *et al*., 2006).

2.2.1.4 *Transfer Station*

A transfer station is an interface between (short-haul) waste collection vehicles and long hauls vehicles more appropriate for long distances to assist in the disposal of waste more economically. The purpose is to reduce not only the transport unit cost of collection vehicles, and obtain more cost-effective payloads, but also to allow quicker turnaround times on collection vehicles and therefore increased productivity. The need for a transfer station and the degree of required sophistication will be determined by the volume of waste generated, the collection systems implemented, and the distance to the disposal site. There no transfer station at the sub-city level.

2.2.2 Reverse logistics in relation to waste management

According to M.P. De Brito, R. Dekker, (2002), cited by Kinobe, J. R (2015) "Reverse logistics differs from waste management in that it focuses on the addition of value to a product to be recovered and then the outcomes do enter a new supply chain while waste management involves mainly the collection and treatment of the waste products that have got no new use."

According to Kinobe, J. R. (2015) the below figure clearly shows the basic traditional reverse logistics of waste management dealing in the return of unwanted products to a central location for processing, stored and then recycled and reused into different streams in new markets.

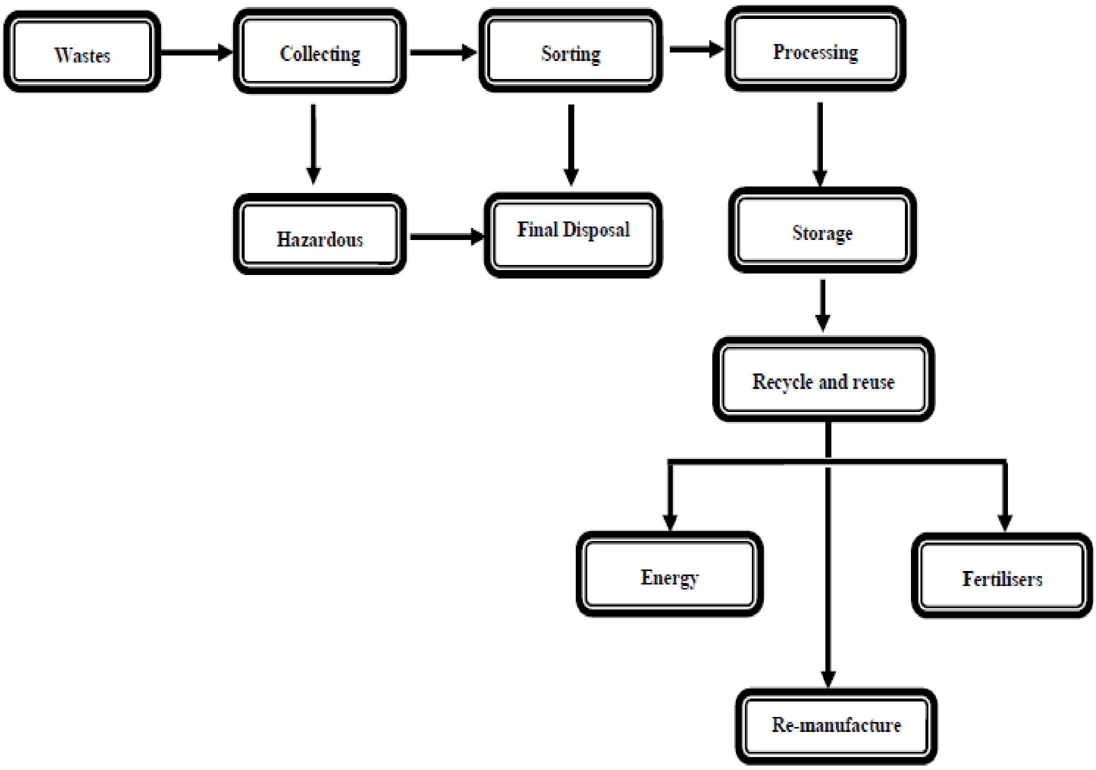


Figure 3. Integration of waste management and reverse logistics (Kinobe, J. R, 2015)

Though there are options to waste management like incineration; recycling, composting and reusing should be the natural alternatives for disposing of waste, as they are associated with lower environmental impacts. These options will elevate an existing landfill life.

The United States Environmental protection Agency (EPA) suggested that in order to significantly reduce the weight and volume of waste material requiring disposal, source reduction, and recycling play an integral role in total waste management reducing transportation, landfill and incinerator costs. Source reduction consists of reducing waste at the source by changing product design, manufacturing processes, and purchasing and sales practices to reduce the quantity or toxicity of materials before they reach the waste stream.

J R Kinobe et al. (2015) stated reusing, recycling and proper waste treatment are activities found in reverse distribution channels where the relationship between reverse logistics and waste management occurs.

According to Holtzer, M. (2001), the logistics waste management conception is mainly concentrated on the collection and processing the waste in an effective way, both, for waste not available to re-use and for waste which can be re-used and some additional value can be generated from them. Proper management and awareness of the environmental implications of logistics activities can significantly reduce the negative impact.

According to Blackburn et al. (2004), reverse supply chains are organized to manage activities related to used product acquisition; transportation of used products to sorting facilities; inspection, sorting, and disposition of collected products; remanufacturing (or refurbishing) of returns; and the creation of secondary markets for remanufactured products. Managing waste through reuse and recycling is typically carried out through reverse supply chain activities.

The main purpose of reverse logistics is creation of waste flows which is described by both ecological efficiency and economic effectiveness. Formation of closed loop systems through the integration and coordination of activities and information concerning waste materials in an economic system is one of the tasks of reverse logistics (Agata Mesjasz, 2018). As cited by Agata Mesjasz (2018), Dziadkiewicz and Kadlubek (2017) suggested that it is therefore necessary to set new and ambitious goals in terms of Prevention, recycling and recovery of municipal waste, especially as a management of waste.

2.3 Route optimization

The business dictionary defines a route as an established or possible path between two points or nodes, from source to destination, or from point of departure to point of termination. There can be many possible routes between a start point and a destination. Solving routing problems by applying different techniques is route optimization.

According to the definition given in Business dictionary cited by Bale, D.L.T. et al. Optimization are discovering an option with largely cost-efficient or premier performance based on certain restraints, by capitalizing on required factors and reducing unwanted ones. According to Bale, D.L.T. et al., route Optimization is finding an alternative route among several others with the most cost or time effective under given constraints.

The main factor necessitating this prior before now was security. But now it can be viewed as financial (Economical) and ecological (Environmental); in which financial (economic) factor is concerned with reducing the cost of traveling and on the other hand ecological factor is concerned with protecting the environment from vehicle emission of smoke.

In any business, transportation is considered as one of the major competitive advantages. A company can save a huge amount of money by optimizing the distance and the routes traveled by vehicles. And this in return helps in improving the logistical efficiency of the company. In fact, transportation costs can reach 30% of the total expenses. Furthermore, transportation is playing an essential and crucial service in the logistical, environmental and economic functions of businesses. In fact, the Vehicle Routing Problem is considered one of the main issues faced in the Logistics field. This problem mainly deals with designing the shortest route for multiple vehicles for various reasons: waste collection, product pickup, and delivery, workers transportation, etc. Also, it is considered a generalization of the Travelling Salesman Problem.

A key step in the municipal waste management system is transportation. According to Larsen et al. (2009), cited by Dr. George Malindretos et al. (2011), the driving of empty truck from garage to the start of the collection route, driving of the full track from the final stop on the collection route to the unloading point, and driving of the empty truck from that point either back to the garage or to a new collection area if more than one area is serviced on the same day is referred MSW transportation. MSW transport is currently based mainly on road transport (Eisted et al., 2009).

Route optimization involves network analysis. Network Analysis can be generated based on two criteria (Lakshumi et al 2006, cited by Nikolaos V. Karadimas et al.).

1. **Distance criteria**: The route is generated taking only into consideration the location of the waste large items. The volume of traffic on the roads is not considered in this case.

2. **Time criteria**: The total travel time in each road segment should be considered as the:

Total travel time in the route = runtime of the vehicle + waste collection of large items time.

The runtime of the vehicle is calculated by considering the length of the road and the speed of the vehicle in each road. The time of the waste large items collection would be the total time consumed by the vehicle to collect these objects from all the loading spots. In determining the time consumed by waste collection of large items, the length, width and volume of traffic are taken into account in each road segment.

Traffic volume is one of the important factors while carrying out route optimization based on time criteria.

2.3.1 Traffic Volume

Traffic volume is defined as the number of vehicles (or persons) that pass a point on a transportation facility during a specified time period, which is usually one hour. In traffic engineering studies, there are many volumes such as daily volume, hourly volume, peak hour volume. In addition, volumes of a day or an hour can vary greatly depending on the different day of the week or different time period of a day. Traffic volume studies are conducted to determine the number, movements, and classifications of roadway vehicles at a given location.

The traffic Volume studies are usually conducted when certain volume characteristics are needed, some of which are: -

- **AADT (Average Annual Daily Traffic)** – is average of 24- hours' traffic volume at a given location over a full 365 day's year. AADT can be used in several traffic and transportation analysis that includes estimate of highway user revenues, computation of accident rates in terms of accident per 100 million vehicle-miles, establishment of traffic volume trends, development of freeways and major arterial street system and development and improvement of maintenance programs.
- **ADT (Average Daily Traffic)** – is average 24-hour volume at a given location for some period of time less than a year. This can be conducted for Planning of highway activities, measurements of current demands or evaluation of existing traffic flow.

- **Peak Hour Volume (PHV)** - Is the maximum number of vehicle that pass a point during a period of 60 consecutive minutes. Peak hour volumes are used for the functional classification of highways, design of the geometric characteristics of highways (e.g. number of lanes, intersection signalization and channelization), capacity analysis, and development of parking regulations and development of traffic operation programs (e.g. one-way street system or traffic routing).
- **Vehicle Classification (VC) -** Records volume with respect to the type of vehicles (e.g. passenger cars, two-axle trucks). Vehicle classifications are used for design of geometric characteristics (turning radii requirements, maximum grades, lane width), capacity analysis (ESAL), adjustment of traffic counts obtained by machines and structural design of highway pavements and bridges.

The traffic volume studies can be conducted either manually or automatically.

- **Manual counts:** are typically used to gather data for determination of vehicle classification, turning movements, direction of travel, pedestrian movements, or vehicle occupancy.

- **Automatic counts:** are typically used to gather data for determination of vehicle hourly patterns, daily or seasonal variations and growth trends, or annual traffic estimates.

The traffic volume data can identify critical flow time periods, determine the influence of large vehicles or pedestrians on vehicular traffic flow, or document traffic volume trends

For this study, time criteria is used. During the field study, the average speed and the time taken to finish the route was collected using hand held Garmin 72 GPS. But it is further recommended to carry out traffic studies for route optimization analysis for the purpose of acquiring better result.

2.3.2 Vehicle routing problem (VRP)

According to T. Caric, and H. Gold (2008), cited by Bale, D.L.T, et al. ,2016, determining the best route (optimal) to be used in serving the clients by a collection of vehicles is termed a VRP. Serving all customers by forming a route with the lowest cost is the objective of VRP.

VRP is very essential in saving the expenses of a company up to 30% (Sabrina El Mouhib, 2017). There are many applications of VRP. Some of them are: -

- Product Delivery and Pickup
- Waste Collection
- Transportation
- Trip planning
- Freight distribution
- Food distribution
- Mail and Package delivery
- Oil, gas and fuel transportation

The goal of VRP is completing all deliveries as soon as possible. The optimal route can be solved based on: -

Capacity constraints: - minimizing the total cost (or length) of routes considering the capacity restriction for the vehicle. The vehicles need to pick up items having quantities, such as weight or volume, from every demand location but with a maximum carrying capacity they can carry. The problem is to pick up or deliver the items for the least cost, while never exceeding the capacity of the vehicles. This version of VRP is known as CVRP (captivated routing problem).

Time windows: - when time windows are taken as a constraint for solving the routing problem, each demand location must be visited within a specific time window. Involves scheduling to visit customers who are only available during specific time windows.

2.3.3 Route Optimization using GIS

GIS has been proved to be an efficient technology for analyzing complex spatial phenomena. A wide variety of its applications include urban utility planning, transportation, natural resources protection and management, health science, forestry, geology, natural disaster prevention and relief and various environmental modeling and engineering. Geographic Information System (GIS) technology provides an advanced modeling framework for decision-makers in order to analyze and simulate various spatial problems, including various waste management aspects. Dijkstra's Algorithm, which is an approach to hard computing route optimization technique, is an approach used by GIS software to compute the shortest paths from a particular node.

GIS is a tool that can provide both spatial and non-spatial information for improved urban planning and management, transportation planning, natural resource management, and business planning. Some literature is reviewed below regarding the use of GIS in Solid Waste Vehicle Route optimization.

