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Modeling an integrated municipal solid waste management system facility locations using fuzzy AHP and goal programming: in case of Bahir dar city.

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I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

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As a member of the board of examiners, we examined this thesis entitled "Modeling an integrated municipal solid waste management system facility locations using a combination of fuzzy analytical hierarchy process and goal programming: in case of Bahir dar city." by Zelalem simeneh. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Masters of Science in production engineering and management.

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Declaration

This is to certify that this thesis entitled "Modeling an integrated municipal solid waste management system facility locations using a combination of fuzzy analytical hierarchy process and goal programming: in case of Bahir dar city", submitted in partial fulfillment of the requirement for the degree of Master of Science in production engineering and management under the Faculty of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificate. The assistance and help I received during this investigation have been uninterestingly acknowledged.

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Abbreviation

Abbreviation	**Description**
FAHP	Fuzzy analytical hierarchical process
GP	Goal programing
SWM	Solid waste management
MSWM	municipal Solid waste management
K_i	kebele
MCDM	Multi-criteria decision making
AHP	Analytical hierarchy process
LP	Linear programing
GIS	Geographical information system
FLP	Facility location problem
MSWMS	municipal Solid waste management system

Abstract

The determination of suitable solid waste transfer station sites location has become indispensable in recent years as the global generation of waste has increased and the use of unsuitable solid waste transfer station sites location results in negative impacts on the ecosystem and economic. One of the main issues with waste management is choosing a suitable location for a solid waste transfer station. The process of selecting where to locate solid waste transfer stations is challenging and complex because it involves balancing cost considerations that require resource allocation with difficult to interpret social and environmental issues. The aim of this study was optimize the solid waste management system considering social, environmental and economical factors when selecting solid waste transfer stations. The selecting process of solid waste transfer stations location also depends on a number of restrictions. Based on the actual conditions of a case study, twenty kebeles and four candidate alternative locations in the West, South, North and South-Este region of Bahir dar city, the paper considered multiple factors such as geological, infrastructure, morphological and social & environmental factors, calculating global priority weights using the fuzzy analytical hierarchy process (FAHP). Subsequently, a new multi-objective facility location problem model was evaluated, known as the combined of fuzzy analytical hierarchy process (FAHP) and goal programing (GP) model, which integrates of FAHP and goal programing (GP). The proposed method can assist in choosing new, suitable locations for solid waste transfer stations through taking final priority weight objectives and total cost into consideration. It was based on the source of data that collected from expert judgment view, observation and literatures of the case study. The decision makers confirmed that these locations (L1, L2 and L3) are appropriate as new locations for solid waste transfer stations, and they believed that the work can provide essential support for decision makers in the assessment of location of solid waste transfer stations problems, in this case study and other areas of the city. This research has the potential to influence future waste management policies by assisting stakeholders in solid waste transfer station siting in a manner that reduces negative impacts on the environment and economic.

Key words: MSW, FAHP, GP, FLP and municipal solid waste management system

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CHAPTER ONE

1. Introduction

1.1 Back ground of the study

Municipal solid waste is produced by company operations, institutional, and residential activity. Solid waste management has gained significant attention from scholars in recent years due to the uncontrolled urban population increase in developing countries. The dynamics of urbanization have risen in developing nations as a result of population growth, globalization, and technological development. The creation, storage, collection, transportation, processing, and disposal of waste materials in a way that supports public health, the economy, resource preservation, fashion, and other environmental criteria is known as solid waste management. It is characterized by a set of consistent and methodical regulations (Panepinto & Zanetti, 2021). Many countries are encountering challenges in handling these issues and require comprehensive and workable answers.

In developing nations, one of the biggest challenges is to provide high-quality solid waste management services while ensuring the system's financial sustainability. Optimal planning must be established by government planners and managers in order to optimize the conditions for a sustainable approach to municipal solid waste management. The increased complexity, ambiguity, and multi-objective nature of this issue are currently being challenged by planners and decision-makers in the field of integrated solid waste management system (Habibi et al., 2017).

Decision-makers should recognize the differences between optimal, good, and unexpected decision-making at this point in time, given the complexity of integrated solid waste management. The ideal problem in optimal decision making can be solved with methods from various disciplines. When using this way of solving problems, a function or functions must be optimized by using certain procedures, and normally, some restrictions (criteria) are taken into consideration. Effective decision-making is achieved through trial and error, experience, or comparison of several integrated SWM choices. While this method of decision-making can help select choices that are near ideal, it is no longer applicable due to the growing number of alternative combinations in the decision-making process. Because decisions generated by random decision-making lack a scientific foundation, the outcomes are unacceptable (Akbarpour Shirazi et al., 2016). The development of solid waste management was caused by five main factors: climate change, public awareness and participation, resource scarcity and waste value, public health, and the environment (Marshall & Farahbakhsh, 2013).

Among all municipal services, the storage, collection, and disposal of municipal solid waste (MSW) present the greatest challenges. Its harmful particles and odor cause a great deal of environmental and health problems. In order to meet the requirements of facilities like Waste Transfer Stations, waste disposal patches are frequently situated distant from densely populated regions. When waste dump yards are situated more than a certain standard distance from waste generation sites, a waste transfer station a facility for the temporary storage of waste is necessary (Jaiswal & Bharat, 2016). These days, it is required in most of the million plus cities as in nearly every developing countries, million plus cities have grown to the extent that transfer stations need to be considered. Not only distance to disposal, but travel times (due to traffic congestion) have dramatically increased in the past decade. A transfer station is necessary for improved solid waste management (Jaiswal & Bharat, 2016).

The position of transfer station is very important as it is the midway service of waste generation to disposal. The purpose of the paper is to list down all important criteria and their respective indicators for locating waste transfer station. Many past researches based on the location of waste transfer station give emphasis on economic and environmental based criteria. However looking at present geographic, environmental and social complexities in urban areas, it was considered to explore several criteria for locating transfer station in urban areas. Thus present paper discusses diverse location based criteria from literature followed by expert consultation in exploring more criteria. Disposal centers and community solid waste collection facilities are connected by waste transfer stations, which are crucial components of a community waste management system (Habibi et al., 2017).

The goal of the waste transfer stations is to combine waste from several collection vehicles into larger transfer vehicles so that it may be shipped to disposal locations farther away more affordably. Put differently, a transfer station is a location where garbage collection vehicles unload their loads into a specified reception area. Usually, waste is compressed before being transferred across great distances in larger vehicles to a final disposal location. A transfer station does not store waste for a longer period of time (Habibi et al., 2017; Jabbarzadeh & Jabalameli, 2016).

The process of choosing appropriate sites for transfer stations is intricate and necessitates a thorough assessment procedure that takes local, national, and environmental laws into consideration (Jabbarzadeh & Jabalameli, 2016). For instance, residents in several towns have expressed concern about improperly located, constructed, or run solid waste transfer stations. Furthermore, some residents may believe that there is an excessive concentration of transfer stations in or close to their neighborhoods. However, transfer stations are crucial to the waste management system of a community (Habibi et al., 2017). It is now more important than ever to completely understand environmental principles in order to choose the ideal location for solid waste collection, as environmental factors in municipal planning have grown in popularity (Önüt & Soner, 2008).

Municipal solid waste does not only have economic impacts on the population, but it also presents considerable social and environmental impacts. A study conducted by (Boadi et al., 2005) found that poor handling and disposal of waste are major causes of environmental pollution which create room for reproduction of pathogenic organisms and spread of infectious diseases. Based on these facts, it can be said that developing countries can positively affect the lifestyle of their people and improve the cleanliness of their cities by implementing effective and optimal municipal management systems.

At present in Bahir dar city, there are 26 kebele, and the generated amount of solid waste is about 472.22 meter cub per day (172,360 meter cub per year), while this waste is expected to increase by 6.6 percent (Biruk, 2017). The generated solid waste in the city was available for production of biomass, compost, biogas and recycled products. According to Asmare, (2019), Bahir Dar city solid waste has a potential to generate 50.19 tons of biomass per day. The collected waste was characterized as 82.5% of them is organic waste that may be converted in to clean energy (briquette and biogas) based on their sized whereas the remaining 17.5% of them were inorganic (plastics, glass, and metals) that can be resent for recycling and reuse to their original sources. (Kassahun & Birara, 2018) Stated that, 78% of the respondents feel that the existed solid waste management service is far below the required level from the survey of 350 households in the city. Among 350 households, a sum of 66.6% practice illegal solid waste disposal with the remaining 33.4% waiting until solid waste collectors come to the area to take the waste away.

(Ayalew et al., 2020). Suggested that, the municipal solid waste (MSW) management system practiced in Bahir Dar was to be improved. This study list the problem to be improved that First, the waste collection and sorting system was weak. Second, the waste composting and recycling efficiency was very low. Third, waste transportation and disposal management were not standardized and environmentally sound. So, it suggested that government commitment, full stakeholders' engagement, and investment are essential to achieve the goal of sustainable solid waste management in the city. (Lohri et al., 2014) examined Bahir dar city solid waste management regarding to fiscal stability of cost and revenue that conducted cost-income analysis based on 2009-2011 data collection. However, the valuable plan optimization of integrated solid waste management in Bahir dar city was never pursued in the form of an executive program. The aim of the presented study is examining the existing solid waste management system and modeling optimal way with in scientific method. Significant trend that increasing Municipal solid waste generation within the increasing of overall population growth rate, urbanization, industrialization and economic growth those are the cause of the solid waste quantity increment in the city. The city household mean weight solid waste generation was 0.22kg per capita per day. It increase from core zone of the city to outer zone which have in core zone (0.28kg, in the outer zone 0.17kg and 0.20kg in the middle zone) (Tassie Wegedie, 2018). Different solid waste treatment techniques must be established in accordance with the characteristics and circumstances of each form of solid waste. The organization and volume of MSW produced serve as the basis for the planning, designing, and operation of the management system (Sharholy et al., 2008).

Although each districts in Bahir dar have their own collection point to collect of their kebele waste, because of environmental concerns and protests by local residents, many collection points have been shut down, and these kebele finally need to use services transfer stations. Consequently, building new, suitable facilities for transfer station more effectively is becoming an issue that is particularly important to consider. In the past, solid waste has disposed at open dumpsite only this caused many problems, such as increasing of solid waste volume at dumped sit and lack of space, and district kebele are one of the service require institutions that have often found common problems because they are far from the locations of service providers or waste disposal dump sites as random observation. For this reason, local governments of Bahir dar city have set up a policy to encourage the establishment of new solid waste transfer stations by integration of neighborhoods, in order to increase the solid waste processing facility (recycling, composting and other waste to energy facility) efficiency by prey sorting of solid waste. The new solid waste transfer station must be compatible with the requirements of governmental regulations, and at the same time must reduce economic, environmental, health and social impacts (Höke & Yalcinkaya, 2021). Legally, municipalities are responsible for establishment of solid waste transfer stations expect the inner part of the city. Therefore candidate locations will be selected from possible locations to serve district kebeles in municipalities. Choosing suitable locations (transfer station) for this case poses complex problems, because it must consider social, environmental, cost and geological impact (Ağaçsapan & Çabuk, 2020). The transfer site must not cause damage to the biophysical environment and the ecology of the neighboring area. In this case, the maximization of satisfaction level regarding to relevant impact, such as social and environmental impact, is as important as minimization of total cost. The satisfaction level regarding relevant impact can be evaluated from various qualitative and quantitative aspects, such as infrastructure, geological, environmental, morphological and social etc. The higher the satisfaction level, the lower the probability that sites cause damage to the biophysical environment and the ecology of the neighboring area. Certainly, both perspectives of total cost and relevant impact definitely must be considered in designing an optimal location network.

In order to achieve an optimal location network, the fuzzy analytic hierarchy process (FAHP) is suitable for solving multi-criteria/objective decision making (MCDM) problems that are difficult to interpret quantitatively (Önüt & Soner, 2008), and goal programming (GP) is suitable for solving multi-objective problems that require allocation of resources. Hence, choosing integrated FAHP and GP techniques (integrate of FAHP&GP model) to solve multi-objective facility location problems, while minimizing total cost and maximizing total location weight, are reasonable for use in this case (Kilic & Yalcin, 2020). The facility location problem model proposed in this study is as the traditional facility location problem model but, the coupling of FAHP&GP model tries to minimize the total cost of the location network and maximize the satisfaction level of its stakeholders, under relevant constraints existing in the decision environment.

Conceptual representation of waste material follow and waste processing facility in case of Bahir dar city.

The conceptual model starts with transportation of wastes from generation nodes to transfer stations where the wastes are sorted and separate into the recyclable, organic, incineration and other type. After the sorting process, the sorted wastes are sent to their distinct destinations by larger vehicles. Recyclable wastes are transferred to recycling centers; organic wastes are sent to biological treatment centers with compatible technologies; incineration which are neither organic nor recyclable is transported to landfill disposal centers. After the treatment process at biological and heat treatment centers, organic waste mass is reduced and the residues parts are sent to landfill disposal centers and getting in incineration waste mass is reduced and the residues parts are sent to landfill disposal centers ; and also the residues parts of recyclable waste are sent to landfill disposal centers. After the recycling and treatment process, recyclable wastes are sent to the markets or other factories, composts and energy are sent to the markets as shown the figure 1.