Chirstos Chalkias and Katia Lasaridi (2009) developed a methodology for the optimization of the waste collection and transport system, based on GIS. The authors developed a model in ArcGIS Network analyst in order to improve the efficiency of waste collection and transportation in the municipality of Nika, Athens, Greece via the reallocation of waste collection bins and optimization of vehicle routing in terms of distance and time traveled. The authors compared two scenarios, in which Scenario-1 is collection vehicle routing optimization and Scenario-2 recollection of bins and routing optimization, with the empirical. Finally, the authors obtained a result that demonstrates that both scenarios provided saving in terms of collection time (3.0% and 17% for S-1 and S-2 respectively) and travel distance reduction (5.5% and 12.5% for S-1 and S-1 respectively) compared to the current empirical collection.

Zdena Zsigraiova et al. (2012) proposed an innovative methodology for the reduction of the operation costs and pollutant missions involved in the waste collection and transport by combining vehicle route optimization with that of waste collection schedule. The authors used GIs for the optimization process of the routes to be traveled. The established methodology was applied to the glass waste collection and transportation system of Amarsul S.A, in Barreiro for isolating the influence of the dynamic load on fuel consumption and pollutant emission. The authors carried out a sensitivity analysis by testing two hypothetical scenarios, one with the collected volume increasing exponentially along the collection path and the other assuming that the collected vol. decreases exponentially along the same path. The results obtained evidenced unquestionable beneficial impacts of the optimization on both operational costs and pollutant emission. Regardless of the optimization criterion used the results obtained were a potential reduction of 62% for total time spent, 43% for fuel consumption and 40% for the emitted pollutants resulting in a total cost saving of 57%.

Amirhossein Malakahmad et al. (2014) used GIS for solid waste collection route optimization. The authors selected 5 routes in different areas of Ipoh city, Malaysia for the pilot study and the routes which were used previously were optimized to reduce the length of the routes and consequently, the time is taken to complete the collection. The results the authors obtained indicate up to 22% length minimization in the routes. In addition, the collection duration was also reduced from 6934 s to 4602 s.

Koushik Paul et al. (2015) conducted a comprehensive study on solid waste vehicle routing and tracking for Kolkata city, India. The authors employed a methodology to determine the least-cost path for the collection and transportation of wastes using GIS while attempting a low-cost tracking method using ArcGIS and Garmin 72H GPs set. The authors concluded that solid waste management incorporating GIS/GPS can be an effective decision support tool for municipal solid waste (MSW) transport, work distribution for conservancy vehicle staff and vehicles and managing fuel consumption.

D. Kahan and SR Samadder (2016) conducted research on the allocation of solid waste collection bins and route optimization using GIS for Dhanbad city, India. The authors presented a suitable solid waste collection bin allocation method at appropriate places with uniform distance and easily accessible location so that the collection routes become short. They used the ArcGIS network analyst tool to find the optimized route for solid waste collection considering required parameters such as solid waste collection bins, the road network, the population density, waste collection schedule, truck capacities, and their characteristics. According to the authors, their study demonstrates the significant cost reduction that can be obtained compared with the current practice in the study area.

According to the above-reviewed literature and other related literature on the subject, GIS was found to be very helpful to determine optimal collection routes by modeling real-world travel conditions and patterns though the function and uses of GIS are not limited only to this. Manipulation of GIS and spatial information eliminate hours spent on unplanned routing, maximize productivity, optimize equipment and staff allocation and allow better waste collection operations.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

Bole sub-city is one of the sub-cities of Addis Ababa, with the emergence and expansion of poorly serviced illegal and informal settlements in peripheral areas. Brehanu Ayalew, (2014) stated that, in these areas the land is traded informally and built on without permission, and existing buildings are often extended or altered over long periods of time, with no official authorization. To "formalize" these settlements completely would require costs that neither municipalities nor inhabitants could handle easily.

The Sub-City is located (in geographical position latitude 080.99" East, longitude 380.79" North) in the eastern fringes of Addis Ababa, where the population growth and settlement is very high and fast. Each Sub-City in Addis Ababa is organized through smaller units called Woredas, as formally independent administrative units. Bole Sub-City is organized into 14 woredas and has a total population of 308,741 according to 2007 CSA. But currently, the sub-city has added one new Woreda to the rest of 14 Woredas increasing the number to 15.

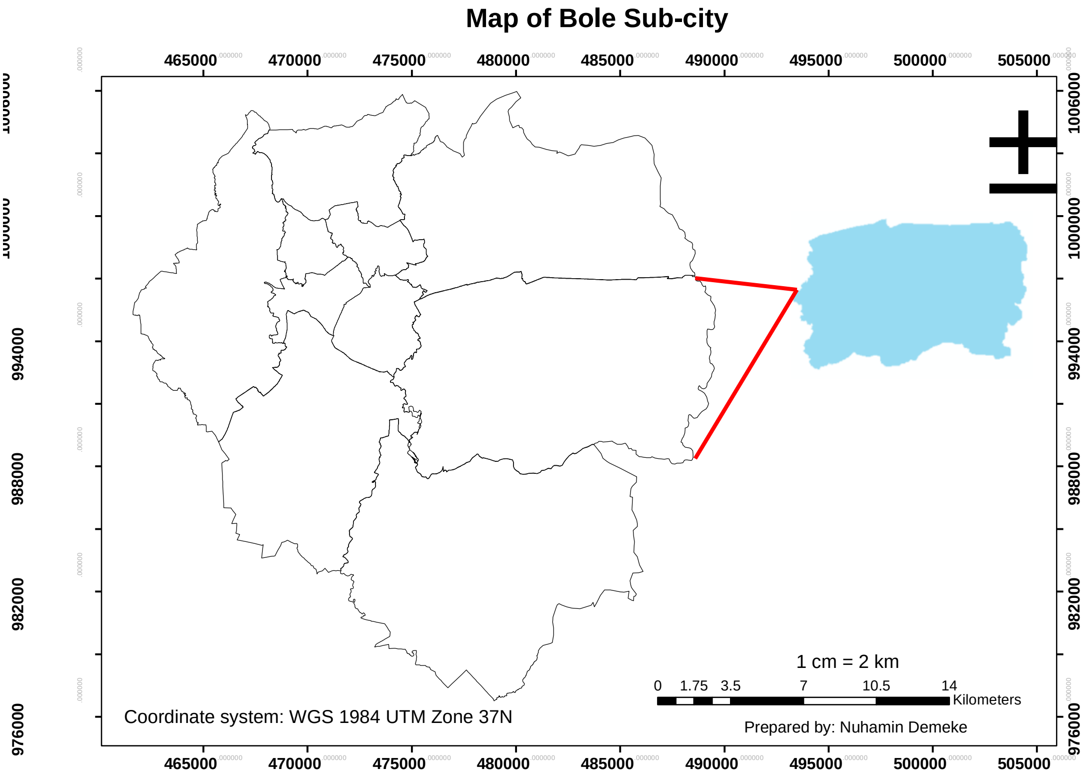


Figure 4. Map of Bole sub-city

According to Addis Ababa city administration, the Sub-City covers a total area of 122.08 km^2 with a population density of 2,694.1 per square kilometer. As Enger and Smith (2008), cited by Brehanu Ayalew (2014), an increasing number of people produce greater amounts of waste: goods of mass consumption are distributed more quickly than waste disposal structures can cop up with.

The major land use activities in the sub-city are residential (apartments, condominiums, Villas) mixed-use, commercial properties (for banks, supermarkets, offices, cafes and restaurants, shops), social services (both private and public schools and clinics), green developments and open communal spaces used for recreational purpose (such as green areas and playgrounds), administration use (such as court office) and small scale manufacturing activities.

3.1.1 Economic status of Bole-sub city

The economic status of Bole sub-city has been reported by the housing and population census of 2007. According to the census report, the unemployment rate was reported to be 11.9 and 23.8 for males and females respectively. According to the report unemployment covers a person who is without work during the reference period but is available for work and seeking for work at the reference period. And the economic activity rate for population aged 10 years and above for both sex was 67.0.

3.2 Data collection

Bole sub-city was selected for the case study among the 10 sub-cities using a lottery data sampling method which is a type of random sampling. For the purpose of data collection both quantitative and qualitative method of data collection was used in order to achieve the set objective of this thesis and the validity of the results. Different methodologies were followed. These are; Literature review, survey, and direct measurements. The qualitative methodology was applied to get a better understanding and a clear picture of the problem under study through different methods such as interviews, questionnaires and document analysis.

The quantitative approach was used to analyze quantitatively waste generation, collection, transportation and disposal. These quantitative analyses were based on data gathered using questionnaire, field measurements and field observations. A comprehensive and extensive literature review of concept studies was conducted from published and unpublished government and nongovernment reports and publications.

3.2.1 Literature review

Different sources were used as a source of secondary data and for the purpose of developing a literature review. These sources were peer-reviewed journals, governmental archives, and web resources.

3.2.2 Survey

A thorough literature study on the topic of this paper: Reverse Logistics was conducted for a short period. Several articles were found on the topic over the internet. After getting somewhat of a fair idea about reverse logistics, a preliminary set of questions were formulated for the survey. The questions were formulated in such a way that it would be easy to understand by the respondents and also it would not take much time to answer.

Questionnaire

A questionnaire survey was conducted with respective sanitation officers from selected 7 woredas using a lottery method of data sampling from the sub-city and from the sub-city sanitation office because it was time consuming and expensive to carry out questionnaire survey in each 14 Woredas in the sub-city. A purposive sampling technique was followed. Respondents were chosen from different woreda administration based on their knowledge of solid waste management. 56 respondents were involved in the questionnaire survey. Purposive sampling can be applied to research in a number of ways such as in preliminary studies where the researcher is still testing the feasibility of a proposed study, sampling informants with a specific type of knowledge or skill, comparisons of cultural practices, case studies, and when the population is too small for a random sample (Tran & Perry 2003, Poggie 1972 Li et al. 2006, Prance 2004, Vargas & van Andel 2005, Neu- pane et al. 2002, Dolisca et al. 2007, Par- lee & Berkes 2006, cited by Ma. Dolores and C. Tongco, 2007).

Interview

A purposive sampling technique was also used to carry out unstructured key informant interviews with waste pickers, korales, sanitation office officers from the sub-city and small scale enterprise waste collectors. 15 peoples were involved in the interview. This was conducted in order to identify the reverse logistics chain present in the sub-city. This includes identifying the reverse logistics network chain before landfill, at the landfill and the underlying activities after the landfill. The interview was recorded using mobile for developing the current RL network chain later on.

3.2.3 Direct measurements

This method of data collection was used during fieldwork for recording the waste collection points and the current waste collection route in order to measure the total distance traveled and time taken from collection point to the landfill and vise versal. A Garmin 72 handheld GPS was used to record all the collection routes.

3.3 Data analysis

In this study, GPS (global positioning system) was used to collect temporary waste collection points and waste collection routes. ArcMap 10.6 was used for the analysis of collection route optimization by managing spatial data including road network maps and other maps, locations and distances. ArcGIS has a network analyst extension which is a powerful tool. As stated by C. Chalkias and K. Lasaridi, economic and environmental gains can be attained using spatial modeling tools and GIS by reducing travel time, distance, fuel consumption, and pollutant emissions. And in this paper GIS was used to calculate the shortest distance between waste collection points (demand points) to the final dumping site. As Ghose *et al.*, 2006, cited by J Kinobe, ArcGIS Network Analyst is a powerful extension that provides network-based spatial analysis including routing, travel directions, the closest facility, and service area analysis.

Microsoft Excel and SPSS were used to enter and analyze questionnaire data.

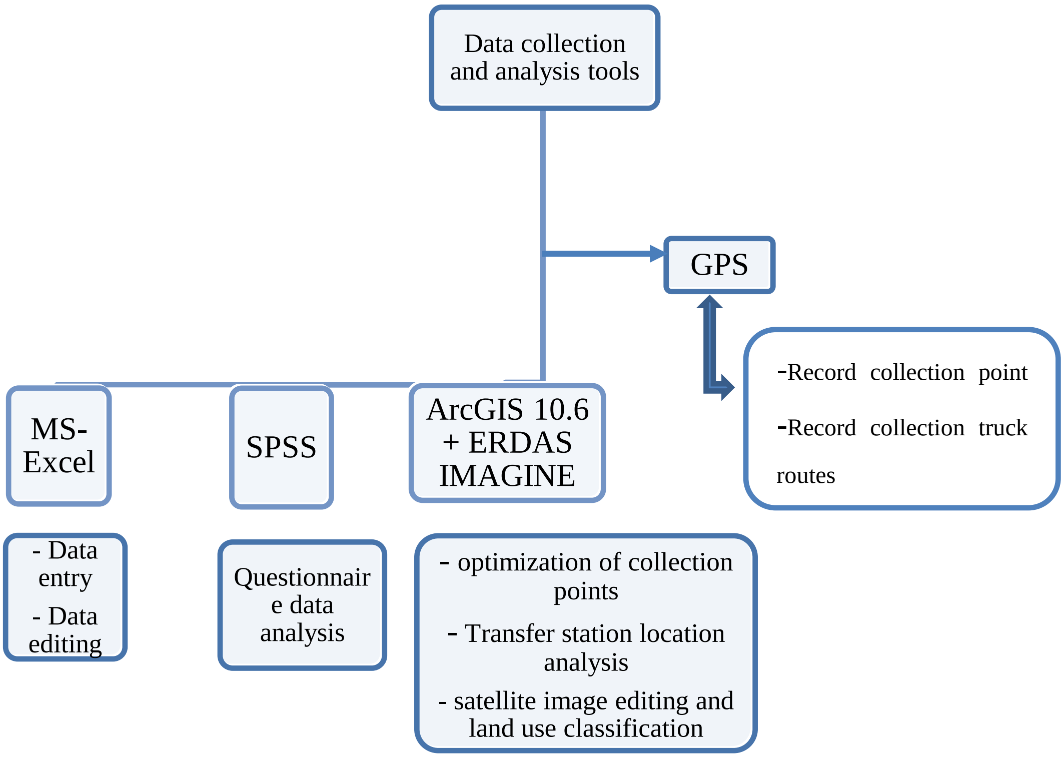


Figure 5. Data collection and analysis tools

3.3.1 Mapping the current waste collection points and final dumping site

This was done by using a Garmin 72 handheld GPS. The collection points of solid waste were mapped by high-resolution GPS devices. The latitude and longitude for each collection were recorded and mapped in ArcGIS using the add XY data tool. All the current waste collection points in the sub-city and the final dumping site (Koshe) were collected for four consecutive days. Mapping the waste collection points is very crucial in determining the optimal route distance to the final dumping site.

3.3.2 Transfer station location analysis

The management step between the collection of MSW and transport is reffered transfer. A transfer is "reloading of waste from one type of transport; transfer facilities make up the end of one line of transport and the beginning of another" (Eisted et al., 2009, cited by Dr. George Malindretos et al.).

This was done by a weighted overlay analysis tool using ArcGIS 10.6. The weighted overlay analysis tool overlays several rasters using a common measurement scale and weights each according to its importance. The weighted overlay table allows the calculation of a multiple-criteria analysis between several rasters.

For this study, Land use and DEM were used to carry out the overlay analysis. Prior to the analysis land-use layer classification was carried out. It was classified into; water, agricultural land, barren land, forest and trees, vegetation and built-up area. Then it was weighted according to importance. Barren land with a flat slope was given a higher weight then the analysis was run. This is because there may be littering of waste and also a bad odor from the collected waste. Therefore it must be far from the built-up area and vegetation to prevent any contamination and arising health problems. After the analysis, a location with a larger area was selected and prepared for the next analysis. The given weights are shown in Table 3. Because the land escape of Bole sub-city is almost flat, a higher weight is given to land use.

Table 3. Weighted overlay analysis

Criteria	Classes	Rank	Weight (%)
Land use	Trees	4	75
	Agricultural land	2	
	Barren land	5	
	Vegetation	3	
	Forest	1	
	Built up area	0	
Slope	0-17	1	25
	17-34	2	
	34-51	3	

3.3.3 Vehicle routing

In this thesis work, the vehicle routing problem (VRP) in ArcGIS network analyst was used. The VRP analysis is commonly used to find the best routes for a fleet of vehicles to service orders and minimize the overall cost. The analysis has the ability to incorporate Truck and Route specific parameters because numerous options are available, such as providing breaks for drivers, allowing route renewals for depot visits and matching capacities of trucks to pick-up quantities, etc.(Braundt Lau,2016).

Using Arc GIS 10.6 a network dataset was built using the network analyst extension tools.

The software builds optimized collection routes based on a set of orders to be serviced by a fleet of vehicles. In the study, the service time of 40 minutes was used taking loading and unloading time of waste into consideration. In the analysis, a break time of 1 hour was assumed for a lunch break for the drivers. Furthermore, the traveling speed of the collection trucks was assumed to be the same cause one type of truck was used in the analysis. The time window for the network location was taken as 8 am and 5 pm as a start and end respectively. A vehicle can’t violate this time window. This means a vehicle can’t depart the depot before 8 am and arrive at the depot after 5 pm. A vehicle with a loading capacity of 40 m3 was assumed for the analysis.

Important parts of the vehicle routing problem are orders, routes, and depots.

Orders: refer to pick up point locations, which are stored in a feature layer in the VRP analysis layer. The orders for this study were point features derived from waste collection points collected by handheld GPS, which represent 23 locations with waste bins to service in the study area.

Routes: A route specifies vehicle and driver characteristics; after solving, it also represents the path between depots and orders. A route can have start and end depot service times in addition to order service time. The service time for this study was assumed to be 40 minutes.

Depots: A depot is a location that a vehicle departs from at the beginning of the workday and returns to at the end of the workday. Vehicles are loaded (for deliveries) or unloaded (for pickups) at depots at the start of the route. In some cases, a depot can also act as a renewal location whereby the vehicle can unload or reload and continue performing deliveries and pickups. For this study, the starting depot was assumed to be the sub-city head office at Megenagna and the end was assumed Koshe (Repi) landfill.

In the current work, using Network Analyst, an optimum route for the waste collection of household items is generated in the area under study.

The spatial database or the type of data and geometry used for the vehicle routing problem (VRP) were:

Table 4. The spatial database used for VRP

Spatial data	**Type**	**Geometry**
Road network	Vector	Line
Waste bin location	Vector	Point
Land use	Raster	-
Population	Tabular	-
DEM (Digital elevation model)	Raster	-
Waste bin attributes	Tabular	-
Existing collection route	Vector	Line

In this analysis, two scenarios were developed and the results will be compared with the existing situation. These are:

- Scenario 1: Optimization of collection route with the application of recorded route
- Scenario 2: Optimization of collection route with the application of transfer station

4. RESULTS AND DISCUSSION

4.1 Waste Generation

As it was explained in the scope of this paperwork, no direct quantification of waste was carried out. But rather documents from different governmental archives were referred and officials from the waste management agency were interviewed to obtain the per capita waste generation information. According to Addis Ababa city waste management agency the per capita waste generation of the city is estimated to be 0.45 kg/day and it was adopted from Addis Ababa solid waste agency for this analysis. According to the officials it is impossible to carry out direct quantification and characterization by the municipality due to budget constraints. Therefore, the per capita waste generation is estimated based on works of IGNIS and ARTELIA. Using this data the waste generation of each 14 Woreda under Bole sub-city was calculated using the formula below (Joel R.Kinobe, based on the population information and per capita waste generation).

$wt = pw * pp$………………………………………………………… (1)

Where:-

- wt is waste in Kg present in the woreda
- PW per capita waste generation per day
- pp is the woreda population

According to a census gathered by a safety net program in the sub-city, it is estimated that there are 95,004 households. The total generated waste in the sub-city was computed using Formula 1 and presented in Table 5.

Table 5. Bole sub-city waste generation detail

Woreda	Household size	Family size	population of Woredas	Waste in kilograms(kg/day)	Volume in m3
W1	5754	20167	20167	9075.15	18.87
W2	1499	4857	4857	2185.65	4.54
W3	2061	7290	7290	3280.5	6.82
W4	5584	20668	20668	9300.6	19.34
W5	3367	12003	12003	5401.35	11.23
W6	4775	16064	16064	7228.8	15.03
W7	8922	31098	31098	13994.1	29.09
W8	6013	22688	22688	10209.6	21.23
W9	14875	47552	47552	21398.4	44.49
W10	11525	41209	41209	18544.05	38.55
W11	3428	14513	14513	6530.85	13.58
W12	12120	39316	39316	17692.2	36.78
W13	10394	34974	34974	15738.3	32.72
W14	4687	15927	15927	7167.15	14.9
Total	95004	328326	328326	147746.7	307.17

4.2 Reverse logistics network chain of household waste

In order to meet this objective, a key informant interview was carried out with waste (rag) pickers at the landfill, small scale enterprise waste collectors, Korales and responsible experts from the sub-city sanitation administrative office. Using the result of the interview, a network chain was developed. There are different actors in a reverse logistics network chain. Based on the interview conducted with waste pickers, ‘korales’, small scale enterprise waste collectors and responsible solid waste management administrative officers from the sub-city, network chains were developed. The network chain contains the actors who are involved in the reverse chain and what materials are being returned.

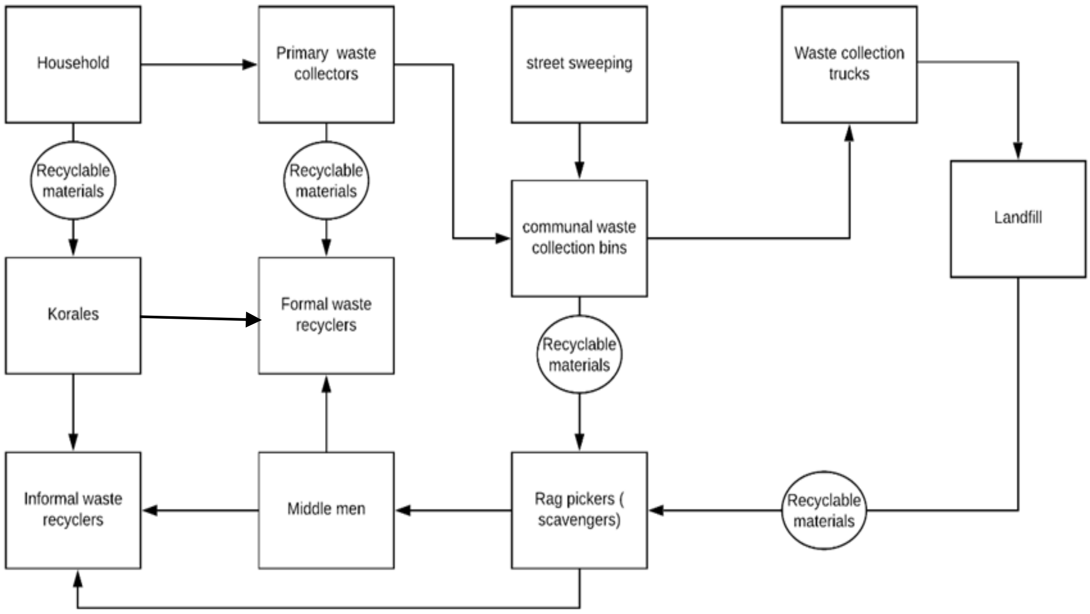


Figure 6. Household RL network chain in Bole sub-city

The recyclable materials are plastic bottles of different types like water bottles, oil plastic bottles and soft drink plastic bottles. Apart from plastic bottles, a certain type of packaging plastics, metals and cardboards are the recyclable materials in the network chain. From the interview, it was understood that the quantity of water plastic bottles is higher than the others. Though waste plastic bottles are in a larger quantity than the other, from the key informant interview with waste pickers in the landfill and 'korales', the selling price is not as higher as metal waste. Metal is the most expensive waste material compared to the others. There are also a limited number of formal waste recyclers who recycle waste. According to the interview, formal waste recyclers only recycle water plastic bottles and cardboards. Most of the recycling activity is carried out by informal waste recyclers. The final destination for most of the recyclable materials is 'Mercato-Min alesh tera'.

The major reverse logistics actors according to the developed network chain are:

- **Small scale enterprise waste collectors: -** these are a group of people engaged in pre-collection of waste from different sources.

- **Rag Pickers (scavengers):-** peoples of different ages including children are engaged in scavenging valuable material from collected waste either from waste collection bins of from landfill. They collect material like plastic bottles, glass bottles of a specific type, metals and plastic packaging materials.

- **Korales: -** are buyers of valuable materials, for example, plastics, glass, and metals as well as textiles and electronics at the household level.

- **Middlemen (waste dealers): -** buy valuable materials from Korales or scavengers or from other middlemen. They buy valuable materials like metals, a different type of plastic materials and woods.

- **Informal waste recyclers: -** most of the recyclable materials are plastics, wood, metals, and rubber. They receive the materials from middlemen or small scale enterprise waste collectors or from scavengers. The informal recyclers mainly work on metal, wood and rubber recycling.

- **Formal waste recyclers: -** Receive materials from middlemen or small scale enterprises. They are plastic and steel industries and also cardboard recyclers.

4.3 Waste logistics practice

The municipal solid waste consists of a highly heterogeneous mass of discarded materials from urban residences, commercial establishments, institutions, street sweepings, and light industrial activities. The major sources of MSW in Bole sub-city are residential areas, commercial areas, street sweeping, institutions, and small scale industries.

Solid waste management experts from randomly selected Woredas from Bole sub-city and also from the sub-city were asked the extent of sorting, recycling, composting and incineration present in the sub-city to measure the practice from 1-5 in a 5 Likert scale as no extent (0%), little extent (10%-20%), Moderate extent (30%-40%), great extent (50%-75%) and very great extent (80%-100%). The finding revealed that the majority of the respondents 28 (50%) agreed that there is a moderate extent (30%-40%) of sorting practice.