Based on the available data, Bahir dar city waste can be categorized in to groups such as municipal wastes, institutional wastes, commercial and marketing waste street sweeping waste and other wastes with the generated of solid waste. The municipality of each region is responsible for collation and transportation of the waste generated in the region. The major part of the municipal wastes along with a part of the institutional, commercial and street sweeping wastes are transferred to the transfer stations available throughout Bahir dar city after collection. The waste transferred to transfer stations in this station the waste able to processed and separate in to different group (compostable, recyclable, incineration, land fill and etc.) Units and transfer to the final disposal sites after processing. Figure 1 is the conceptual model that represents and considering the future development of Bahir dar city municipal solid waste management system modeling.

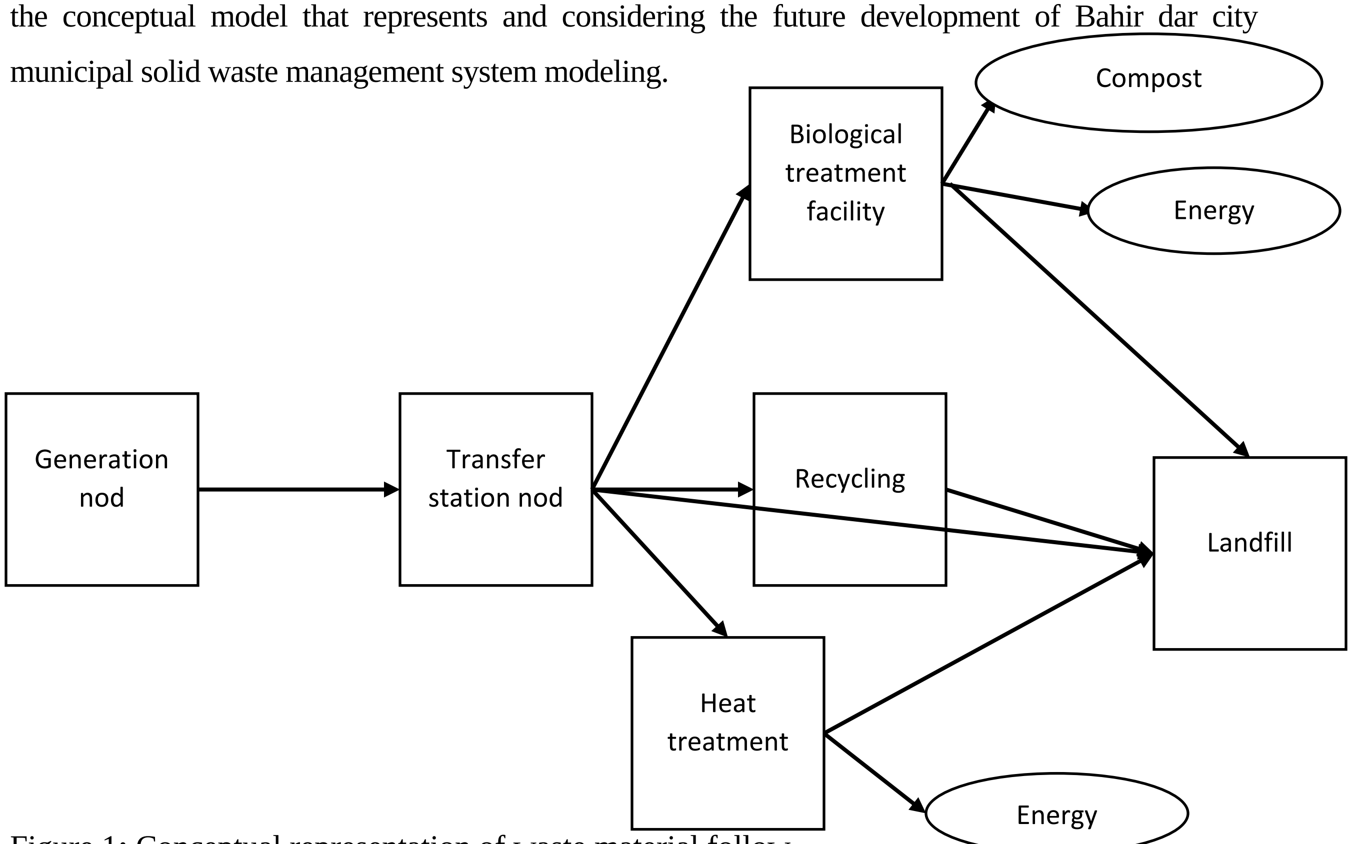

Figure 1**:** Conceptual representation of waste material follow

1.2 Problem Statement

The population growth and the rate of urbanization are alarmingly increasing in Ethiopian cities. Within the increase of population, the solid waste management is the main issue for the environment and resources due to the lack of infrastructures, technology, technical experience, and financial capacity. When Municipal solid wastes are not adequately available, it would have been difficult task for local authorities and managers.

The majority of the literature concerning solid waste transfer station location siting was consisting of mathematical optimization model with quantitative data based, MCDM-based analysis with qualitative data that was multi-criteria decision making approach such as fuzzy analytical hierarchy and mathematical modeling like goal programing within qualitative and quantitative data analysis (Habibi et al., 2017; Kilic & Yalcin, 2020; Önüt & Soner, 2008).

Bahir dar city population is rapidly increasing due to the influx of new residents from small towns and rural areas. This increase of population cause the increases solid waste volume. The City has no transfer station and solid waste processing facilities and also the society has no trend to source separation of the waste. Administer of The city have only one open damp solid waste disposal site at SEBATAMIT which is located in norther part of the city, so, any type of mixed solid waste that collected in anywhere in the city and the satellite cities has been disposed. There was no prior sorting of solid waste collected from any part of the city except for occasional metal and plastic materials informally sorting for additional income of employers. This type of solid waste disposal practice eliminates the benefits of solid waste, such as solid waste compost, waste to energy recycled solid waste and other benefits. (Lohri et al., 2014). Faraway of the new kebele that cause incremental of solid waste transportation and the increasing of solid waste volume year to year ware the issue to manage the current and future of solid waste management systems. Due to this the authority the optimal solid waste transfer station that govern the environmental legislation and economic manner. If the present trend of solid waste generation and disposal practices continues without additional waste processing facilities, the solid waste management cost will have been increase and it also will have been difficult task for local authorities to manage municipal solid waste system. According to (Tassie Wegedie, 2018) from 196 household solid waste generation data collection, 112 (57%) of households are served by door-door waste collection service whereas 84 (43%) of households never received solid waste collection, transportation. In areas where compacting vehicles are not available like Bahir dar city, waste transfer stations used as solid waste compacting center. So the volume of the waste would have been reduced and greater quantities of solid waste can be loaded at once to the final disposal sites.

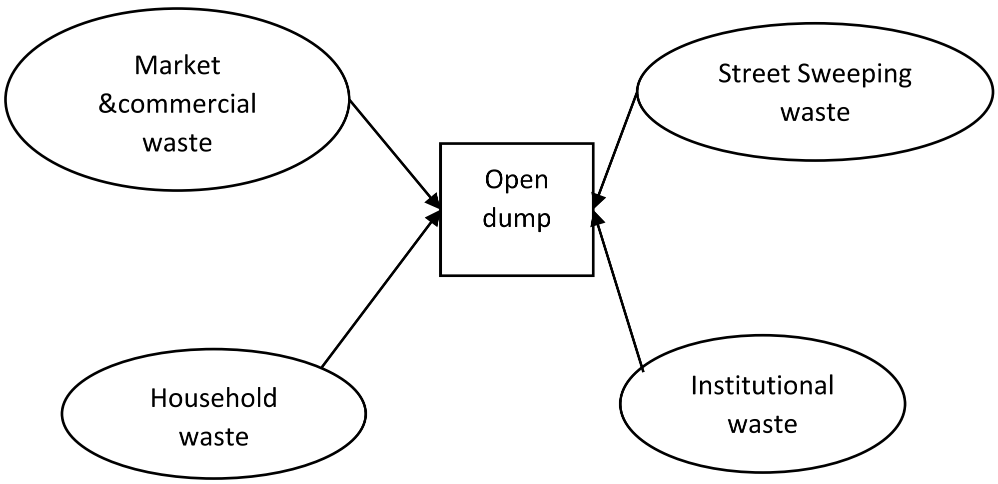

Figure 2 : The existing solid waste disposal system of Bahir dar city

The issue that faced the solid waste management system in the city ware; the transportation cost due to faraway of the new kebele from the disposal site and since it have no waste sorting place, mixed solid waste was disposed at single open dump disposal site. So, It decrease the service life time of the waste disposal site and decrease the requirement of solid waste processing facility raw materials quantity and quality. Therefore, this study will have fulfilled the gaps by determining the location of transfer station for municipal solid waste management system of the city.

The sum up, the utilization of the waste transfer stations within the waste management process, a good number of benefits will be provided in terms of environmental and resource protection, land use and energy efficiency, emission reduction and social health. In order to achieve these benefits, it is important that the transfer stations are located in appropriate areas (Azadeh, Ahmadzadeh, & Eslami, 2018).

1.3 Research questions

This study tries to answer the following questions that stated from problem statements (section 1.2):

- ✓ What is the method to determine the new facility potential site location of solid waste transfer station?
- ✓ How to evaluate the optimal cost of the solid waste transfer station location network?
- ✓ How to determine the optimal required number of the solid waste transfer station in the city?
- ✓ How to determine the satisfaction level of the stakeholders in new facility location problem?

1.4 Objective of the study

1.4.1 General Objective

The main objective of this study is to optimize the solid waste management system, in case of Bahir dar city by selecting suitable site location for siting MSW transfer station using fuzzy analytical hierarchy process and goal programming.

1.4.2 Specific Objective

To achieve General Objective of the study the following specific objective are considered.

- ✓ To determine the potential site location of solid waste transfer station.
- ✓ To evaluate the satisfaction level of the stakeholders in solid waste management facility location.
- ✓ To evaluate the optimal cost of the location allocation network of solid waste management system.
- ✓ To select new suitable solid waste transfer station locations.

1.5 Scope of the study

This study will have been conduct at Bahir dar city in Ethiopia. Bahir Dar is the capital city of the Amhara National Regional State (ANRS) in northern Ethiopia. It is located near Lake Tana, the headwaters of the Blue Nile, and it is a major tourist destination. Bahir Dar city has a flat plateau earth structure which is located at 11°36"North latitudes and 37°23"East longitudes. It is located in north of Addis Ababa which is the capital city of Ethiopia. The scope of this study is solid waste management system in the city. In which, the city municipal, institutional, commercial and street sweep solid waste collection, processing, and waste disposal system. It is manly focus on the solid waste sorting and collection system, the waste transportation method and the solid waste disposal method. But it is not concerning the liquid waste management system in the city and industries and hospital solid waste. In this study the feasibility study of transfer station has no dedicated so, it indicates the location of transfer station and the ideal operational capability of the facility.

1.6 Significant of the study

This study has several significances, In the first place the residents of the city can make use of the findings of the study through improved solid waste management practices and will have reduce a health risk due to insufficient solid waste management practice.. Secondly it has opportunity to develop suitable environment for investment attraction due to sucking clean area habits, but it needs supporting of solid waste managers and environmental protection agencies of the city that can make use of the findings of the study through improved solid waste management practices. Thirdly, it gives some guide line information to the municipal and other solid waste management system managers and environmental protection agencies about the existing situation of municipal solid waste management of Bahir dar. It also will reduce the amount of landfill waste, and help local industries (agriculture) to do soil amelioration. Inanition to those, the findings has significant change for solid waste volume reduction and cost minimize for solid waste management systems.

In Bahr Dar the municipal solid waste needs for “just in time” collection system in the area which high and vast organic waste fraction production and it needs a high collection frequency. Transfer stations increase the frequency of collection by pre collection vehicle as it reduces their time and distance to be travelled. Therefore Introduction of waste transfer stations in municipal solid waste collection system has significant to solid waste providers and receivers by reduces the transportation cost, number of waste collection vehicles, pollution and noise level, and traffic congestion inside the city. They increase the frequency of collection to ensure the maximum collection of waste at right time. It provides an opportunity to increase waste density that reduce the number of truck journey. In areas where compacting vehicles are not available, waste transfer stations may be used to compact the waste so greater quantities can be carried at once to the final disposal sites. Conclusively, the inclusion of waste Transfer station enhances the efficiency of the collection system. Transfer station can serve as a controlled place for sorting and processing the waste. Particularly in many low-income countries where a thriving informal economy exits in recycling of waste, these waste transfer stations can minimize health hazards and may limit the amount of waste picking that is done in the streets, which will reduce the amount of waste that is scattered around communal calefaction material and waste accumulation point. The findings of the study will be important input for other researchers who would like to conduct detailed and comprehensive studies either in our country

The rest of the paper is organized as follows. Section 2 is Literature review. Section 3 is Methodology of the study, section 4 is result and discussion based on the proposed methodology and finally, section 5 is the Conclusion of the study.