Table 6. Sorting practice

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no extent	10	17.9	17.9	17.9
	little extent	18	32.1	32.1	50
	Moderate extent	28	50	50	100.0
	Total	56	100.0	100.0	
Missing	System	0	0		
Total		56	100.0		

Sorting is an essential component of solid waste management. It is a kind of activity which is separating different types of wastes in their respective nature. It makes waste management easy and simple. However, it should not be a onetime activity, rather should be a habit for proper and sustainable solid waste management. Separating different types of waste components helps to sort recyclable materials from non-recyclable and identify decomposable (organic) materials from non-decomposable.

The process is also efficient in reducing the problem of landfill sites and expenses. Nevertheless, according to the officials, there is no/little separation of solid wastes in Bole sub-city whereby over 17.9 % of the respondents, consistently confirmed the absence of solid wastes separation practices during both collection and disposal periods. 50 % of the respondents replied that solid wastes were sorted into organic and inorganic wastes to a moderate extent. Inorganic wastes like plastic bottles are usually sorted for sale. The results are presented in Table 6. The results show that 21 (37.5%) disagree that sorting is not being conducted during the waste collection period and also 6 (10.7%) respondents believe that sorting not carried out during the disposal period.

Table 7. Sorting practice at collection and disposal period

		Frequency	Percent	valid Percent	Cumulative percent
Sorting of waste is being conducted at the collection period	highly disagree	10	17.9	17.9	17.9
	disagree	21	37.5	37.5	55.4

	agree	18	32.1	32.1	87.5
	highly agree	7	12.5	12.5	100.0
	Total	56	100.0	100.0	
	Missing System	0	0		
Sorting of waste is being conducted at the disposal period	highly disagree	10	17.9	17.9	17.9
	disagree	6	10.7	10.7	28.6
	neutral	8	14.3	14.3	42.9
	agree	19	33.9	33.9	76.8
	highly agree	13	23.2	23.2	100.0
	Total	56	100.00	100.0	
	Missing System	0	0		

4.3.1 Recycling

Table 8. Recycling practice

			Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no extent		2	3.6	3.6	3.6
	little extent		31	55.4	55.4	58.9
	Moderate extent		23	41.1	41.1	100.0
	Total		56	100.0	100.0	
Missing	system		0	0		
Total			56	100.0		

From Table 7, 55.4 % of the respondents agreed that there is little extent (10%-20%) of waste recycling practice. Recycling is a significant factor to ease the amount of waste to be dumped at the landfill. The study result indicates that there is a little extent recycling practice of waste. Most of the waste is dumped without a proper separation and this makes the sorting process harder. So, most of the wastes that can be recovered go to the landfill like papers and plastics making the city aesthetically unpleasant. Furthermore, the formal practice of waste recycling is not as satisfactorily as it should be practiced in the sub-city though there is a small number of waste plastic bottle recyclers are present in the city as a whole. However, there are "*Korales*" who move through the city to buy recyclable items such as glass, plastic, tin cans, metals, shoes, etc. from different houses, hotels, restaurants, repairs services and sell them to small recyclers and industries. There are also people engaged in similar types of jobs known locally as "*Liwach*" who go around the city and exchange used clothes and shoes with new household utensils and sell them to low-income people.

Table 9. Formal waste recycling practice

			Frequency	Percent	valid Percent	Cumulative percent
Valid		highly disagree	19	33.9	33.9	33.9
		disagree	15	26.8	26.8	60.7
		neutral	17	30.4	30.4	91.1
		agree	5	8.9	8.9	100.0
		Total	56	100.0	100.0	
Missing		system	0	0		
Total			56	100.0		

Table 8 shows that respondents believe that the formal practice of waste recycling is at a very low level in the sub-city.

4.3.2 Composting

Gardner (2001) and Bezaye (2008), argued that composting is an ancient practice where more cities in the world nowadays are reclaiming the benefits of reusing solid organic waste material. It is a natural way to prepare the waste for reuse.

According to solid waste management project conducted in December 2013 by Addis Ababa city government in collaboration with a French organization shows that 57.1 % of the waste generated by households is organic waste taking most of the share. Though organic wastes are generated in a great amount due to our lifestyle, no researches indicate that the practice of composting at a household level and at a higher intuitional level is practiced to a great extent.

Table 10. Waste composting practice

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no extent	36	64.3	64.3	64.3
	little extent	14	25.0	25.0	89.3
	Moderate extent	6	10.7	10.7	100.0
	Total	56	100.0	100.0	
Missing	system	0	0		
Total		56	100.0		

The results from Table 9 show that 64.3% of the respondents agreed that there is no composting practice present in the sub-city.

4.3.3 Incineration

Table 11. Incineration practice

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no extent	36	64.3	64.3	64.3
	little extent	20	35.7	35.7	100.0
	Total	56	100.0	100.0	
Missing	system	0	0		
Total		56	100.0		

The respondents, who agreed that there is a little extent of incineration practice present in the sub-city, were interviewed whether incineration has been practiced at secured places or not. Accordingly to the interviewed respondents, the practice of incineration at secured places is confined to health institutions typically to manage medical wastes even though the practice takes place only sometimes. So far, no incineration taking place in or near the compound of households. Also, 36 (64.3%) responds to no extent of solid waste incineration practice in the sub-city.

4.3.4 The solid waste transport system in Bole sub-city.

Table 12. Waste transport system

		Frequency	Percent	valid Percent	Cumulative percent
1. The participation of the private sector in transportation service of waste is satisfactory	highly disagree	14	25	25	25
	disagree	22	39.3	39.3	64.3
	neutral	8	14.3	14.3	78.6
	agree	12	21.4	21.4	100.0
	Total	56	100.0	100.0	
	Missing System	0	0		
2. The optimal route has been determined and applied using different algorithms	neutral	4	7.1	7.1	7.1
	agree	52	92.9	92.9	100.0
	Total	56	100.0	100.0	
	Missing System	0	0		
3. There are Specialized trucks deployed for Hazardous wastes used	highly disagree	11	19.6	19.6	19.6
	disagree	38	67.9	67.9	87.5
	neutral	7	12.5	12.5	100.0
	Total	56	100.0	100.0	
	Missing System	0	0		
4. There is proper preventive maintenance of Vehicles therefore minimum out of service periods of trucks	highly disagree	21	37.5	37.5	37.5
	disagree	34	60.7	60.7	98.2
	neutral	1	1.8	1.8	100.0
	Total	56	100.0	100.0	
	Missing System	0	0		
5. There are available truck types designed to handle different types of the waste stream with different compartment for different types of waste	highly disagree	30	53.6	53.6	53.6
	disagree	17	30.4	30.4	83.9
	neutral	9	16.1	16.1	100.0
	Total	56	100.0	100.0	
	Missing System	0	0		
6. There is an application of technologies to routing such as GIS to optimize routing is applied	highly disagree	10	17.9	17.9	17.9
	disagree	42	75	75	92.9
	neutral	4	7.1	7.1	100.0
	Total	56	100.0	100.0	

	Missing System	0	0		
7. There is a scheduled plan for collection by trucks Drivers haul waste before need arise	highly disagree	7	12.5	12.5	12.5
	disagree	19	33.9	33.9	46.4
	neutral	12	21.4	21.4	67.9
	agree	18	32.1	32.1	100.0
	Total	56	100.0		
	Missing System	0	0		
8. There are a sufficient number of trucks with the different size used for collection and haul of SW from the transfer station to dumpsite	highly disagree	13	23.2	23.2	23.2
	disagree	26	46.4	46.4	69.6
	neutral	3	5.4	5.4	75.0
	agree	14	25	25	100.0
	Total	56	100.0		
	Missing System	0	0		
9. The existing numbers of trucks are sufficient for the current SW generation and collection	highly disagree	20	35.7	35.7	35.7
	disagree	16	28.6	28.6	64.3
	neutral	7	12.5	12.5	76.8
	agree	13	23.2	23.2	100.0
	Total	56	100.0		
	Missing System	0	0		
10. The frequency of waste collection by drivers is High (time travel time for shuttling back and forth to disposal site)	highly disagree	16	28.6	28.6	28.6
	disagree	10	17.9	17.9	46.4
	neutral	5	8.9	8.9	55.4
	agree	21	37.5	37.5	92.9
	highly agree	4	7.1	7.1	100.0
	Total	56	100.0		
	Missing System	0	0		

From Table 11 25% and 39.3 disagree and highly disagree respectively that the participation of the private sector in solid waste logistics systems is satisfactory. It is necessary to involve a third party logistics in order to alleviate the shortage of resources the sub-city faces. The implementation of vehicle routing techniques is very essential in ensuring effective decision making in the field of management system by taking advantage of new technologies such as the geographic information system (GIS). Since routing models make extensive use of spatial data, GIS can provide effective handling, display, and manipulation of such geographical and spatial information. These tools eliminate hours spent on unplanned routing, maximize productivity, optimize equipment and staff allocations, and allow better control of waste collection operations. Among the respondents, 42(75%) disagree on the application of GIS and other technologies to improve waste collection routing. These tools work with a computer software application that generates efficient vehicle routes for solid waste collection over a road network and can be used for recycling collection services as well.

The other question the respondents asked was regarding the presence of a scheduled plan for the collection trucks. 12.5 % and 33.9% disagree and highly disagree respectively that there is a scheduled plan for trucks to collect waste before a need arises. 53.6 % of the respondents disagree about the availability of truck types designed to handle different types of the waste stream with a different compartment for different types of waste.

A municipal waste collection poses a high cost of operating and maintenance costs of vehicles. It is necessary to maintain vehicles on regular bases. Old trucks have a negative impact on the environment due to the number of miles driven, fuel type, engine inefficiency, and exhausted gasses emission. 60.7 % of the respondents responded that the absence of proper preventive maintenance for the vehicles in Bole sub-city. There are temporary stations for secondary waste collection and use as transfer stations. But almost all are placed on the roadside making the sub-city aesthetical unpleasant and also they are not standardized to be referred to as a transfer station. 23.3% and 46.4% of the respondents believe that appropriate types of vehicles are not used for collection and haul SW from these transfer stations to dumpsite. A total of 69.6% of the respondents replied that the number of vehicles being under operation in Bole sub-city is not sufficient compared to the amount of waste generated. During the study majority of respondents agreed that the frequency of waste collection by drivers to below.

4.4 Current waste collection loading and unloading stops

All the collected temporary waste collection points are presented in Table 12.

Table 13. Bole sub-city waste bin location

Collection point	X	Y	Size of bin	Bin type
1	0480085	0995772	8 m3	Metallic
2	0480529	0994565	8 m3	Metallic
3	0478671	0996586	8 m3	Metallic
4	0479316	0995713	8 m3	Metallic
5	0477051	0994764	8 m3	Metallic
6	0477604	0994538	8 m3	Metallic
7	0475676	0995134	8 m3	Metallic
8	0476541	0989763	8 m3	Metallic
9	0476763	0988984	8 m3	Metallic
10	0477989	0993579	8 m3	Metallic
11	0478504	0994374	8 m3	Metallic
12	0485934	0996559	8 m3	Metallic
13	0482064	0996268	8 m3	Metallic
14	0483721	0995878	8 m3	Metallic
15	0484464	0995068	8 m3	Metallic
16	0483755	0995658	8 m3	Metallic
17	0483668	0994240	8 m3	Metallic
18	0482259	0994821	8 m3	Metallic
19	0481286	0995258	8 m3	Metallic
20	0481669	0996205	8 m3	Metallic
21	0477964	0995719	8 m3	Metallic
22	0474767	0992491	8 m3	Metallic
23	0481264	0993648	8 m3	Metallic

During the field survey, 23 waste bin location was able to be recorded. Then using ArcGIS 10.6 add XY data tool, the waste bin location was mapped as shown in Figure 7. In all of the 23 locations, 8 m3 metallic waste collection bins were placed by Addis Ababa's solid waste management agency. After all solid wastes from households are collected by hand pushcarts and small vehicles which are not properly designed for waste collection, all the waste will be dumped into the nearby waste collection bins.