CHAPTER TWO

2. Literature Review

2.1 Introduction

The management of solid waste is a multidisciplinary and technologically complicated process. Technologies related to the management of solid waste generation, handling, storage, collection, transfer, transportation, processing, and disposal are among them.(Varma & Kalamdhad, 2018). All of these procedures must be followed in accordance with current laws and societal norms that safeguard the environment, public health, and what is both aesthetically and financially feasible. Administrative, financial, legal, architectural, planning, and engineering tasks are among the disciplines that must be taken into account in order for the disposal process to be sensitive to public opinion. For an integrated solid waste management plan to be effective, all of these disciplines must positively engage in interdisciplinary communication and interaction.

Building sustainable and habitable communities requires effective waste management, although many developing nations and cities still struggle with this. Costly waste management is necessary. To run this vital city service, integrated systems that are effective, long-lasting, and socially beneficial are needed. The various nations across the world have been administered differently. There were significant differences in both the quantity and value of solid waste between and within geographical regions. These variations stem from variations in the nation's economic standing, way of life, rate of literacy, and age distribution. (Kolekar et al., 2017). Kawai & Tasaki (2016) reported that developed countries accounted for 40% of global waste generation compared to 37% for developing countries and 23% for undeveloped countries. Quantification and characterization of urban solid waste generation are necessary to make decisions for adequate solid waste management strategy. The composition of MSW varies widely within countries. This variety is due to the countries geographical location, industrial activities, food habits, lifestyle and living standards of the people, energy sources, and weather(Das et al., 2019). Waste from poor nations has more organic materials than waste from industrialized nations, which produces a variety of wastes with higher proportions of paper and plastics. There is a moderate variation in the percentage of organic component in garbage amongst wealthy nations like the US (24%), EU (34%), and Japan (40%). The majority of this organic weight was made up of paper trash, agricultural residue, and food waste. The amount of organic garbage in Indonesia, a developing nation, accounted for 60–70% of all waste produced there. The waste processing technologies, and waste management infrastructures could be considered depending on the amount of waste composition (Razil et al., 2017).

Solid waste transfer stations have been the subject of numerous studies. The majority of the literature on transfer station siting uses mathematical optimization techniques such as fuzzy programing, game theory, dynamic programming, integer programing, goal programming, and linier programming, which are operational research techniques. Vitorino de Souza Melaré et al., (2017) and system dynamic model of the solid waste management. there are also different types of municipal solid waste treatment techniques, but the most popular are: composting, recycling, open dumping, open burning, landfill, incineration, and anaerobic digitations (Nanda & Berruti, 2021) to do this primarily awareness of solid waste management principle or terms in sequence such as generation, collection separation or sorting ,transportation and treatment of the collected waste are required (McAllister, 2015). Because of solid waste management needs large amount of money, manpower, and proper technical knowledge.

2.2 Solid Waste Generation

The amount of waste produced is rising at an incredibly quick rate. Both highly populated and developing countries may attest to this. For example, garbage generation in India is approaching critical levels, particularly in metropolitan areas. The main cause of citizens' improper rubbish disposal is a lack of environmental knowledge among the general public. (Kumar et al., 2011). A significant portion of the waste generated is still not properly handled, despite attempts by the government and institutions to manage wastes generated in developing and marginalized nations, such as African cities. For instance, collecting unsegregated rubbish and disposing of it in designated regions inside each city is the most widely used waste management technique in Nigeria. By weight, the organic fraction accounted for the largest portion of the waste stream, followed by inert elements. This has led to rubbish being dumped carelessly, piled high in skips, bins, and dumpers, and littered throughout major cities and the nation as a whole. Ethiopia is predicted to generate between 0.6 and 1.8 million tons of rubbish annually in rural areas and between 2.2 and 7 million tons of waste annually in urban areas Press, (2005).The Solid waste generation rate and characterization study for 10 towns in Ethiopian such as SNNPR, Amhara, Oromia, and Tigray revealed that the overall household generation rate was 0.32 kg/capita/day (Tassie et al., 2019). 67.4% of the waste produced overall in Ethiopia's cities is organic, biodegradable waste. Because of the massive amounts of solid waste that industrial facilities and unplanned human settlements release into the environment. The main undeveloped nations that contribute significantly to the creation of solid trash are Nigeria, Bangladesh, Sudan, and Ethiopia countries(Das et al., 2019).

Table 1 : Quantity and proportion of solid waste of Ethiopian cities

City	Organic waste	Paper/ cardboard	Plastics	Glass	Metal	Others
Addis Ababa	64.8	5.3	5.2	2.1	1.2	21.4
Bahir dar	86.6	3.3	2.2	0.6	0.3	7
Adama	58	12	20	1	1	8
Hosaina	51.4	3.3	2.6	0.4	0.3	42
Lagatafo	76	4.75	9.5	1.69	0.37	7.69
Average	67.4	5.7	7.9	1.15	0.63	17.2

Source (Teshome, 2020)(Municipal solid waste management in Ethiopia; the gaps and ways for improvement)

The majority of the solid waste generated in the northern Ethiopian region of Dilla is organic trash, which is followed by inert, miscellaneous, plastics, papers, textiles, leather, and rubber, and metals that, by weight, are equivalent to or less than glass. (Fereja & Chemeda, 2022) Under such circumstances, the most meaningful way for waste reduction must be to educate the citizens to produce less wastes and also to install in-house recycling equipment to reduce the total waste load (Loan et al., 2019). In developed countries, the circumstances is not necessarily better. High living standards and per capita income are associated with high rates of refusing, resulting in huge heaps of waste

2.3 Solid Waste Collection

The costs and emissions associated with managing solid waste are largely attributed to waste collection, a crucial part of solid waste management systems. Waste collection has been reported to account for more than 40% of the overall cost of municipal solid waste management, despite the fact that gathering costs vary depending on population, population density, location, labor expenses, and many other factors (Chalkias, 2015)cited by (Jaunich et al., 2016) examined that Description of the processes involved in collecting municipal solid garbage. The cost, emissions, and fossil fuel needed to handle municipal solid waste are all impacted by solid waste collection. The study's three main objectives are to: (1) create an empirical data set to characterize MSW collection; (2) create a default input parameter set for use in mechanistic life-cycle collection models; and (3) use six different cities' data sets to demonstrate how model parameters can be used in a particular collection model. Additionally, there are two categories of residential family data: commercial collection data and single-family and multi-family residential collection data. The practice of solid waste collection in this study is a non-uniform task that is difficult to characterize simply because of the many interrelated factors that need to be taken into account. For example, the amount of automation in a collection vehicle affects how long it takes to collect waste at each stop, as does the driver's or collection workers' skill.

Ferronato et al (2021). Evaluate the collection of municipal solid trash in order to prevent unregulated disposal and increase the choices for recycling waste. In order to identify a way to encourage trash harmless disposal and recycling, the study evaluates how families gather waste in a developing city in Bolivia. It does this by using geographic information systems and the life cycle assessment approach. According to the study's findings, the system optimization suggests that: in the first scenario, collection distances increase by eight percent, while selective collection increases them by twenty-seven percent; in the second scenario, collection coverage increases from fifty-one percent to ninety-four percent, and selective collection switches from zero to six point seven percent; in the third scenario, approximately seventy-five percent of CO_2-eq emissions are reduced, and the eutrophication potential is again evaluated; fourth scenario recycling reduces the human toxicity potential of two hundred sixty percent and depletion of abiotic resources of thirty percent; and finally, the cost per ton of waste collected reduced.

Bertanza et al (2018) evaluated the municipal solid waste collection strategies' techno-economic performance indicators. The study's goal is to propose a set of easily calculable indicators that get around the restrictions and take into account both the operational and financial performance as well as the features of the waste that has been collected. The primary elements of the collecting system—labor, vehicles, and containers—were examined independently in this study to enable comparison and measurement of their respective contributions to the overall procedure. As an illustration of how the studies suggested methodology was put to effect, the MSW collection methodologies were contrasted. The case studies include four localities in Northern Italy where the same company provides the collecting service. The study's findings are provided, discussing and contrasting three different indicators descriptive, performance, and economic with alternate techniques for assessment that can be found in the scientific literature.

Chalkias & Lasaridi, (2009) designed a GIS-based strategy to optimize the collection of municipal solid garbage. In this work, a methodology for the optimization of mixed MSW collection was developed using GIS technology. This study's methodologies combine sophisticated spatial analysis GIS tools with a variety of geographical data, including the location of waste storage facilities, the road network, and operational land uses. This model's objective is to investigate waste-stored material reallocation as a means of improving the current layout and route optimization. The case study of a single garbage collecting industry served as the model used in this work. According to the study, the ideal situation is more effective in terms of collection time and travel distance. These savings are closely linked to reductions in fuel use and gas emissions. The study demonstrated the value of GIS technology as a waste collection optimization tool, capable of guiding decision making. The conflict between economic optimization and environmental protection has received wide attention in recent research programs for solid waste management system planning. (Erkisi-Arici et al., 2021) examines the potential benefits of come point collection over door-to-door collection systems as well as the impact of pertinent local issues. This study's main goal is to measure the environmental effects of the background system and establish the limits of a safe and environmentally beneficial chemical recycling process. The life cycle assessment is carried out in comparison to analyze both systems, and then sensitivity analysis is used to investigate the impact of regionally changing elements. The research examines several situations in which the procedures of collection, transportation, and sorting the model result is the reveal development of source separation.

Mora et al., (2014) provides a case study on how the waste collecting system might be improved. A multi-scenario analysis has been carried out to assess from an economic and environmental perspective, using alternative case study collection systems. The present study regards the economic and environmental implications as components of the assessment and verification of the optimal integrated waste system for the case study under consideration. The life cycle assessment technique has been used to support the environmental analysis, which quantifies the effects of the integrated waste management system on ecosystem quality, human health, and resource depletion. The most cost-effective outcome is produced by the setup with three zones and no synchronization.

The life cycle assessment analysis showed that in the case study, lower values of damage than those of bring collection such that the respiratory organic and inorganic, minerals and climate change, these results beneficial effect of the higher sorting waste quantity intercepted and the higher percentage of recycling.

Das & Bhattacharyya, (2015) an optimization solution for the problem of the best waste transportation and collection that arises during the design of an efficient waste management system. The research specifically examined the issue of waste collection in the Indian metropolis of Kolkata, where waste sources are dispersed in an uneven manner. This work also examined the problem of garbage transportation in order to build a waste management system that is both timely and economical. To overcome the problem, the paper divided the entire waste management system into three stages. Each stage has been optimized with the aid of travelling Salesman Problem. The proposed scheme computes optimal waste collection and transportation path at each stage. Computational results and real-life experiment have been shown the effectiveness of the proposed scheme. Results of this paper shows that the proposed scheme is able to reduce more than 30% of the total waste collection path length. This reduction of path length in waste collection and transportation determines consistent monetary saving in the waste management operations. (Saxena et al., 2021)proposed models to addresses the solid waste management problem. This model used a mixed integer linear programming model by applying a case study at Chennai in India to numerically solve the model. The study numerical illustration is presented to understand the functionality of the model. The proposed model relaxes few of the constraints which existed in the past work by using a set of binary variables controlling each trip individually. The main concept of the proposed model is that it allows only existing transfer stations to be potential transfer stations. The proposed model aims to minimize the total cost of solid waste management for 30 days. (Yadav & Karmakar, 2020)proposed collection and transportation municipal solid waste management system model. The model classified into three domains, vehicle routing; facility location; and flow allocation. These model computationally difficult and hence offers the need for scalable algorithms. The Provided modeling recommendations pave the way for a suitable, sustainable, and improved municipal solid waste collection and transportation structure in urban centers. These mathematical models attempted coupled with some cutting-edge technologies, such as artificial intelligence to make them more computationally robust and simpler for all stakeholders.

2.4 Solid Waste Source Separation

W. Zhang et al. (2012) present current perceptions of the Shanghai, China population toward the source separation of municipal solid garbage. The main objectives of this research were to identify a workable reduction strategy and assess public perception about MSW source separation. Additionally, employing survey data collection and interaction analysis, identify and clarify the disparity between resident awareness and behavior. According to this study, the four main factors causing poor municipal solid waste management separation contribution are mixed transit and disposal, inadequate source separation infrastructure, inadequate public education, and a lack of separation responsiveness. This result confirms that respondents' attitudes and actions in the pilot villages were noticeably superior to those in the non-pilot towns. The results of the research revealed that although the respondents only seldom separate, they are aware of the environmental effects of doing so. The main drawbacks of municipal solid waste source-separated collection are adverse neighbor effects, imprecise classification of the garbage, and combined transportation and disposal. Moh & Abd Manaf (2017) present Solid waste management transformation and future challenges of source separation and recycling practice in Malaysia. The main objective of this research is to transform outdated solid waste management plans and policies into ones that have led to significant systemic improvements and the strict application of the policy's requirement for source separation. In eight states of Peninsular Malaysia, a two-pronged policy of federalization and privatization would be formally adopted. According to the report, many households have difficulties since they do not have enough space at home to store recyclable products. Additionally Households must be willing to segregate waste for recycling and have the infrastructure necessary to support them in doing so. The article also takes socioeconomic realities into account and explores the possibilities of creating a recycling system that works for everyone. Additionally, source separation and recycling provide some difficulties, particularly with regard to administration, facilities, and services. Lack of public conscientious in today’s modern lifestyle has resulted to increasing amount of waste generated and disposed at landfills especially when it comes to packaging, as these materials are dispensable to them (Desa et al., 2011).