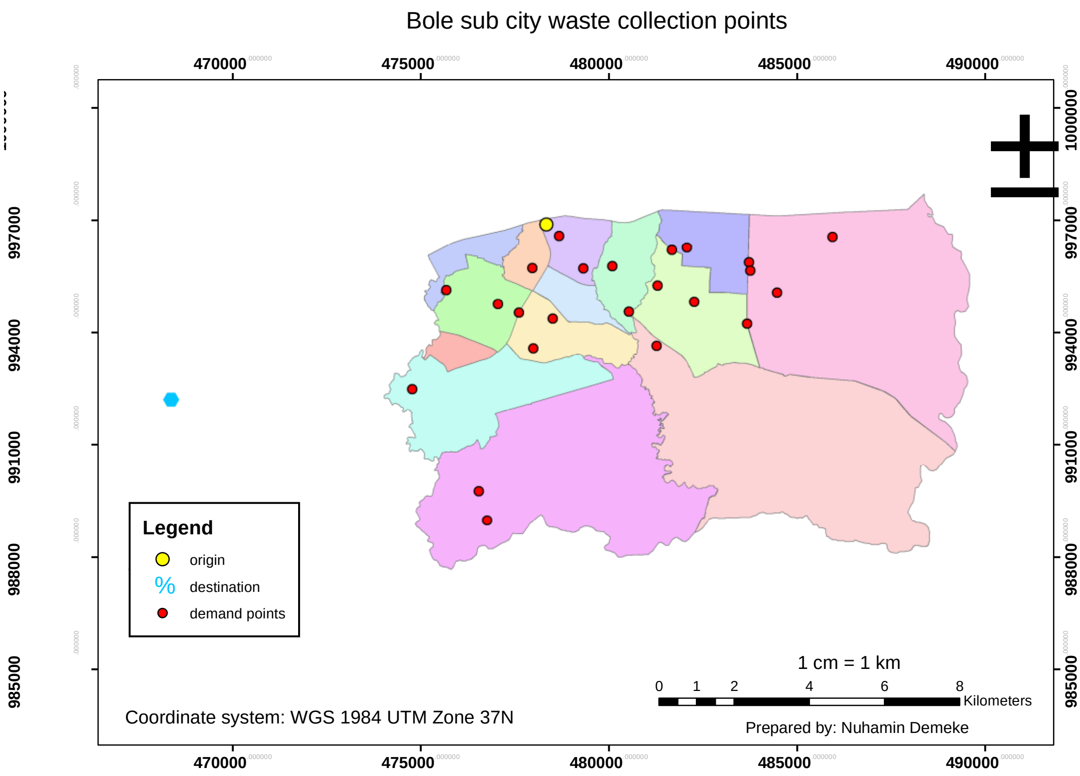


Figure 7. Map of Bole sub-city waste collection points

4.5 Recorded waste collection route

The waste collection route was recorded using a Garmin 72 handheld GPS for 5 consecutive days. The major vehicle model used by the sub-city is UD-NISSAN container loader with a carrying capacity of 8 m3. Though there is a small number of compactor trucks, they are not fully utilized due to frequent breakdowns.

Table 14. Recorded waste collection route

Route Id	Start	Pick up location	End	Distance (Km)	Time(hr.)	Average speed (Km/hr)
Route 1	Last stop	Woreda 2	koshe	20.1	2.25	16.8
Route 2	koshe	72 NOC gas petrol	Koshe	50.7	3.36	14
Route 3		Woreda 13 (1)		14.6	1.55	12.3
Route 4	koshe	Woreda 13 (2)	Koshe	15.8	1.45	15.8
Route 5	koshe	Endode	Koshe	26.4	2.16	13.2
Route 6	koshe	Egzihair Ab	Koshe	23.1	1.58	14.3
Route 7	koshe	Amche	Koshe	24.6	2.19	13.8
Route 8	koshe	Robera coffee	Koshe	35.8	2.04	12.8
Route 9	koshe	Yerer	Koshe	36.7	2.1	12.5
Route 10	koshe	Goro Gebriel	Koshe	38.1	2.16	18.7
Route 11	koshe	Woji	Koshe	27.7	2.22	17.2
Route 12	koshe	Ayat zone 3	Koshe	51.6	3.1	19.3
Route 13	koshe	Moenco	Koshe	14.5	1.46	11.7
Route 14	koshe	Atlas	Koshe	13.9	1.28	12.1
Route 15	koshe	W 8 (1)	Koshe	20.6	2.1	13.4
Route 16	koshe	W 8 (2)	Koshe	21.3	2.13	11.8
Route 17	koshe	safari	Koshe	46.5	2.58	16.4
Route 18	koshe	feyel bet	Koshe	46.9	3.02	16.1
Route 19	koshe	sefere selam	Koshe	36.3	2.3	17.1
Route 20	koshe	W12 tena tabiya	Koshe	12.5	1.13	12.2
Route 21	koshe	W12 condominum	Koshe	13.6	1.3	11.3
Route 22	koshe	figa	Koshe	37.2	2.3	16.7
Route 23	koshe	Mandela	koshe	48.7	3.08	15.5
Total				677.2	48.84	

The collected route was exported to ArcGIS 10.6 to present it using a map. It is shown in Figure 8.

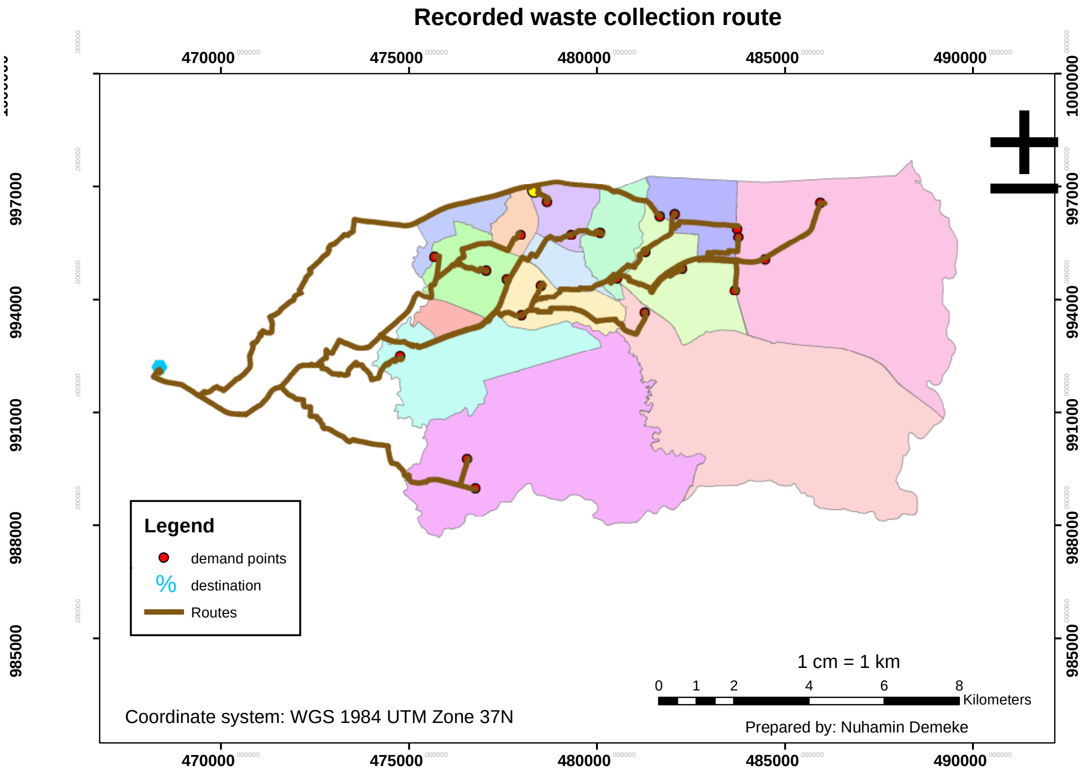


Figure 8. Recorded waste collection route

4.6 Scenario 1: Optimized route with the vehicle routing problem solver with the application of recorded route

All the collection truck routes were recorded. Prior to optimization, from the recorded route it was found that the total distance traveled and the total time to be 677.2 Km and 2930.4 minutes. But after the analysis, the distance traveled and the total travel time was reduced to 141.3 Km and 1327.9 minutes. The significant difference between the recorded route and the optimized route is because of the total number of trips made in the recorded route is greater than the optimized route. The result is further discussed in the discussion part.

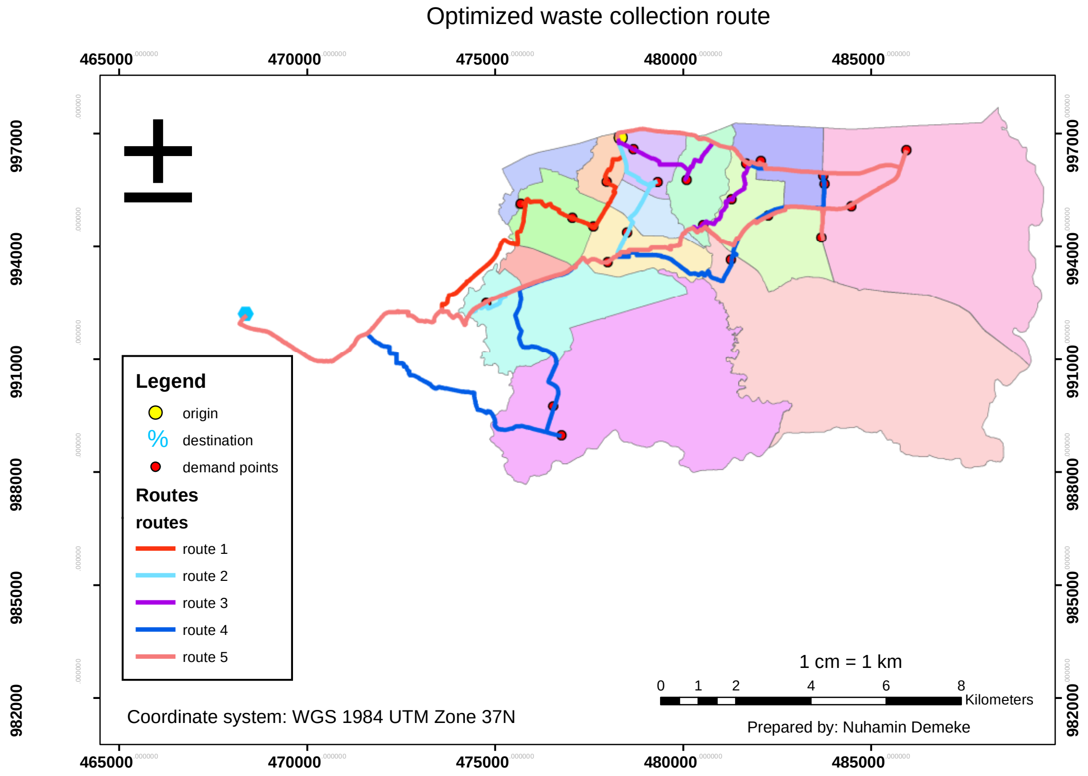


Figure 9. Optimized waste collection routes

4.7 Scenario 2: Optimized route using the vehicle routing problem solver with the application of transfer station

The location of the transfer station was first determined by weighted overlay analysis using ArcGIS 10.6. Land use layer and DEM (digital elevation model) were used for the weighted overlay analysis. 2 transfer station locations were proposed based on the overlay analysis. After the location for a transfer station was determined, a vehicle routing problem run to generate an optimized waste collection route to the proposed transfer station locations and to the final disposal site. The proposed locations for the transfer station is shown in Figure 10.

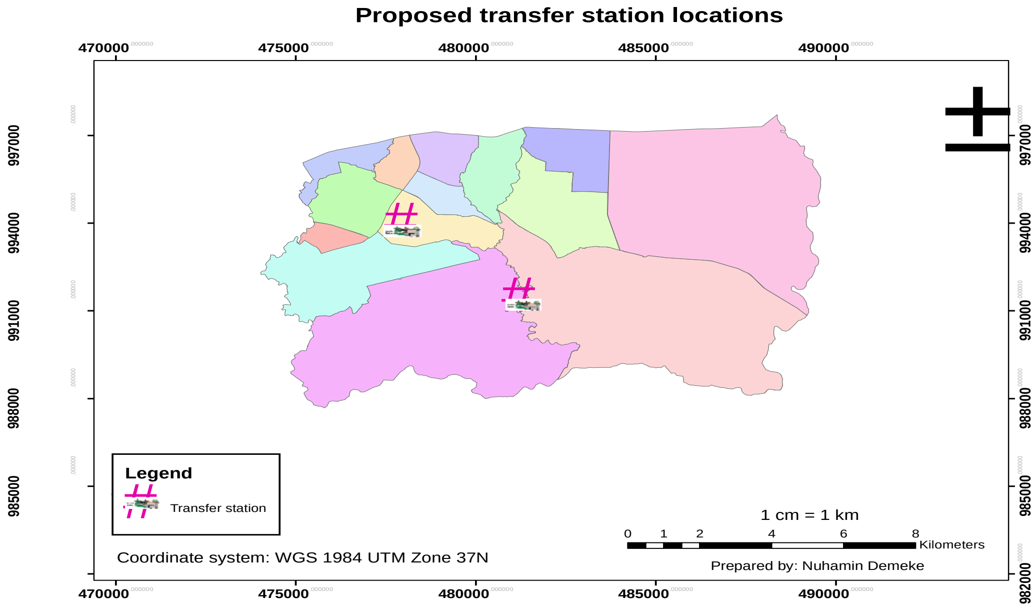


Figure 10. Proposed transfer station locations

Using the first proposed transfer station location, the collection route was optimized to a total collection distance and total travel time of 94.9 Km and 929 respectively. The result is shown in Figure 11.