The public's attitude toward making source separation and recycling a habit is one of the biggest obstacles to source separation and recycling practices. There is a serious absence of a clean mentality, a sense of accountability for managing waste, and worry about the consequences of not sorting waste for recycling (Omran et al., 2009)and clearly depicted in the cases of illegal dumping and open dumping. It was suggested that proper instruction on the topic, especially in schools, has the potential to improve long-term behavior since it increases understanding and the ability to address related issues. This is because waste separation is a natural fit with current educational agendas, both practically and ethically. (Ward et al., 2014).

H. Zhang & Wen (2014) separated the sources of home solid waste. In this study, the home solid waste source separation pilot program that was already in place helped to improve residents' source separation behavior. More pilot programs should be implemented. Nonetheless, by teaching kids and teens to form good household solid waste source separation practices, the current initiatives for this purpose can be strengthened. This study proposes targeted advertisements and the use of some favorable policies during the start phase. The development of stringent guidelines for the follow-up infrastructures in order to align the household solid waste source separation, collection, transportation, and disposal chain with the peculiarities of various age groups. The household solid waste source separation system from the perspective of the residents in Suzhou, China, is the study's goal. The result of the study found that the accurate household solid waste source separation rate is only 23% through conducting a survey in the field on resident's household source separation activities. The main determinants of resident's household solid waste source separation behavior are residents 'age, household solid waste source separation facilities and government preferential policies.

Sukholthaman & Sharp (2016) simulated the system dynamic model. The six scenarios that represent the actual situation in Bangkok, Thailand, are displayed in the simulated model result. This research suggests tactics: Economic: incentive programs (free collection assistance, awarding prizes, generating extra revenue). Social: public benefit (cleaner environment, more livable society), environmental education (benefits of conducting source separation, extra revenue, homemade compost, decreased risks of disease or virus caused by waste), Environment: environmental education (importance of having effective MSWM system, possible impacts of waste) Legislative: waste separation and waste collection policy, waste collection fee payment, fine). (Yang et al., 2011) conducted a mathematical model of source separation activity. The goal is to create a mathematical model of source separation activity that links the parameters—awareness, transportation, facilities for separation, participation atmosphere, environmental profit, sense of honor, and economic profit with the source separation ratio. There were two presumptions in this study: Only internal motivations and external circumstances had an impact on the source separation activity, and group behavior rather than individual behavior was the focus of the mathematical source separation investigation. As a result, the actors' gender, age, education, and other personal characteristics were left out of this model. The data analysis findings came from a year-long study and survey administered at 128 municipal solid waste clusters in and around Beijing, China. It revealed that residential communities and elementary and middle schools lacked a stable separation ratio, while office buildings had a starting separation ratio of eighty present and a stable separation ratio of sixty present (Rousta et al., 2015). The subjective process of source separation of trash involves people gathering recyclables or compostable materials from a mixture, classifying them at the location of waste generation, and placing them in various containers for collection. The process of source separation benefits greatly from public engagement since it makes the collection, transportation, treatment, and disposal of waste materials easier. Sustainable public participation is essential for a successful municipal solid waste management ratio when it comes to source separation. (Dhokhikah et al., 2015)

2.5 Mathematical Model of Solid Waste Transfer Station Management.

The focus of recent study has been on examining various methods, frameworks, and mathematical models related to the siting of solid waste transfer stations. Waste collection, transfer stations, separation centers (transfer stations), and disposal with waste treatment facilities and technologies are typically included in these systems. The key components of a successful municipal solid waste management ratio in integrated solid waste management are the determination of the best way to allocate garbage to treatment centers, the best vehicle route to these centers, and the methods for treating and transporting waste that can be optimized using linear programming (Akbarpour Shirazi et al., 2016; Paul et al., 2019). Mathematical programming models are broadly used in the design of optimal SWM systems in the past(C. Dai et al., 2011). By using mathematical programing methodology, some study for example (Ayvaz-Cavdaroglu et al., 2019) is conducted the optimal cost-effectiveness, environmentally friendly and multi-objective optimization on the application of five solid waste technology, (namely; material recovery, compost, incineration, anaerobic digestion and land fill) on the best mixture of the six waste components (paper, organic material, plastic metal glass and others) with these five technologies. Additionally, a sensitivity analysis is performed and a multi-objective problem that combines two problems is presented.

Benítez et al. (2008) present mathematical model based on the three variables: In order to figure out the quantity of waste generated in a household and to establish reasonable rates and a payment system for residential solid waste, factors such as education, income per household, and the number of residential units are taken into consideration. Additionally, the relationship between the known and the future event was built in order to make the predictions with the regression model, discovering the relationship of the variables involved in RSW production. Other studies have proposed a model that mathematical modeling with geographical information system for municipal solid waste management system. For example, (Arribas et al., 2010) Integer programming and geographic tool approach are used in this study to improve Istanbul's current solid waste collection system while reducing collection times, operational costs, and transportation expenses. Additionally, the goal of this study is to provide an effective design for the urban solid waste collection system that includes tactical and operational decisions for the intricate solid waste collecting system with an emphasis on economy. Linear integer programming models have been utilized to address tactical problems like designing convoys of vehicles and defining districts for the collection of solid waste. Likewise, operational decisions associated with the truck routing problem have been solved using tabular search metaheuristic in a GIS situation to incorporate physical and operational characteristics of urban road networks and existing traffic conditions.

L. He et al.(2011) presents two mixed integer decision making models which bi-level method for integrated municipal solid waste management and green house generation emissions control. Two components comprise this model's decision process. The first illustrates a top-down decision-making process, where the lower-level target is provided by the waste management sectors at the local level decision maker and the upper-level objective is dominated by the environmental sectors at the national level. The second model suggests a decision-making process that is bottom-up and in which the municipality takes the lead. According to the studies model results, bottom-up decisions would result in a reduction of around 13% in emissions, whereas top-down decisions would result in a reduction of roughly 59% in metric tons of carbon emissions but an increase of 8% in overall management costs.

(Lee et al., 2016) developed a mathematical model. The objective of this mathematical model, which combines mixed integer programming with integer linear programming, is to aid in the decision-making process related to municipal solid waste management. The model determined the ideal quantity of waste management infrastructures or facilities and recommended making use of an incinerator's capacity. The model is designed for scenario analysis and uses mixed integer programming and integer linear programming, respectively linear program with a constraint that the variables can only be integers can be handled via the integer linear programming technique. Because the variables must have integer values, there are situations where the problem is challenging to solve. An issue where the variables can only be integers or non-integers can be solved using mixed integer programming. It performs case studies on Hong Kong's solid waste issue. China. Sensitivity analysis has been performed to ascertain how the objective function and, more crucially, the preferred building technology can be affected by varying specific parameters.

Abou Najm et al. (2002) proposed optimization model of regional planning to optimize the overall integrated solid waste management system. Regional planning affects the design, implementation, and efficiency of the overall ISWM system. In order to implement a successful strategy, decision-makers look for regional waste management planning that is optimized. This study's goal was to create a regional LP model that addresses the planning stage of the regional integrated solid waste management system, which is the first step that must be taken care of in order to optimize SWM overall. Furthermore, the model was used at the regional level to replicate and enhance MSW management in a particular area, and a sensitivity analysis was carried out to evaluate significant model parameters Most significantly, the preferred building technology.

C. Dai et al. (2011)developed for the planning of municipal solid waste management by coupling two models, the support-vector-regression model with an interval-parameter mixed integer linear programming. This is an attempt to improve the analytical accuracy in the MSW management system optimization. While the mixed integer linear programming approach can be used to plan waste flow allocation and facility capacity expansion schemes under uncertainty, the SVR technique is employed to estimate waste generation rate as the input of optimization models. Additionally, it carried out a sensitivity study to look into how various input elements affected the system's cost and landfill capacity usage. The study's findings are helpful in modifying the city's current waste allocation plans to increase trash diversion rates and in designing the waste management system's ability to meet the growing demands of the city for waste treatment and disposal. (Lu et al., 2009) Developed municipal solid waste management system using an inexact dynamic in association with greenhouse gas-emission control under uncertainty. It lands upon conventional mixed-integer linear programming approaches, and integrates components into the modeling framework. The developed model has supported by case study to validate the model and to achieve an optimal allocation scheme. It indicates that the most significant concern of climate-change impact in the study system component that CH_4-emission. The results of this study indicate that anticipated waste-flow patterns with a minimized system cost and GHG-emission amount can be gained. Add more importance, which is significant economic implication for real implementations of these model.

Syauqi & Purwanto, (2020) Observes MSW gasification using multi-integer nonlinear programing model. The goal of this project is to maximize municipal solid waste gasification for modern power plants. In order to produce syngas that would be fed into power generation systems, the study mimicked an MSW gasifier. The four power generation technologies solid oxide fuel cell, gas turbine, gas engine, and steam turbine have been chosen for the data processing. An ideal method for the lowest leveling cost of power and the lowest CO2 emissions has been devised through the use of mixed-integer non-linear programming multi-objective optimization.

Abbasi et al. (2022) Develop a model using mixed integer linear programming to optimize the municipal solid waste management system within a network of supply chains with multiple tiers. The basic idea was to simplify several detail-level elements while simplifying the decision-variables of several integrated waste supply chain network functions that were conservatively optimized separately due to integration complexity. In order to create the most workable and economical strategy, it is crucial to design and integrate waste management supply chain components into a synchronized system, which is the main emphasis of the suggested model. The model's goal was to reduce the MSW management system's cost as much as possible while maximizing sales revenue from recycled goods made at recycling facilities and electricity produced in waste-to-energy plants. The study's findings showed that, of the waste types included in the analysis plastic, metal, glass, paper, and non-recyclable recycling of plastic trash contributed significantly to the economy and was the most advantageous kind of waste management.

2.6 Solid Waste Transfer Station

Höke & Yalcinkaya (2021) examined the best location and financial effects of MSW transfer stations using a vehicle route problem-based scenario analysis approach, suitability analysis, which involved a series of studies to identify possible transfer station locations, and an economic assessment to determine whether adding a transfer station is a practical improvement and, if so, the most practical transfer station location in the southeast of Izmir, Turkey. The study area's establishment of a transfer station resulted in shorter collection times and fewer shifts, as well as lower fuel usage and less air pollution caused by solid waste collection. The system is more susceptible to changes in labor and fuel costs, according to the.

Chatzouridis & Komilis (2012) provide a framework for creating the best possible MSW regional collection system, with municipalities serving as the waste production nodes, waste transfer stations serving as the intermediate node, and landfills serving as the ultimate node. The matching optimal MSW collection coefficient is optimized by the model. When the waste transfer station allocation is modeled, even in cases where it is not included in the system. Two siting approaches were used to run the optimization model. In the first approach, as many candidate waste transfer stations as possible were located in close proximity to municipality centers, ranging in distance from roughly 1 km to up to 5 km from the center of the waste production nod; in the second approach, the closest candidate waste transfer stations were located at the intersections of the 16-km radius buffer zones that encircled each municipality center. Thus, they proposed that the first siting technique resulted in a somewhat cheaper collecting cost than the second site approach. So, it appears that it is preferable to site waste transfer station very close to the center of a waste production nod.

Jabbarzadeh & Jabalameli (2016) suggested a multi-objective optimization model for the structure of a waste management system with collection trucks, landfills, transfer sites, and clients. The multi-objective model was solved using an interactive fuzzy programming solution approach, and the suggested model is then applied to a case study involving the Iraqi city of Tehran. The location and distribution of transfer stations, together with the choice of waste processing technologies, can all be determined by the model. Collecting cost in relation to the second-best siting strategy. The obtained results revealed that the optimal solution requires adopting high technologies for transfer stations for large costs.

Monzambe et al.(2021) developed, a mathematical model for the optimal design of the MSW transportation system. A mixed-integer, non-linear model was the description given to the constructed model. By creating and solving a mathematical model, as well as figuring out the best site and capacity for waste management facilities (waste transfer station and land dump), the study aimed to reduce trash transportation time and costs. Additionally, to help local governments and waste management organizations save the time and expense associated with moving waste. One example study utilizing the created approach is a city in South Africa. The results of the study were a reduction in waste transportation cost from an estimated amount and decrease in waste transportation costs.

F. Dai & Chen, (2022) designs a MSW transfer station location model considering the dynamic characteristics of MSW generation within the case study of HUANGSHI in china. The main objective of this investigation is to create and solve a mathematical model that will allow researchers to determine the combined tactical and strategic choices for the MSW transfer station location problem. The three capacity levels of transfer stations—small, medium, and large—as well as the dynamic site selections of the MSW transfer station are taken into consideration. Since MSW is collected daily and each period represents a year, the transportation costs for each period should be equal to the sum of the daily transportation costs. Eighteen MSW transfer stations have been built as a result of this.

Yadav et al.(2016) Propos analytical approach consists of two basic elements: a mathematical model to optimize overall cost for municipal solid waste management; and geographical information system tools to create a data inventory for the mathematical model. The aim of this study is to suggest a method for determining the most advantageous locations from an economic standpoint and to demonstrate the viability of establishing trash transfer stations as a municipal solid waste management infrastructure unit. By selecting the optimal sites for transfer stations, the overall cost can be optimized through the use of mathematical models and geographical information system interconnection techniques. They take into consideration three different cases of metropolitan areas in terms of waste load and measuring method with two different scenarios at Nashik city in India. This study has produced an optimum collection system design including best locations, capacity and number of transfer station and details for the amount of MSW need to be transferred using primary collection vehicles and secondary collection vehicles as a result.

Yadav et al. (2020) Proposed Multi-attribute decision making approaches to found out very effective for ranking several potential locations. The objectives of this study is to explain a novel two-stage multi-attribute decision-making model for choosing suitable locations for municipal solid waste transfer stations in urban areas and to illustrate its application using the example of the Indian city of Nashik. Nashik is chosen to illustrate the study methodology through the construction of study scenarios there. The suggested model employs two fundamental evaluation phases: the first involves identifying the attributes and conducting an economic assessment of every possible combination; the second involves evaluating the shortlisted alternatives using the Technique for Order of Preference by Similarity to Ideal Solution, which helps choose the best locations for transfer stations. The current study advised stakeholders to select appropriate sites for MSW handling facilities while taking social, technical, environmental, and economic factors into account.

2.7 Fuzzy Analytical Hierarchy Process and Goal Programing

MCDM technique often suggested for solving the complex problems of the ground problems across in the world. Fuzzy logic and fuzzy set theory are models of human reasoning that incorporate comparison data and uncertainty in order to make conclusions (Dong et al., 2021). In this study the main source used to rank the criteria according to significance in relation to the spatial problem is the decision-makers' judgments. Certain linguistic characteristics serve as qualitative representations of these assessments. In order to quantify the decisions at this point using the appropriate membership function, a fuzzy set is needed. In this investigation, the verbal factors were translated into quantitative values using a triangular fuzzy set. The connection between language factors and quantitative values.

Many approaches to solving MCDM problems have been put out in recent years, including MCDM approaches to tackle MCDM problems that are challenging to comprehend as well as mathematical approaches (such as mathematical programming and artificial intelligence approaches) (Kilic & Yalcin, 2020). One of MCDM technique often suggested for solving these complex problems is AHP, because it is a simple and powerful approach (Önüt & Soner, 2008). Due to the complexity of the decision-making environment and ambiguity of each problem, some researchers (Kilic & Yalcin, 2020; Raut et al., 2011) have suggested utilizing AHP alone or AHP plus other approaches to solve MCDM challenges since these issues cannot be adequately resolved by focusing just on the cost factor. AHP has been extensively employed by researchers and professionals in the MCDM process. (Chaudhary et al., 2016; Luthra et al., 2016; Yagmur, 2016) over the last 20 years. Since AHP alone will not be able to handle existing environmental restrictions, some researchers have combined AHP with mathematical techniques, in order to deal with environmental restrictions simultaneously.

In the literature, the AHP is frequently used in conjunction with mathematical programming techniques such as goal programming (GP) and linear programming (LP). While the GP model was created to address multi-objective problems, the LP model is utilized to solve single-objective problems. Charges, Cooper, and Ferguson studied GP in 1955 in order to solve LPs that could not be solved. For example, some researchers (Badri, 2001; Quezada & López-Ospina, 2014; Raut et al., 2011) (Badri, 2001) Have developed combined AHP-mixed GP models for addressing multi-objective problems and coupled AHP-mixed LP models for addressing single-objective problems. While AHP is often used to address MCDM issues, traditional AHP is unable to capture the nature of human thought processes. The traditional AHP method is challenging because it uses an exact value to represent the decision maker's opinions in an alternative comparison. Additionally, the AHP method is frequently criticized for using an unbalanced judgment scale and failing to appropriately address the inherent imprecision and uncertainty in the pair-wise comparison process(Barbosa & Gomes, 2015). Later, the fuzzy analytic hierarchy process (FAHP), based on the fuzzy set theory of (Sajjad Ashfaq, 2018), was developed to address this weakness, and it is frequently employed in place of traditional AHP to tackle MCDM problems, particularly those that are challenging to interpret. As a result, rather than using classic AH to handle MCDM challenges, several academics have recently turned to FAHP (Gholipour et al., 2014; Torfi et al., 2010).

Although FAHP is widely used to solve MCDM problems, there are few papers that report combined FAHP mathematical techniques to solve MCDM under existing environmental restrictions. For example, (T. He et al., 2012) suggested using an FAHP-LP model to solve the multi-criteria transshipment problem in order to minimize logistics costs and maximize customer service level. (Kannan et al., 2013) Presented an integrated fuzzy multi criteria decision making method and GP approach for supplier selection and order allocation in a green supply chain. Also, (Bakeshlou et al., 2017) proposed evaluating a green supplier selection problem using a hybrid MODM algorithm, in order to effectively consider existing environmental restrictions.

2.8 Summary and Identification of Research Gap

In summary, based on the highlights of earlier research covered in earlier parts, it is not yet possible to prioritize the site of new facilities for solid waste transfer stations using an integrated FAHP and goal programming approach. The majority of earlier research has focused on the issue of building new solid waste facilities, with little attention paid to the integrity of FAHP and GP programing factors that may be involved in the selection of new facility locations. The possible causes of the criteria must then be prioritized using the MCDM technique, since their significance can aid managers, investors, practitioners, and researchers in offering viable solutions. Last but not least, as most decision-making scenarios involve uncertainty, MCDM approaches must be combined with fuzzy logic. As a result, an FAHP is used to rank various elements according to the environmental viewpoint. This appears to be the first study to use FAHP integration within goal programing.

To sum up, the utilization of the waste transfer stations within the waste management process, a good number of benefits will be provided in terms of environmental and resource protection, land use and energy efficiency, emission reduction and social health. In order to achieve these benefits, it is important that the transfer stations are located in appropriate areas (Azadeh, Ahmadzadeh, & Eslami, 2018). There are many studies about transfer station site selection process in the literature. Table 1 summarizes the selected related studies.

Table 2 Overview of waste transfer station site selection studies

Authors	Study area; Methodology
Manaf, Pei Pei, Zukki, & Abu (2008)	Malaysia: Rule- based expert system by using Kappa- PC diagnosis of site selection and problems of transfer station
Rafiee, Kohrasani, Mahiny, Darvishsefta, Danekar & Hasan(2011)	Iran; A multi-criteria evaluation (MCE) model
Fernandes, Captivo, &Clímaco (2014)	Portugal; GIS integrated with interactive decision support system (DSS) (SABILOC)
Yadav, Karmakar, Dikshi, & Vanjari (2016)	India; GIS, Mixed integer nonlinear programming
Kůdela, Šomplák, Nevrlý, Lipovský, Smejkalová & Dobrovský (2019	Czech Republic; Multi-objective two-stage mixed-integer stochastic programming
Samsung Lim, Mojtaba Maghrebi and Hossein Asefi (2015)	Australia: mixed integer programming model

CHAPTER THREE

3. Methodology

3.1 Introduction

In this study, the outer offers two stapes for the selection of new suitable locations for determination of the location of proper sits for transferring and processing facility of solid waste with an economical manner and to optimize the current system of solid waste management in Bahir Dar city was presented. Furthermore, presented mathematical model that helps assignment of solid waste transfer station for solid waste processing facilities. The aim of siting solid waste processing facilities and mathematical assignment model are based on increasing the profitability of the entire system of solid waste management. The evaluation method of the study was applying MCDM in FAHP approach and goal programing mathematical model. The selection of factors for the new candidate locations for solid waste transfer station from the given area is made using legislation, regulation and expert from published literatures. Experts give their view for relevant factors that impact location selection for transfer stations site and then each criteria weight have been calculated according to their opinion using FAHP. There are important factors or general factors that impact the selection of new suitable candidate locations of transfer stations. Four main factor are adopted for this study which are: infrastructure, environmental, geological and morphological. The detail information were presented in section 3.1.2. The next was present mathematical model for optimization of the entire system.

3.1.1 Research Design

The gap or problem must be identified as the first step of the study. Then, after appropriate literature has been investigated in order to support the gap in comparison to existing or previous study, the analysis of solid waste transfer station is subjected to the effects of several criteria factors that cause to effectiveness of solid waste transfer station location selection, as stated in the problem statement. This variation is due to the analysis of environmental, social and economic considerations (Ağaçsapan & Çabuk, 2020).

The author of this study focused on the evaluation system of solid waste transfer station location selection within the four criteria's. The fuzzy analytical hierarchical process and fuzzy analytical hierarchical process with goal programming were the two approaches used to choose new, suitable locations for solid waste transfer stations. First, the FAHP is introduced as a stand-alone methodology. Next, it is extended to account additional criteria in a new multi-objective facility location problem with the introduction of an integrated FAHP and GP model. A flexible methodology that can be applied to this case study and address complicated goals on both a qualitative and quantitative level should be used in the location selection process. Consequently, this article offers a number of objectives to be met, including cost and other pertinent objectives. The conceptual framework's specifics are displayed.

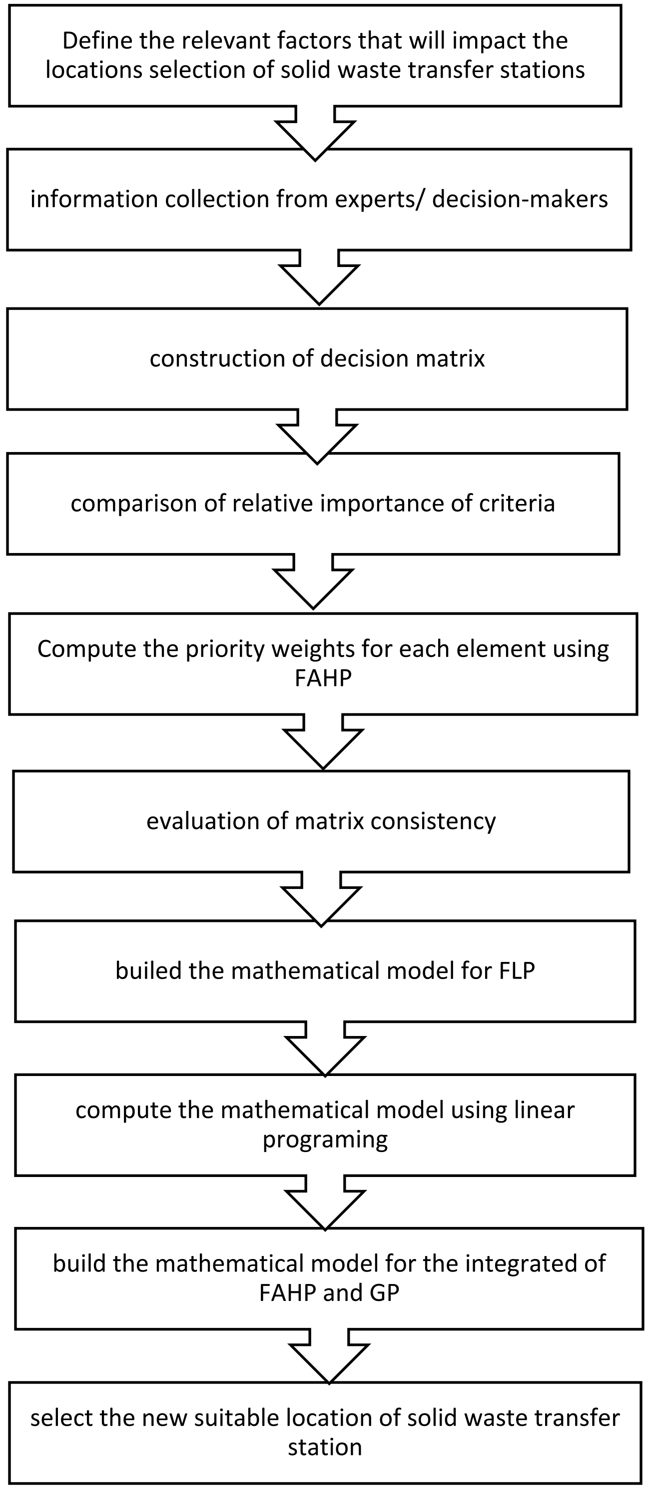

Figure 3 : The research design

3.1.2 Relevant factors for the selection of solid waste transfer station.

The first step is to define relevant factors in order to select candidate locations. The selection of the new suitable locations for waste transfer station from the candidate locations is made using legislation, regulation and expertise.

3.1.3 Morphological perspective

Slop and elevation: Land surface with steep slopes and high elevation is inappropriate for transfer station sites. (Ağaçsapan & Çabuk, 2020) stated that very steep slopes will entail higher excavation costs. Land slopes between 4° and 8° have been suggested as being appropriate for the construction of transfer station sites. Areas with a slope greater than 9° were considered to be unsuitable while areas having only a slight slope of less than 4° were considered as very highly suitable. And similarly, elevations above 120m were considered as unsuitable while elevations below 40m were considered as very highly suitable in this study (Ağaçsapan & Çabuk, 2020).