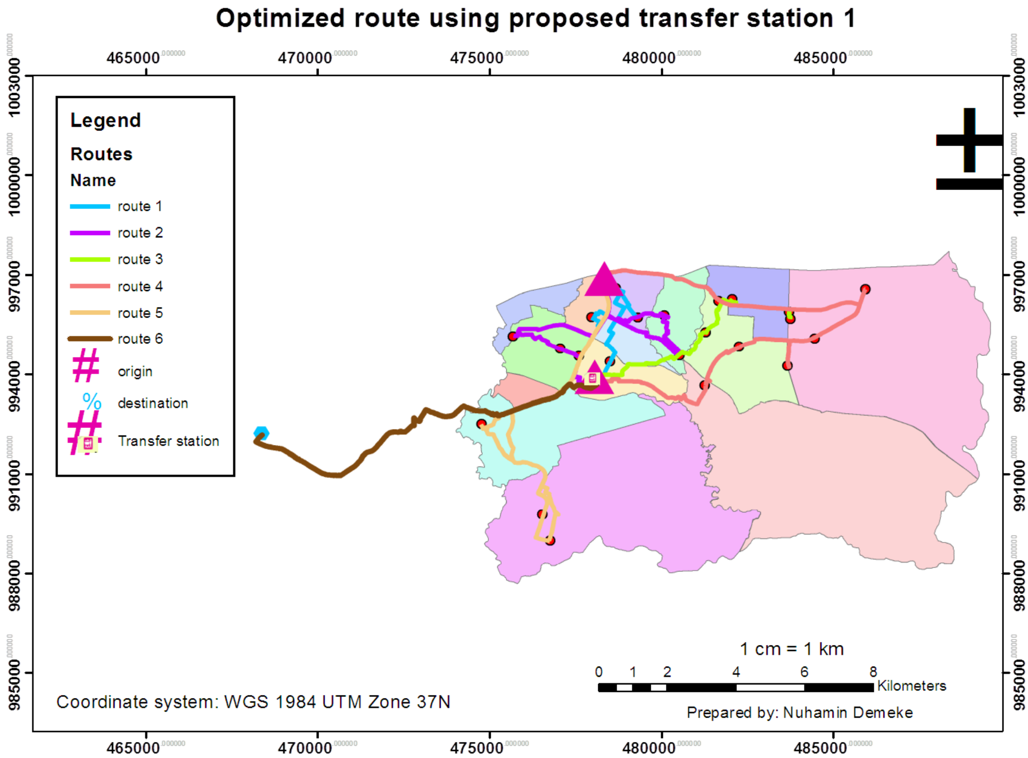


Figure 11. Optimized route using the proposed transfer station location 1

When the second proposed transfer station location is used, the collection route was optimized to a total collection distance and total travel time of 118.9 Km and 1216.2 minutes. The result is shown in Figure 12.

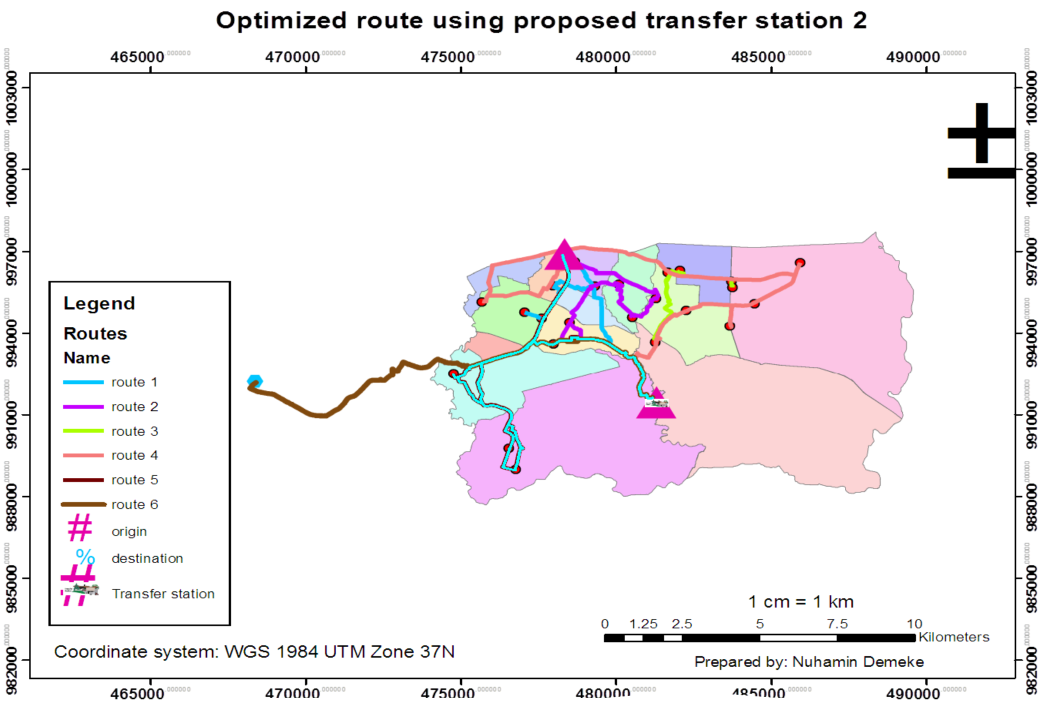


Figure 12. Optimized route using proposed transfer station location 2

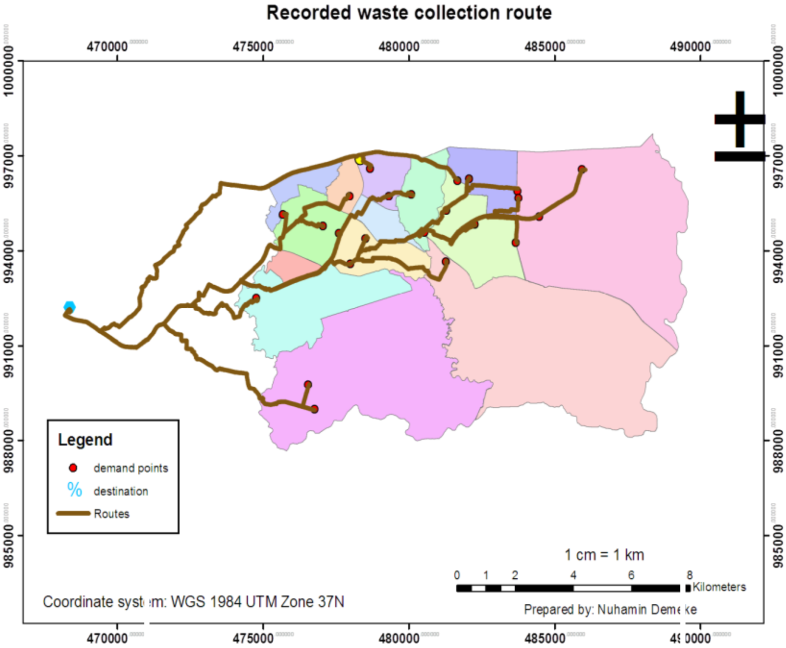
The final optimized total distance of the routes using transfer station locations 1 and 2 is 94.9 Km with a total travel time of 929 minutes and 118.9 Km with a total travel time of 1216.8 minutes respectively. The results of the two scenarios are presented and compared using a table in Appendix B.

4.8 Comparison of the results of the recorded route, scenario 1 and 2

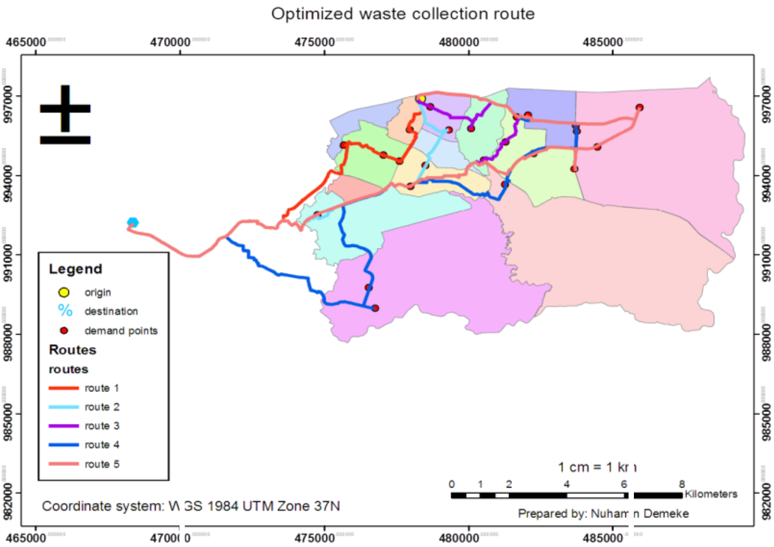
Table 15. Collection route comparison

	Recorded route	Optimized route	Optimized route with transfer station 1	Optimized route with transfer station 2
Total Distance(Km)	677.2	141.2	94.9	118.9
Total travel time (Minutes)	2930.4	1327.9	929	1216.8

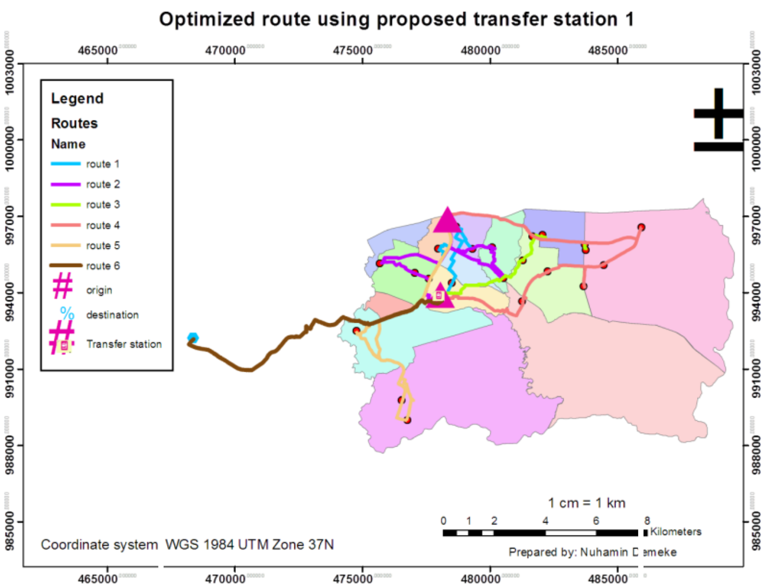
From Table 14 it can be clearly seen that there is 79.1 %, 86% and 82.4% benefit of the optimized route distance and 54.8%, 68.3% and 58.5% benefit of total travel time without the application of transfer station and with the application of transfer station locations 1 and 2 respectively. The comparison maps are presented in Figure 13.



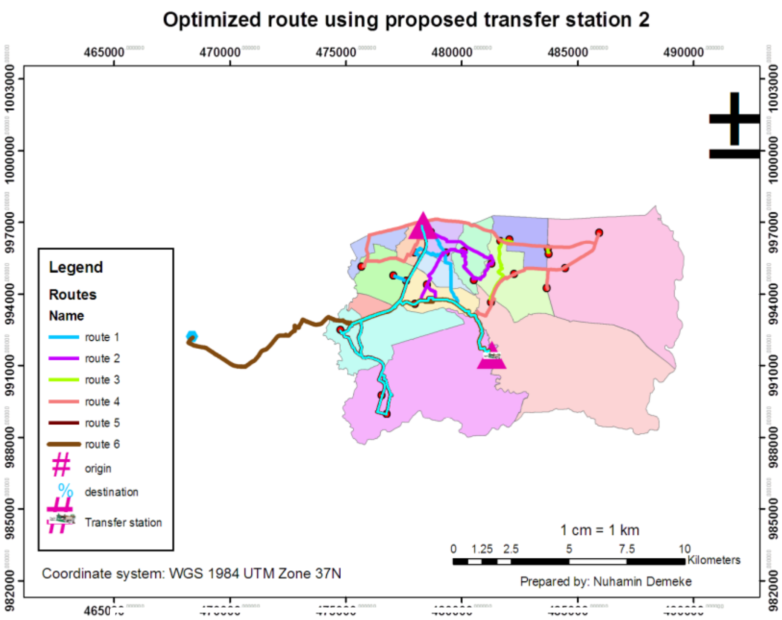
a) Recorded waste collection route



b) Optimized waste collection route



c) Optimized Route using transfer station location 1



d) Optimized Route using transfer station location 2

Figure 13. Comparison of the recorded route (a), optimized route (b) and optimized route using transfer station (c) and (d)

4.9 Discussion

4.9.1 Current waste logistics practice

Reverse logistics is a very important part of city logistics which is not given much attention in developing countries. Waste logistics is a type of city logistics that occurs in a reversed manner and involves the driving of the empty truck from the garage to the start of the collection route, and visiting all waste pick up location then driving off full truck from the final stop on the collection route to the unloading point, and driving of the empty truck from that point either back to the garage or to a new collection area if more than one area is serviced on the same day. Practices such as sorting, recycling, composting and incineration are part of the waste logistics.