Soil type: permeable soil, such as sand and sandy loam, are therefore unsuitable while low permeability soils, such as, clay and clay loam are suitable, and relatively low to medium permeability soil such as sandy clay are fairly suitable for transfer stations (Bosompem et al., 2016).

3.1.4 Environmental perspective

Aquifer: a contained of sand, gravel and clay from old river deposits and have limited water absorption potential and these aquifer units were classified as semipermeable while Carboniferous metasedimentary, granitic, Triassic carbonate and floodplain deposits are impermeable because of the clay, rock and shale content and were considered as being highly suitable for the location of transfer station sites.

Groundwater: depth ranges from 0 to 1.5 m, 1.5 to 3m and 3 to 4.5m were determined as unsuitable, moderately suitable and highly suitable, respectively to build solid waste transfer stations (Höke & Yalcinkaya, 2021)

Surface water: buffer zone of fewer than 300m from surface water was considered unsuitable, between 300m to 600m and 600m to 900m were considered moderately suitable and highly suitable, respectively, and greater than 900m was considered to be very highly suitable for surface water (Ağaçsapan & Çabuk, 2020).

3.1.5 Geology

Geological fault Areas: less than 300m distant were considered as unsuitable; those between 300m and 400 and 400m and 500m distant were considered as moderately suitable and highly suitable, respectively, while areas greater than 500m distant were considered to be very highly suitable in this study (Bosompem et al., 2016).

Flood plain*:* Areas located in the 100-year floodplain are therefore inappropriate for transfer stations since the floodplains of major rivers may represent a risk to the stability of the waste transfer station. Hence, transfer stations should not be placed within 300m of a major rive(Yadav et al., 2020)r.

3.1.6 Accessibility

Road network: Many researchers have recommended a 1000m buffer zone for the location of a transfer station site from the road network (Ağaçsapan & Çabuk, 2020).

Waste production centers: The economic feasibility of a candidate transfer station site is a significant factor since the proximity of a transfer station site to waste production centers will reduce transportation costs (Ağaçsapan & Çabuk, 2020).

3.1.7 Land use

The aim of this criterion is to protect highly productive or underdeveloped areas and to ensure low capital costs. Thus, residential areas and mixed forests were considered inappropriate for siting transfer stations. And tourist areas were also regarded as unsuitable. Industrial areas play an important role in the development of a region and were classified as moderately suitable while agricultural and orchard lands were evaluated as highly suitable. Finally, in this study, the most highly suitable areas classified for transfer station sites were grassland and pasture (Ağaçsapan & Çabuk, 2020).

Other factors to be consider

Public places.

Residential areas: The proximity of a transfer stations site to a residential area entails various environmental issues such as human health, land prices and future. For this reason, in this study, a buffer zone of 1000m was adopted around residential areas to avoid public opposition. A buffer zone of less than 1000m and greater than 2000m were evaluated as unsuitable and very highly suitable, respectively (Cobos-Mora et al., 2023)

Historical place

A buffer zone of less than 1000m was evaluated as unsuitable and one greater than 2500m was evaluated as very highly suitable in this study

3. 2 Data collection

3.2.1 Primary data source

Observation

Observation is data collection method used to obtain actual and direct observable data. In this study the existing solid waste disposal site one of the observation site to obtained the required data. While solid waste collection point, open transfer station and waste generation pion are including in the observation of solid waste management system in the city.

The four direction of the city was observe to gather the information of the four criteria's for the selection of suitable location, such as land type, the accessibility of road network and other infrastructure, land owners, nearest to water body, nearest to waste production center, and also public place, historical place, Soil type and other condition of the areas.

Direct measurement

The collected amount of solid waste that collected by 14 MSE and private solid waste collector company have been direct measured interims of volume and weight to determine the daily, weekly and yearly production of solid waste in the six district of the city and also the percentage of waste type.

Expert judgment

Another simple approach for gathering data that is derived from the opinions of experts is judgment. The specialists convert the qualitative data from the specified environment into quantitative data based on their assessment (point of view). Saaty, (1990) point scale was used to convert the qualitative input into quantitative data representing the expert's viewpoint. Additionally, information on expert viewpoints was gathered from workers at solid waste processing facilities as well as from disposal sites in order to determine the best location for solid waste transfer stations. Each criterion was assigned a Weight based on the opinions of experts and stakeholders' familiar with the local situation, including consideration of the local MSWM scenario and the relative lack of organized scientific methods and technical skills available in the four districts studied. Previous studies have variously employed the judgment of two, three and four experts for example (Fernandes, Captivo, &Clímaco 2014). However, in this study, a total of five experts variously drawn from the local administration office and the provincial environmental agency as well as experts in the fields of civil and water engineering, solid waste management office worker, were consulted, along with representatives of the operators of the open dump in Sebatamit and stakeholders in the study area. The experts' importance of the various criteria to them For example, for environmental scientists, environmental issues would be assigned first priority, whereas stakeholders might prioritize issues such as waste disposal expenses and aesthetic places in the study area and civil engineers and soil science experts would emphasize the topographic conditions of the area since neglecting morphological criteria could ultimately lead to the failure of any transfer station site selection project.

3.2.2 Secondary data source

The secondary data of this study ware: Governmental office, Non-governmental institutes and Articles.

In this study the source of secondary data: published paper (Standards and formulas had been obtained from books and articles); governmental office (municipality sanitation and beauty office, environmental protection and sanitation office, water resource office, land admiration office, written documents,); and non-governmental institutes are the main source of data collection. To this end, up-to-date data was collected from various online portals and government institutions and, the most recent data for waste production centers was provided by the Regional Environmental Office in Bahir dar city where the groundwater table and aquifer data being obtained from the department of groundwater resources and the data relating to surface water, the road network, soil texture, residential areas and land use were acquired from the city and rural land development department. A topographic map defining slope and elevation contour lines was obtained from the municipality survey department while For floodplain data, the Bahir dar Flood Monitoring System online portal was accessed and the locations of historical places and geological fault area data was obtained from Geo-Informatics and environmental protection office and the Department of Mineral and Resources agency of Bahir dar city, respectively.

3.2.3 Tools and technique of data collection and analysis

The process of gathering and analyzing accurate data from various sources to find answers to research problems was completed through data collection and analysis. The following points are Tools and technique of data collection and analysis of the study

3.2.3.1 Tools:

Lingo mathematical model and analysis software

LINGO is a comprehensive tool designed to make building and solving mathematical optimization models easier and more efficient. LINGO provides a completely integrated package that includes a powerful language for expressing optimization models, a full-featured environment for building and editing problems, and a set of fast built-in solvers capable of efficiently solving most classes of optimization models.

Online portals

An online or web portal is a webpage that gives users an entryway to information, tools, and links. In other words, it's a platform that provides users with a single access point to data. Also, imagine a centralized digital hub that engages with focus community members to get relevant information.

3.2.3.2 Techniques

Triangular fuzzy number analysis techniques.

Finding the best opinion among all the viable options when faced with several, frequently opposing, decision criteria is known as multi-criteria decision management (MCDM). The main categories of the existing methods might be categorized as priority-based, outranking, distance-based, and mixed methods. (Torfi et al., 2010).

Fuzzy numbers are defined under situations of uncertainty and used in actual scientific and engineering challenges. There was no mathematical term for ambiguity in the past. The principles of identity, logic, non-contradiction, and excluded middle were presented and are applicable in a variety of contexts.. This logic is the origin of Fuzzy(Dong et al., 2021). The number theoretical foundations of fuzzy numbers and triangular fuzzy numbers are established in this study. A regular, real number is a generalization of a fuzzy number. It alludes to a linked collection of potential values, each of which has a weight between 0 and 1(Dong et al., 2021). That is to say, a convex, normalized fuzzy set of the real numbers is a specific instance of a fuzzy number Line.

Mathematical modeling (Linear programing)

A method for assessing different inequalities in a situation and determining the optimal value that can be attained within the limitations provided is known as linear programming. A mathematical technique for optimizing operations under constraints is known as linear programming. The main objective of linear programming is to maximize or decrease a numerical value. It is made up of linear functions that are constrained by inequalities or equations of linear functions. Linear programming is a widely used method for determining the most efficient use of resources. Additionally, it contains linear functions that are constrained by either linear equations or linear inequalities. Linear programming (LP) or linear optimization is the problem of maximizing or minimizing a linear function under linear constraints. One can impose constraints by using equality or inequality. Calculating profits and losses is one of the optimization issues. One kind of optimization problem is linear programming, which helps identify the feasible region and optimize the solution to obtain the highest or lowest function value.

3.2.3.3 Analysis method

MCDM (FAHP)

The fuzzy theory is supportive in most of the MCDM applications as it has the capability of representing vague measures within mathematical operators to make decisions in the fuzzy domain. The fuzzy theory itself has been combined with the AHP (FAHP) to evolve its outcomes in several studies like(Moslem et al., 2019)

The analytic hierarchy process (AHP) has been one of the most popular multi-criteria decision-making (MCDM) methods in dealing with various industrial and business problems since the 1980s. With continuous development and modification, the AHP has been extended to consider different situations, e.g., fuzzy/interval, gray(Chen & Huang, 2022) environments. Among these methods, the fuzzy analytic hierarchy process (FAHP) is undoubtedly the most popular way to extend the AHP to consider the subjective uncertainty problem

Equations (1–5) in this paper illustrate how Triangular Fuzzy Numbers (TFNs) are utilized to estimate priority weights using fuzzy arithmetic operations. Let $K` = \{k`_{ij}\}$ be the TFN

Judgment matrix containing all pair-wise comparisons between each criterion *i* and each

Alternative j. K` can be defined by equation (1).

$$K` = \begin{bmatrix} K`_{11} & k`_{12} & \dots & k`_{1n} \\ K`_{21} & k`_{22} & \dots & k`_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ K`n1 & k`n2 & \dots & k`_{nn} \end{bmatrix} \quad i = \in \{1,2,3,\dots,n\} \quad j = \in \{1,2,3,\dots,n\} \qquad (1)$$

Where $k`=(l_{ij}, m_{ij}, u_{ij})$ is TFN and l_{ij}, m_{ij}, and u_{ij} are the least possible value, modal value and highest possible value respectively. The fuzzy arithmetic operations on TFN can be expressed as follows (Khorramrouz et al., 2019).

Addition $F1 + F_2 = (l_1+l_2), (m1+m_2), (u_1 + u_2)$ (2)

Multiplication, $F1 * F_2 = (l_1*l_2), (m1*m_2), (u_1 * u_2)$ (3)

Division, $F1 / F_2 = (l_1/u_2), (m1/m_2), (u_1 /l_2)$ (4)

Reciprocal, $F^{-1}{}_1 = (1/u_1), (1/m_1), (u_1\ 1/ l_1)$ (5)

Table 3 : Scale of relative importance of FAHP

(1, 1, 1)	Equal importance
(2, 3, 4)	Moderate importance
(4, 5, 6)	Strong importance
(6, 7, 8)	Very strong importance
(8, 9, 9)	Extreme importance

2, 4, 6,8	Intermediate values between the two adjacent judgments

Like the classical AHP, in this paper, the steps of the FAHP are as follows:

Step 1 construct the hierarchy level: To define relevant factors, the n decision factors can be defined by asking questions of experts or decision makers about each criteria factors, that which criterion is more important with regard to the goal. The problem will be decomposed into a multi-level hierarchy levels. In Figure 4, the hierarchical structure is based upon AHP Methodology. At level “1”, the goal is to select new suitable transfer station locations. At level “2”, the main criteria are M1, M2,...,Mn, and at level “3”, the alternatives are location 1 (Alternative 1), location 2 (Alternative 2) and location n (Alternative n) with respect to the main criteria.

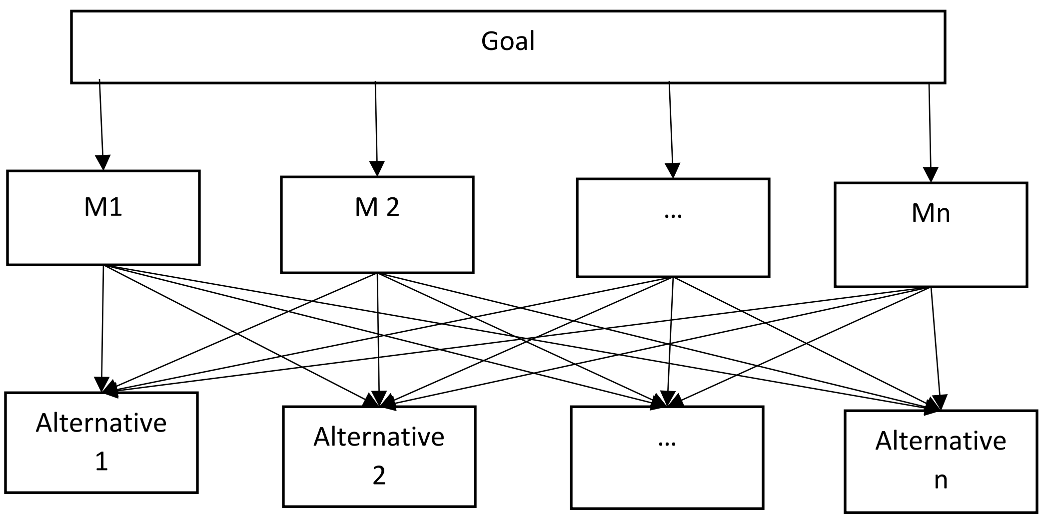

Figure 4: Multi-level hierarchy for location selection

Step2 Construct the comparison matrices of each decision makers: the experts view or the answers for each decision maker *a* can be constructed using pair-wise comparison matrices as follows:

$$K`a= \begin{bmatrix} K`_{11a} & k`_{12a} & \dots & k`_{1na} \\ K`_{21a} & k`_{22a} & \dots & k`_{2na} \\ \vdots & \vdots & \vdots & \vdots \\ K`_{n1a} & k`_{n2a} & \cdots & k`_{nna} \end{bmatrix} \qquad a = 1, 2, 3 \dots A \qquad (6)$$

Where $K`$ is fuzzy pair-wise comparison matrices for each decision maker a, and A is the number of decision makers

Step3 Combine the comparison matrices of each decision maker: The pair-wise comparison matrices in which given by the experts judgment can be aggregated with the fuzzy geometric mean method and can be defined by equation (7)

$$Q` = (\Pi_{i=1}^{a} k`)^{1/a} = \begin{bmatrix} q`_{11} & q`_{12} & \cdots & q`_{1n} \\ q`_{21} & q`_{22} & \cdots & q`_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ q`n1 & q`n2 & \cdots & q`_{nn} \end{bmatrix} \quad (7)$$

Where Q` is aggregated comparison matrix for each experts view point view combined to a single point of experts view.

Step4 calculate the priority weight of each hierarchical level: after aggregation of the pair wise comparison matrix, the aggregated matrix will be normalized within the following equation x

$$Q`` = \begin{bmatrix} \frac{q`11}{\sum_i^n q`i1} & \frac{q`12}{\sum_i^n q`i2} & \cdots & \frac{q`1n}{\sum_i^n q`in} \\ \frac{q`21}{\sum_i^n q`i1} & \frac{q`22}{\sum_i^n q`i2} & \cdots & \frac{q`23}{\sum_i^n q`i3} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{q`n1}{\sum_i^n q`i1} & \frac{q`n2}{\sum_i^n q`i2} & \cdots & \frac{q`nn}{\sum_i^n q`in} \end{bmatrix} \quad (8)$$

After that, the priority weights of each level can be defined by calculating the mean of each row *i* of the normalized matrix, as shown in equation (9). The fuzzy priority weights are TFN, which can be converted to crisp priority weights using equation (10) (Tsaura et al., 2002)

$$W = \begin{bmatrix} w1 \\ w2 \\ \vdots \\ wn \end{bmatrix} = \begin{bmatrix} \left[\frac{q`11}{\sum_i^n q`i1} + \frac{q`12}{\sum_i^n q`i2} + \cdots + \frac{q`1n}{\sum_i^n q`in}\right]/n \\ \left[\frac{q`21}{\sum_i^n q`i1} + \frac{q`22}{\sum_i^n q`i2} + \cdots + \frac{q`23}{\sum_i^n q`i3}\right]/n \\ \vdots \quad \vdots \quad \vdots \quad \vdots \\ \end{bmatrix} \quad (9)$$

$$\left[\frac{q`n1}{\sum_i^n q`i1} + \frac{q`n2}{\sum_i^n q`i2} + \cdots + \frac{q`nn}{\sum_i^n q`in}\right]/\mathrm{n}$$

Step 5 check for the consistency ration: the consistency ration is a method that can check the calculated value is wither correct or not. For this it should be taken the same way to pair wise comparison which not normalize. It may occur due to the involvement of expert judgment. To check the level of inconsistencies, a measure known as the consistency ratio (CR) was introduced by (Saaty, 2002).

$$CR = \frac{CI}{RI} \qquad (10)$$

Where CI is the consistency index and RI the random index or mean consistency index, which depends on the matrix size

$$CI = \frac{\lambda max - n}{n - 1} \qquad (11)$$

Where λmax is the average weight value and n is the matrix size (n × n) in a pairwise comparison. The RI values utilized for different matrix sizes are given in Table x (Schwartzman et al., 2010).

Generally, the CR should be maintained at less than 0.10 in order to maintain the consistency of the matrix (Şener et al., 2010) and, a CR greater than 0.10 indicates inconsistency in the expert's judgments which require re-evaluation.

To calculate the λmax the following equation was applied

$$w = \begin{bmatrix} w1 \\ w2 \\ \vdots \\ wn \end{bmatrix} = \begin{bmatrix} (w1 *\ q`11 & w2 * q`12 & \ldots & w * q`1n)/w1 \\ (w1 * q`21 & w2 * q`22 & \ldots & w * q`2n)/w1 \\ \vdots\vdots & \vdots & & \vdots \\ (w1 * q`n1 & w2 * q`n2 & \cdots & w * q`nn)/w1 \end{bmatrix} \qquad (12)$$

$$Wi = de - fuzzfication \begin{bmatrix} w1 \\ w2 \\ \vdots \\ wn \end{bmatrix} = \begin{bmatrix} w1 \\ w2 \\ \vdots \\ wn \end{bmatrix} \qquad (13)$$

$\lambda max = Wi - Wj$,

$wher\ Wi\ is\ weigth\ of\ not\ normiliz\ and\ Wj\ is\ weith\ of\ normalazed$ (14)

Table 4: List of random index value

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.23	1.32	1.41	1.45

Finally compute the final priority weights for each alternative locations

By summarizing the weights assigned to each candidates and multiplying the result by the weights of the relevant criteria, the final priority weights are determined. For every potential location, a final score is determined. The greatest value of the final priority weight is the ideal option, and a high priority weight is preferable to a low priority weight.

Mathematical modeling

Facility Location Problems involve determining the location of one or more new facilities in one or more of several potential sites. The number of sites location that facilities being located must serve the given assigned number of kebele in the city. The first theoretical study on the facility location problem began in 1909 when Alfred Weber introduced a warehouse location problem to minimize the total distance between a warehouse and a set of customers (Ahmadi-Javid et al., 2017) and classified discrete facility location problems into three categories: covering-based problems, median-based problems, and other problems. Covering-based problems are divided into three basic types: set covering problems, maximal covering problems, and p-center problems; (Griffin, 2009). See the details in the two above literatures. This study aims to achieve lowest total cost, which is similar to set covering problems. Therefore, based on set covering problems, a location selection model was formulated to solve the location selection for infectious waste disposal in this case, with details are as follows.

The facility location problem model is formulated to solve the optimization problem of waste transfer station site with multiple locations. The candidate location are assumed to have enough space, budget and staffing, and the site of the transfer station can be made anywhere within the candidate municipalities. Details of the mathematical model of this problem are shown below.

Sets

The sets, parameters and decision variables of model problem are presented below

Sets:

N = (V, A) is a transportation network of nodes V and arcs A

G = {1… g} is a set of waste generation nodes, G ∈V

K = {1… k} is a set of potential transfer station nodes, K ∈V

T= {1… T} is the facility types at transfer station locations

Parameters

Cij (Uij*Dij) is a transportation cost of solid waste on link (i,j) ∈A, i ∈G, j∈K (birr/day).

Fc is a facility cost of opening a transfer station at node i ∈K (birr/day).

N_c the number of customers of transfer station (facilities) *i*.

Oc is operating cost birr/day.

Dsij is actual distance between generation i and zone (transfer station) j (km).

ut is unit transportation cost (birr/km).

dj is the demand of district j (m3/day).

Decision variables

Xij is a binary decision variable; Xij =1 if the kebele i is served by transfer station j; Xij=0 otherwise

Yj is a non-negative integer decision variable; Yj =1 if zone j is opened, Yj= 0 otherwise

Objective

$$\text{minmiz Z} = \sum_j \sum_i ut * \text{Di, j} * xij + \sum_j \sum_i \text{Oc} * \text{Yi} + \sum_j \sum_i Fc * \text{Yi} \qquad (15)$$

Constraints

$$\sum_i Xij = 1 \qquad \forall J(i = 1,2 \dots n) \qquad (16)$$

$$\sum_{j} Xi,j \leq \sum_{j} \sum_{i} NcYi, \quad \forall\ (j = 1,2 \dots m) \quad (17)$$

$$\sum_{i} \sum_{j} Xij * yi,t \geq Yi \quad (18)$$

$$\sum_{j} Yj \leq N \qquad \forall\ (j = 1,2 \dots m) \quad (19)$$

$$Xij, \in \{0, 1\} \quad (20)$$

$$Yi \in \{0, 1\} \quad (21)$$

$$Nc \in \{0,1\} \quad (22)$$

The objective function (15) minimizes the total costs: the setup costs of opened sites, the setup costs of assigning facilities to opened sites, the costs of serving customers by the facilities in opened sites. Constraints (16) ensure that the demand of each customer is satisfied; constraints (17) express that the Service provided by a site cannot exceed its capacity; constraints (18) ensures that the sum of the services provided by a site cannot exceed its capacities, and the number of facilities in an opened site cannot be larger than allowed; constraint (19) establishes that the total number of opened sites is at most *n*. constraints (20), (21), and (22) binary. The optimal solution of this model can be solved by LINGO18

The Integrated model of (FAHP and GP)

A new multi-objective facility location problem model which combines the fuzzy analytic hierarchy process and goal programming, namely coupling FAHP and GP model, is proposed to select new, suitable locations for solid waste transfer station. This proposed model is required to achieve the two main goals, lowest total cost and maximum weight, under the limits of available resources, at the same time. Traditional linear programming is used to solve only one single objective, minimization goal or maximization goal. In order to solve a multi-objective optimization problem, GP was developed in the early 1960s for such complex problems with multiple objectives. Moreover, GP can solve problems with non-homogeneous units of measure(Liu et al., 2021). The FAHP provides the priority weights for each element *i*. The maximum final weight of FAHP is the best alternative for the relevant factors, but the minimum cost of candidate location is the best solution for the total cost factor. Therefore, in order to achieve the above goals simultaneously, the FAHP couple GP model can be formulated to solve the problem. The objective can be written as Equation (23), and Equations (16-22, 24) and Equation (25) are the constraints of this model.

Addition variables:

d_i^-, d_i^+ are vectors of under achievement and over achievement of target for each objective.

Additional parameters:

W_i is the final priority weights of alternative location i.

TC is the target for total cost (defined by total cost of the FLP model).

W_{tc} is the objective's weight of total cost according to experts' opinions.

W_{FAHP} is the objective's weight of FAHP according to experts' opinions.

Objective functions of the FAHP couple GP model:

Minimis Z= $W_{tc}, d_i^+ + W_{FAHP}\, d_i^-$ (23)

$$\left(\sum_R \sum_i ut * \mathrm{Di,j} * xij\right)/\mathrm{TC} + \left(\sum_i \sum_i \mathrm{Oc} * \mathrm{Yi}\right)/\mathrm{TC} + \left(\sum_i \sum_i Fc * \mathrm{Yi}\right)/TC + d^-_1 - d^+_1 = 1 \quad (24)$$

$$\sum_j WiYi + d2^- - d2^+ = 1 \quad (25)$$

The objective is the minimization of unwanted deviations, d^-_i - d^+_i: these deviations are deviation variables of under achievement and over achievement of targets for each objective. In these data, each objective has different units; therefore this paper has to normalize all units to 1. Like the multi-scale facility model, the optimal solution of the FAHP couple GP model can be solved by LINGO18.

CHAPTER FOUR

4. Result and Discussion

The methodology proposed in section 3 was used to identify suitable locations of solid waste transfer stations in Bahir Dar. Decision makers evaluated four candidate districts sites, namely Tana district (L1), Atse tewedros district (L2), Belay Zelek district (L3), and Dagmawi minlik (L4), whereas Gishabay and Facilo are not a candidate districts due to several limitations such as the density of population between the candidate area and communities, and the population density. New, suitable locations were selected from four candidate districts to serve twenty six kebeles, given the resource restrictions and preferences. The steps of calculation are shown in sections 4.1, 4.2 and 4.3.

4.1 Calculate the final priority weights of each candidate alternative locations using FAHP

The techniques to be used for figuring out each element's priority weight at each level are shown in this section. First, after engaging with stakeholders and five decision makers with over 10 years of experience in the sector, a three-level hierarchical structure was established. (See Figure 4). In the hierarchy, level 1 was the objective, the new suitable location for solid waste transfer station, and level 2 was the relevant criteria. There were four criteria: infrastructure (C1), geological (C2), environmental & social (C3) Morphological (C4). Secondly, fuzzy pair-wise comparison matrices were constructed from the five decision makers, using the 9 - point scale of FAHP, as shown in Table 2. Third, the fuzzy pair wise comparison matrices of the decision makers were aggregated into a FAHP combined matrix (Q`) using equation (7), and the priority weights of level 1 were calculated using equations (8-10), shown in Table 5. Finally, the local priority weights of level 2 and the final priority weights of level 3 were computed, as shown in Table 10-13 and Table 14 Respectively.