4.9.1.1 *Sorting*

Reverse logistics is often associated with waste and recycling activity. According to most respondents through the questionnaire survey, the application of reverse logistics in solid waste management is still very low. The extent of the sorting practice of waste logistics in Bole sub-city from the questionnaire was found to be little (10%-20%) measuring below 50%. This shows that sorting is not well practiced in the sub-city. This directly affects the amount of waste material that can be recycled and reused.

Sorting is an important component of waste logistics practice which plays a great role in increasing the service year of the landfill by reducing the amount of waste delivered to the landfill. In addition to effective recycling, we need effective sorting practice. It first needs to happen at the household level and second in waste sorting centers.

It is very common to witness a commingled waste on roadsides and from the pile of collected and stored waste on roadsides in the sub-city. Because the type of waste which should be landfilled will be transported to the landfill without proper sorting practice, waste transportation can be affected. That is why it is common to see people of different ages working in ‘Koshe’ scavenging to find valuable materials to make a living. It can be seen in Figure 14. This causes a lot of environmental and social problems in the cities.

Figure 14. Scavengers (rag pickers) scavenging valuable materials at 'Koshe'

The waste sorting is a low-cost task in waste management if it is carried out from the source but it needs a lot of effort to consider the social aspects.

Furthermore, unsorted waste which is landfilled presents no production value and it is the biggest challenge for reverse logistics. Therefore, enough awareness should be given to the society living in the sub-city as one of the arguments for having a very low sorting practice is lack of awareness. The people should have enough information on the materials that needed to be sorted separately.

4.9.1.2 *Recycling*

From the questionnaire survey, 31 respondents (55.4%) among the total respondents believed that recycling is practiced to a little extent (10%-20%) in the sub-city. The majority of the respondents (60.7%) indicate the level of formal waste recycling in the sub-city to below. This shows that recycling is at its infancy in the sub-city.

According to a report by ARTELIA on their final report on solid waste management strategy and institutional report of Addis Ababa city, the maximum potential of waste recycling could be around 15% by weight at the source. But the recyclable materials would be unclean and contaminated by organic waste due to mixed collection. This, in turn, requires washing and drying before being recycled. This could potentially affect the amount of material to be recycled reducing the potentially recyclable materials to less than 8% without informal picking according to their report. This also holds true for Bole sub-city, as it is one of the sub-cities found in the city.

This can be directly related to the waste sorting practice of the people living in the sub-city and the city as a whole. The attitude of each individual should be changed towards sorting and recycling of waste material in order to improve the waste management system.

Though recycling is not the first priority in waste hierarchy, much consideration should be given in a later stages next to the re-using of waste. The first top priority is to prevent waste. Preventing waste means using less material during the production stage. It is also known as source reduction. The waste hierarchy is shown in Figure 15.

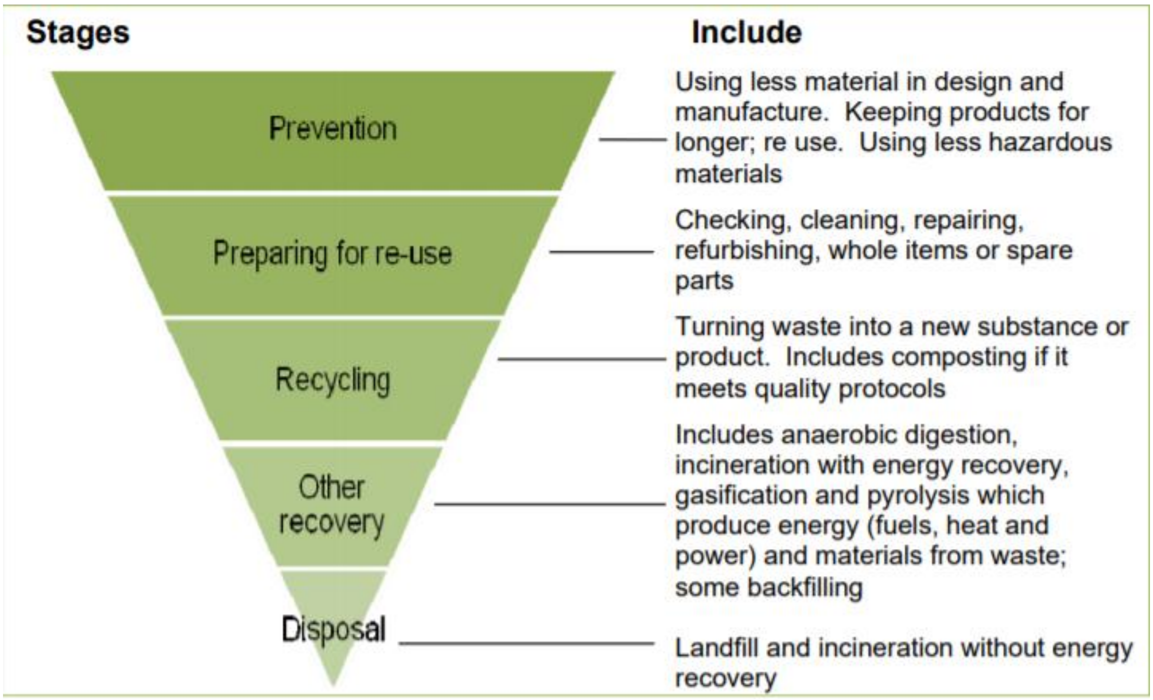


Figure 15. Waste hierarchy (Waste hierarchy Guidance, 2011)

Source: Department for Environment, food and Rural Affairs, UK

The major uses of recycling include:

- Recycling helps protect the environment. This because most of the materials which could have been ended up landfilled without proper management will be recovered through a recycling process and this, in turn, reduces soil, water, and air pollution.

- Recycling is the best means to conserves natural resources. Because as more material can be recycled, the need for the production of raw material, which is being extremely depleted, will decrease. So we won't depend too much on the raw material.

- Recycling saves energy. If the production of raw materials is reduced, the energy to produce the materials will also be reduced. Recycling materials requires a small amount of energy compared to the production of raw materials. This means we are more energy-efficient and the prices of products can come.

- Recycling creates jobs**.** People are employed to collect, sort and work in recycling companies. Others also get jobs with businesses that work with these recycling units. There can be a ripple of jobs in the municipality.

Municipal solid waste recycling is part of the field of reverse logistics; the logistics activities all the way from used products no longer required by the user to products again usable in a market (Fleischmann et al., 1997). Though recycling waste is the most common waste treatment option, great emphasis should be given to reducing and reusing waste prior to the recycling waste.

4.9.1.3 *Composting*

From the questionnaire survey result, 64.3% of the respondents confirmed the absence of composting practice in the sub-city. Composting is a way of harnessing the natural process of decomposition to speed up the decay of waste. Through composting the amount of garbage sent to the landfill is reduced, the organic matter is reused rather than dumped, and it is recycled into a useful soil amendment.

Due to our lifestyle, we consume a great amount of organic food and produce a large amount of organic waste compared to other waste types. According to solid waste management project conducted in December 2013 by Addis Ababa city government in collaboration with a French organization shows that 57.1 % of the waste generated by households is organic waste taking most of the share. Though organic wastes are generated in a great amount due to our lifestyle, researches doesn't indicate that the practice of composting at a household level and at a higher intuitional level is practiced to a great extent.

Through composting the amount of large organic waste sent to 'Koshe' will be reduced and instead the organic material can be composted into a useful soil material. The administration of the sub-city should work on composting waste at the individual level and at an institutional level. Then, in turn, it could be possible to reduce the total operational cost of waste management especially the transportation cost as it consumes a great amount of administrative budget.

4.9.1.4 *Incineration*

Among the total respondents, 36 (64.3%) responds to no extent of solid waste incineration practice in the sub-city. The rest of the respondents, 20 (35.7%) argued that there is a little extent of incineration practice. These respondents were further interviewed whether incineration has been practiced at secured places or not. Accordingly to the interviewed respondents, the practice of incineration at secured places is confined to health institutions typically to manage medical wastes even though the practice takes place only sometimes. This practice doesn't occur near households. Incineration is the least preferred option in a waste management system.

4.9.2 A solid waste transport system

Apart from the waste logistics practice, the waste transport system is not supported using the application of technologies to routing such as GIS to optimize routing and no optimal route has been determined and applied using different algorithms based on the questionnaire survey results. Among the respondents, 42(75%) disagree on the application of GIS and other technologies to improve waste collection routing.

Through the optimized routes, it is possible to measure the efficiency of a management system, for instance generating an optimal route for a given vehicle will help minimize the cost in terms of distance and time. The optimal routes are then determined by comparing the different paths by applying different algorithms such as Tabu search, ant colony or generic algorithm.

There must be increasing awareness and need for municipal authorities to reduce their overall operational costs. The use of GIS technology is one aspect that cost-conscious decision-makers implement to keep costs down. This is because GIS provides a powerful resource for identifying cost savings in an efficient way. One of the main aims of optimized routing is to minimize travel distances and reduce the fleet size through the design of the optimal and cheapest distribution pattern to serve scattered customers.

Apart from that, a total of 69.6% of the respondents replied that the number of vehicle being under operation in Bole sub-city to be insufficient compared to the amount of waste generated. Though the results from the questionnaire show that the number of waste collection vehicles is not enough compared to the generated waste, owning a number of waste collection vehicles doesn't guarantee an efficient waste collection system unless a proper type of waste collection vehicle is utilized.

4.9.3 Reverse logistics network chain

The developed network chain tried to explain the fundamentals of reverse logistics; what is being returned and who the actors are (who is executing the activities). A former study by Fleischmann et al. (1997), has argued that these types of characteristics are relevant to characterize reverse logistics.

- What is being returned: describe product characteristics which make recovery attractive or compulsory and give examples based on real cases (products and materials);
- Who is executing reverse logistics activities: the actors and their role in implementing reverse logistics (reverse chain actors);

From the results, it was possible to describe the key actors involved in the reverse network chain of solid waste materials. The major actors were found to be small scale enterprise waste collectors, rag pickers (scavengers),'Korales', middlemen (waste dealers), formal waste recyclers and informal waste recyclers. And in addition, the recoverable materials were found to be metals, plastics bottles, and Plastic packaging materials of a certain type, cardboards, woods, and rubber. Though plastic water bottles and metals are the most scavenged materials, metals were found to be the most valuable materials.

The above results were obtained only through key informant interviews with responsible stakeholders. But still, the network chain for household wastes and other waste types should be studied in detail using a different methodologies. The fundamentals of reverse logistics in the sub-city should further be analyzed from four basic viewpoints, Who, Why, What and why. Because these characteristics are relevant to characterize the reverse logistics practice in the sub-city.

4.9.4 Optimized route impact

The application of GIS presented by the results attained percentage reductions of up to 79.1%, 86% and 82.4% in the total distance traveled without and with the application of transfer station locations 1 and 2 respectively. This result shows there is a significant amount of reduction in total waste collection distance. This is because of the type of waste collection system used by the sub-city. In general, there are two types of solid waste collection system. These are:-

- Haul container system
- Stationary container system

Haul container system: this is a type of waste collection system where the waste collection truck picks up the waste collection bin and drive to the disposal site and return the empty collection bin. This type of collection system is time-consuming and not economical.

Stationary container system: in this type of waste collection system the waste collection vehicle visits different waste loading points as much as possible in a single drive before visiting the transfer station or the final disposal site.

The type of waste collection which is used by Bole sub-city and Addis Ababa city as a whole is a Haul container system. In this type of waste collection system, the waste collection container is transported directly to the landfill and an empty container is replaced. This, in turn, increases the number of trips made to the landfill. Except for the few numbers of compactor trucks with a loading capacity of 40 m3 and 80 m3, the major type of trucks used by the sub-city is designed for this type of waste collection system.

In using the VRP solver tool, a vehicle will visit pick up locations in a set of orders not in a random manner. And with one single drive to the landfill, the vehicle can visit as many pick up locations as possible. Due to this, a significant reduction in the collection route distance was obtained.

The collection of unseparated and separated solid waste in an urban area is complex as waste generation becomes more diffuse. Of the total amount of money spent on the collection, transportation, and disposal of solid waste, approximately 50 to 70 percent is spent on the collection phase (Amirhossein Malakahmad et al., 2013). A significant saving in the overall cost can be affected by small percentage improvements in the collection operation. Therefore, interest in the analysis of solid waste collection systems arises to optimize the operation of existing systems and to develop data and advanced techniques to design and evaluate new systems for urban areas. A GIS tool for optimization proves to be a powerful tool and can be used as a decision support tool by responsible municipal authorities for efficient waste logistics system.

The applicability of a GIS should be analyzed not only by economics but also the environmental aspects that are related to solid waste. An efficient system of collection and transportation of solid waste should minimize any type of pollution including soil, air or water pollution. Moreover, an efficient system of collection and transportation of solid waste should help to improve the aesthetic appearance of the city, to make life more pleasant for its residents to avoid visual pollution. A system that achieves these goals with the least possible cost is desirable, but the financial and technical resources of the authorities responsible for urban sanitation are often limited. Seto et al. (2014), cited in urban development brief on solid waste management by World Bank (2019), asserts that potential approaches to reducing transportations emissions can be reducing collection fleet lag times, improving routing efficiency such as through the use of geographic information systems, selecting cleaner fuels, and using fuel-efficient.

The application of GIS in waste collection and transportation is very important in the production of routing solutions in less time using actual values of distances and travel time across a road network.

Different studies show that the application of GIS can result in a reduction of travel distance and time resulting in the efficiency of an organization. Prior to this study, no significant research was carried out in Bole sub-city and Addis Ababa as a whole.

The findings of this study are directly in line with previous findings. Koushik Paul et al. (2015) employed and found GIS to be an effective decision support tool for municipal solid waste (MSW) transport, work distribution for conservancy vehicle staff and vehicles and managing fuel consumption.

The application of GIS presented by the results obtained, a percentage reduction up to 86% and 82.4% in total distance traveled using the application of proposed transfer station locations 1 and 2; and 79.1% reduction with the application of the recorded route compared to the current service. The results demonstrate that the proposed scenarios are significantly efficient in terms of collection distance covered.

The advantages of GIS for vehicle routing of the solid waste collection are production of a routing solution in less time, using actual values of distance the road network, and the possibility of change analysis of the variables such as fleet and period of operation or analysis constraints, such as vehicle capacity.

Due to the limitation of traffic data (traffic volume) availability on road segments, it was not possible to carry out the optimization of the collection truck route in terms of travel time. Therefore further suggestions couldn’t be made regarding optimization of collection route in terms of travel time through different previous studies have demonstrated a potential travel time reduction through the application of GIS.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this study, the current waste logistics practice in Bole sub-city has been assessed and the application of GIS as an optimization tool was explored in improving the waste collection and transportation system. From the study, it was concluded that, the waste management of the sub-city suffers from a poor waste logistics practice and an inefficient waste collection and transport system. The performance of current waste logistics practice in the sub-city, in general, was found to be unsatisfactory measuring below 50%. These practices include sorting, recycling, composting and incineration. And this has a direct impact on waste collection and transportation system. Though organic waste is generated in a large amounts, composting of waste is almost absent in Bole sub-city. Prior to using waste to generate electric energy, other options like reusing, composting and recycling of waste should be encouraged.

Using the key informant interview it was possible to develop the reverse logistics network chain of household waste in Bole sub-city. Identifying the key actors involved and the material flow is an important aspect of reverse logistics in the waste management sector. Future development of studies could be suggested to assess the role of the private sector in waste management. Except for the results acquired through key informant interviews, it was impossible to find a document from the Sub-city administration sanitation office, on the material and information flow of the reverse supply chain of household solid waste. From this, it was understood that the role of reverse logistics in waste management is not better understood and given much attention.

The results from the questionnaire regarding the waste transport system showed that there is no systematized waste collection route and no technologies are employed to improve the waste collection and transportation system. Optimization is an important aspect of waste management. GIS is a tool that can display spatial and non-spatial data and it is a powerful tool for optimization analysis. In this study, the application of GIS in Bole sub-city was explored and has shown a positive result.

It was possible to reduce the total travel distance and total travel time by 79.1%, 86%, 82.4% and by 54.8%, 68.3%, 58.5% without and with the application of transfer station locations 1 and 2 respectively by using a truck of 40m3 loading capacity. The study showed that GIS can be used as a tool in a waste logistics system for improving the efficiency of waste collection and transportation. Therefore, the administration of the sub-city could use GIS as a decision support tool for efficient management of waste.

Though the results from this study are encouraging enough to further expand the scope to cover all sub-cities in Addis Ababa, in order to improve the waste logistics practice in the sub-city, a lot of effort is needed to create an awareness on reverse logistics to the public. And an efficient and effective waste logistics practice has to be introduced to tackle the problem through the cooperation private sectors and different stakeholders in the system.

5.2 Future research

Further researches should investigate and examine to get a better result in the optimization of waste collection and transport systems using different techniques. Future research could be:

- Location analysis for the location of a landfill for carrying out an optimization analysis to the proposed new landfill for different waste streams.
- Allocation of waste collection bins collection using GIS for better optimization and also obtaining traffic data on each road segment will improve the result.
- Transfer location analysis using a weighted overlay analysis using multiple layers in addition to land use and DEM layer.
- Development of a reverse network chain of different recyclable waste materials from different sources other than household wastes to better identify the actors involved in the reverse network chain including the flow of recyclable materials

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APPENDIX A

Addis Ababa University
አዲስ፡አበባ፡ዩኒቨርሲቲ
Seek Wisdom, Elevate your Intellect and Serve Humanity

Addis Ababa Institute of Technology

Department of Civil and Environmental Engineering

Dear respondents: The intent of this questionnaire is gathering information to a thesis to be conducted with regard to **Improving solid waste logistics systems of Addis Ababa city in the case of Bole sub city** in partial fulfillment of the requirements for Master Of Science in Road And Transport Engineering; to be submitted to Addis Ababa Institute of Technology Department of Civil and Environmental Engineering. Therefore, I humbly request you to consider your participation in responding the questionnaire so as to give the researcher a great deal of clarity about the issue. Also, I can assure you that the information to be collected from you are solely for academic purpose and will be treated with strict confidentiality. Once again, I demand your valuable support in filling the questionnaire as patiently and frankly as possible. Thank you for your time and consideration!

Nuhamin Demeke Zewde
Contact Address +251939597074

Instruction: Please, put a tick (√) mark in which you want to select.
Part I: Questions related with Background Information

1. Gender: Male □ Female □
2. Age: 18-25 years □ 26-35 years □
3. Educational Level :
   Elementary school □ 12th grade □ Diploma □ Masters □
   High school □ Vocational □ Degree □ PhD □
4. Current Position…………………………………………………………….
5. Year of service in the current position …………………………………………….

Part II: Question Directly Related to the Study

Section A: To what extent is the solid waste logistics practices (Sorting, Recycling, Composting and Incineration) at the Sub city?

The five Likert Scale points denote: 1=No extent (No waste is sorted, recycled, composted or incinerated), 2=little extent (10%-20%), 3= moderate extent (30%-40%) 4=great extent (50%-75%) and 5= a very great extent (80%-100%)

1. Waste Logistics practices	1 (No extent)	2 (Little extent)	3 (Moderate extent)	4 (Great extent)	5 (Very great extent)
1.1 Sorting					
1.2 Recycling					
1.3 composting					
1.4 Incineration					

Section B: Questions related with SWLS. To be answered by putting ✓ in the box related to your designated answer.

The five Likert Scale points denote: 1=Highly Disagree, 2=Disagree, 3=Neutral 4=Agree and 5= Highly Agree

2. Waste collection, storage, recycling, and Composting and disposal process.	1 (Highly Disagree)	2 (Disagree)	3 (Neutral)	4 (Agree)	5 (Highly Agree)
2.1 There is appropriate use and care for containers so that there is no scattering of waste around the containers					
2.2 The containers placed are enough with respect to the amount of waste generated					
2.3 Sorting of waste is being conducted at collection period					
2.4 Sorting of waste is being conducted at disposal period.					
2.5 There is a practice of Institutional Composting of organic waste.					
2.6 The formal practice of waste recycling is high					

3. Waste transport System	1 (Highly Disagree)	2 (Disagree)	3 (Neutral)	4 (Agree)	5 (Highly Agree)
3.1 The existing numbers of trucks are sufficient for the current SW generation and collection.					
3.2 There are sufficient number of trucks with different size used for collection and haul of SW from transfer station to dumpsite.					

3.3 The frequency of waste collection by drivers is High (travel time for shuttling back and forth to disposal site)					
3.4 There is a scheduled plan for collection by trucks. Drivers haul waste before need arise.					
3.5 There is an application of technologies to routing such as GIS to optimize routing is applied.					
3.6 The available truck types designed to handle different types of waste stream with different compartment for different types of waste.					
3.7 There is proper preventive maintenance of Vehicles therefore minimum out of service periods of trucks.					
3.8 There are Specialized trucks deployed for Hazardous wastes used.					
3.9 Optimal route has been determined and applied using different algorithms.					
3.10 The participation of private sector in transportation of waste is satisfactory					

Thank you for your time and consideration!!!

Appendix B

Key Informant Interview Guide

I. **For SWM officials in Bole sub-city**

a) Who are engaged in solid waste collection and transportation in the sub-city?
b) What is their role in SWM?
c) Who are involved in solid waste
d) Are there formal waste recyclers recruited by the sub-city?
e) What type of material is being recycled by the formal waste recyclers?

II. **For Korales, waste pickers and small scale enterprise waste collectors?**

a) From where do you collect the recyclable waste materials?
b) What type of recyclable materials do you collect?
c) After collecting the recyclable materials, where do you sell it and to whom?
d) Which material is you think is more valuable? And why?
e) Why are you involved in the solid waste sector?

Appendix C

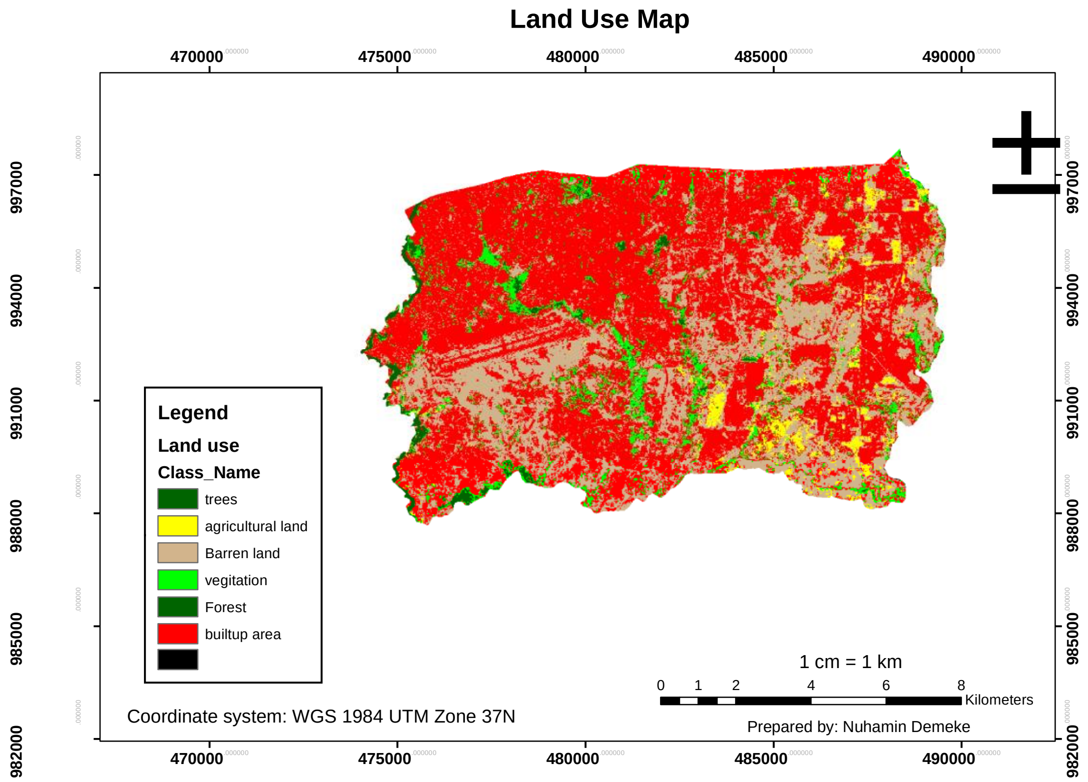
Optimized route comparison based on different scenarios

Table 16

Optimized route		Optimized route using transfer station 1		Optimized route using transfer station 2	
Route Id	Distance(Km)	Route Id	Distance (Km)	Route Id	Distance (Km)
Route 1	20.6	Route 1	10.8	Route 1	15.3
Route 2	23.8	Route 2	15.2	Route 2	16.7
Route 3	27.6	Route 3	14.3	Route 3	15.5
Route 4	35.1	Route 4	22.1	Route 4	29.1
Route 5	34.2	Route 5	20.2	Route 5	25.1
-	-	Route 6	12.3	Route 6	17.2
Total	141.3	Total	94.9	Total	118.9

Appendix D

Land use Map



Appendix E

Digital Elevation Model (DEM)