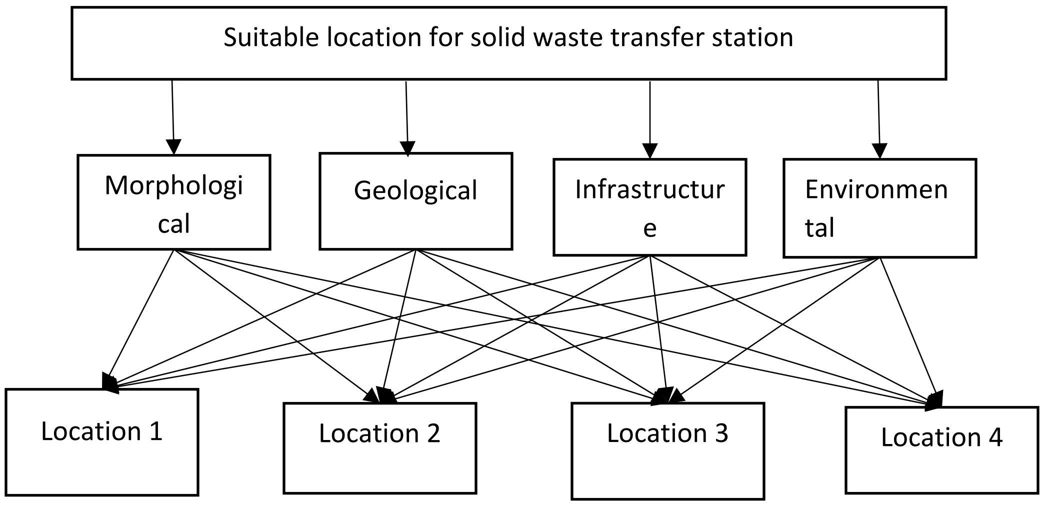

Figure 5: A hierarchy for selecting locations for solid waste transfer station.

Table 5: Comparison matrix of criteria with respect to goal from five decision makers

Goal objective	C1	C2	C3	C4
C1	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00)	(0.25, 0.33, 0.50), (0.17, 0.20, 0.25), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00), (2.00, 3.00, 4.00),	(0.11, 0.11, 0.13), (0.11, 0.11, 0.13), (1.00, 1.00, 1.00) (0.13, 0.14, 0.17), (0.13, 0.14, 0.17)	(2.00, 3.00, 4.00), (.17, 0.20, 0.25), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00), (0.25, 0.33, 0.50),
C2	(2.00, 3.00, 4.00), (4.00, 5.00, 6.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00), (0.25, 0.33, 0.50),	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(0.13, 0.14, 0.17), (0.13, 0.14, 0.17), (1.00, 1.00, 1.00) (0.13, 0.14, 0.17), (0.13, 0.14, 0.17)	(5.00, 6.00, 7.00), (5.00, 6.00, 7.00), (1.00, 1.00, 1.00) (6.00, 7.00, 8.00), (6.00, 7.00, 8.00)
C3	(8.00, 9.00, 9.00), (8.00, 9.00,9.00), (1.00, 1.00, 1.00) (6.00, 7.00, 8.00), (6.00, 7.00, 8.00)	(6.00, 7.00, 8.00), (6.00, 7.00, 8.00), (1.00, 1.00, 1.00) (6.00, 7.00, 8.00), (6.00, 7.00, 8.00)	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(0.13, 0.14, 0.17), (0.11, 0.13, 0.14), (1.00, 1.00, 1.00) (0.13, 0.14, 0.17), (0.13, 0.14, 0.17)
C4	(0.25, 0.33, 0.50), (4.00, 5.00, 6.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00), (2.00, 3.00, 4.00),	(0.14, 0.17, 0.2), (0.14, 0.17, 0.2), (1.00, 1.00, 1.00) (0.13, 0.14, 0.17), (0.13, 0.14, 0.17)	(6.00, 7.00, 8.00), (7.00, 8.00,9.00), (1.00, 1.00, 1.00) (6.00, 7.00, 8.00), (6.00, 7.00, 8.00)	1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)

Where C1, C2, C3, C4 are criteria 1, 2, 3 and 4 (Morphological, geological, infrastructure and environmental)

Table 6: Combined comparison matrix of criteria with respect to goal

Goal	C1			C2			C3			C4			w	CR
C1	1.00	1.00	1.00	0.54	0.67	0.84	0.56	0.60	0.67	0.13	0.14	0.16	0.08	0.03
C2	1.19	1.50	1.86	1.00	1.00	1.00	0.77	0.89	1.01	0.13	0.16	0.18	0.11	
C3	6.16	7.17	7.97	5.42	6.44	7.44	1.00	1.00	1.00	4.19	4.87	5.47	0.50	
C4	4.25	5.26	6.02	3.25	4.27	5.25	1.48	1.72	1.94	1.00	1.00	1.00	0.31	

Where C1, C2, C3, C4 are criteria 1, 2, 3 and 4 (Morphological, geological, infrastructure and environmental).

Based on the scoring by the experts, this study found that infrastructure was the most significant criterion for solid waste transfer station site selection with a weight of 0.50(50%) and this factor has also been considered as posing environmental health risks in previous studies (Wang et al., 2018). The experts assigned a weight of 0.31 (31%) to environmental, which was the next most significant criterion. with geological fault areas being the third most significant criterion with a weight of 0.11 (11%). And under the natural future perspective, morphological were given a weight of 0.8 (8%).

The weight values obtained were used to calculate an economical optimization for each criterion using the mathematical analysis, and the field calculator and overlay union of the FAHP-GP analysis were used to create a final suitability location. The transfer station suitability index was used to calculate the suitability for the siting of transfer station in the study area after the screening out of restricted areas.

Table 7: Fuzzy comparison matrix of each location I with respect to criteria 1.

C1	A1	A2	A3	A4
A1	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(0.14, 0.17, 0.20) (0.25, 0.33, 0.50) (0.20, 0.25, 0.33) (0.20, 0.25, 0.33) (0.17, 0.20,0.25)	(0.13, 0.14, 0.17) (0.13, 0.14,0.17) (0.14, 0.17, 0.20) (0.17, 0.20, 0.25) (0.11, 0.13, 0.14)	(0.13, 0.14, 0.17) (0.17, 0.20, 0.25) (0.14, 0.17, 0.20) (0.13, 0.14, 0.17) (0.11, 0.13, 0.14)

A2	(5.00, 6.00, 7.00) (2.00, 3.00, 4.00) (3.00, 4.00, 5.00) (3.00, 4.00, 5.00) (4.00, 5.00, 6.00)	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00)	(0.17, 0.20, 0.25) (0.20, 0.25, 0.33) (0.20, 0.25, 0.33) (0.17, 0.20, 0.25) (0.20, 0.25, 0.33)	(0.17, 0.20, 0.25) (0.14, 0.17, 0.20) (0.13, 0.14, 0.17) (0.25, 0.33, 0.50) (0.17, 0.20, 0.25)
A3	(6.00,7.00, 8.00) (6.00,7.00,8.00) (5.00,6.00,7.00) (4.00,5.00,6.00) (7.00,8.00,9.00)	(4.00,5.00,6.00) (3.00,4.00,5.00) (3.00,4.00,5.00) (4.00,5.00,6.00) (3.00,4.00,5.00)	(1.00, 1.00,1.00), (1.00, 1.00,1.00), (1.00, 1.00,1.00), (1.00, 1.00,1.00), (1.00, 1.00, 1.00)	(0.2,0.25,0.33) (0.2,0.25,0.33) (0.2,0.25,0.33) (0.143,0.167,0.2) (0.167,0.2,0.25)
A4	(6.00,7.00,8.00) (4.00,5.00,6.00) (5.00,6.00,7.00) (6.00,7.00,8.00) (7.00,8.00,9.00)	(4.00,5.00,6.00) (5.00,6.00,7.00) (6.00,7.00,8.00) (2.00,3.00,4.00) (4.00,5.00,6.00)	(3.00,4.00,5.00) (3.00,4.00,5.00) (3.00,4.00,5.00) (5.00,6.00,7.00) (4.00,5.00,6.00)	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00)

Where A1, A2, A3 and A4 are alternative 1, 2, 3 and 4 (location one, location two, location three, and location four. Respectively)

Table 8: Comparison matrix of each location I with respect to criteria 2

C2	A1	A2	A3	A4
A1	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(0.20,0.25,0.33) 90.25,0.33,0.50) (0.25,0.33,0.50) (0.20,0.25,0.33) (0.20,0.25,0.33)	(0.17,0.20,0.25) (0.20,0.25,0.33) (0.17,0.20,0.25) (0.14,0.17,0.20) (0.17,0.20,0.25)	(0.14,0.17,0.20) (0.14,0.17,0.20) (0.13,0.14,0.17) (0.11,0.11,0.13) (0.11,0.13,0.14)
A2	(3.00,4.00,5.00) (2.00,3.00,4.00) (2.00,3.00,4.00) (3.00,4.00,5.00) (3.00,4.00,5.00)	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(0.13,0.14,0.17) (0.14,0.17,0.20) (0.17,0.20,0.25) (0.17,0.20,0.25) (0.14,0.17,0.20)	(0.11,0.11,0.13) (0.11,0.13,0.14) (0.11,0.13,0.14) (0.13,0.14,0.17) (0.14,0.17,0.20)
A3	(4.00,5.00, .006) (3.00,4.00,5.00) (4.00,5.00,6.00) (5.00,6.00,7.00) (4.00,5.00,6.00)	(6.00,7.00,8.00) (5.00,6.00,7.00) (4.00,5.00,6.00) (4.00,5.00,6.00) (5.00,6.00,7.00)	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(0.17,0.20,0.25) (0.20,0.25,0.33) (0.20,0.25,0.33) (0.14,0.17,0.20) (0.17,0.20,0.25
A4	(5.00,6.00,7.00) (5.00,6.00,7.00) (6.00,7.00,8.00) (8.00,9.00,9.00) (7.00,8.00,9.00)	(8.00,9.00,9.00) (7.00,8.00,9.00) (7.00,8.00,9.00) (6.00,7.00,8.00) (5.00,6.00,7.00)	(4.00,5.00,6.00) (3.00,4.00,5.00) (3.00,4.00,5.00) (5.00,6.00,7.00) (4.00,5.00,6.00)	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)

Where A1, A2, A3 and A4 are alternative 1, 2, 3 and 4 (location one, location two, location three, and location four. Respectively)

Table 9: Comparison matrix of each location I with respect to criteria 3

C3	A1	A2	A3	A4
A1	((1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	0.25, 0.33, 0.5 0.17,0.20 ,0.25 1.00,1.00,1.00 2.00,3.00,4.00 0.20 ,0.25,0.33	(0.11,0.11,0.13) (0.11,0.11,0.13) (0.13,0.14,0.17) (0.13,0.14,0.17) (0.11,0.13,0.14)	(0.13,0.14,0.17) (0.13,0.14,0.17) (0.13,0.14,0.17), (0.11,0.13,0.14) (0.13,0.14,0.17)
A2	(2.00,3.00,4.00) (4.00,5.00,6.00) (1.00,1.00,1.00) (0.25, 0.33, 0.5) (3.00,4.00,5.00)	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(0.17,0.20,0.25 (0.14,0.17,0.20 (0.25,0.33,0.50 (0.20,0.25,0.33 (0.17,0.20,0.25	(0.13,0.14,0.17) (0.11,0.13,0.14) (0.14,0.17,0.20) (0.13,0.14,0.17) (0.11,0.130.14)
A3	(8.00,9.00,9.00) (8.00,9.00,9.00) (6.00,7.00,8.00) (6.00,7.00,8.00) (7.00,8.00,9.00)	(4.00,5.00,6.00) (5.00,6.00,7.00) (2.00,3.00,4.00) (3.00,4.00,5.00) (4.00,5.00,6.00)	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(0.14,0.17 ,0.20) (0.13, 0.14,0.17) (0.11,0.13,0.14) (0.13,0.14,0.17) (0.17,0.20,0.25)
A4	(6.00,7.00,8.00) (6.00,7.00,8.00) (6.00,7.00,8.00) (7.00,8.00,9.00) (6.00,7.00,8.00)	(6.00,7.00,8.00) (7.00,8.00,9.00) (5.00,6.00,7.00) (6.00,7.00,8.00) (7.00,8.00,9.00)	(5.00,6.00,7.00) (6.00,7.00,8.00) (7.00,8.00,9.00) (6.00,7.00,8.00) (4.00,5.00,6.00)	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)

Where A1, A2, A3 and A4 are alternative 1, 2, 3 and 4 (location one, location two, location three, and location four. Respectively)

Table 10: Comparison matrix of each location I with respect to criteria 4

C4	A1	A2	A3	A4
A1	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(0.17,0.2,0.25 (0.14,0.17,0.2 (0.13,0.14,0.17 (0.2,0.250.33 (0.17,0.2,0.25	(0.25,0.33,0.5 (0.17,0.2,0.25 (0.25,0.33,0.5 (0.2,0.25,0.33 (0.17,0.2,0.25	(0.13,0.14,0.17 (0.11,0.11,0.13 (0.11,0.13,0.14 (0.13,0.14,0.17 (0.11,0.11,0.13
A2	(4.00,5.00,6.00) (5.00,6.00,7.00) (6.00,7.00,8.00) (3.00,4.00,5.00) (4.00,,5.00,6.00)	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(0.2,0.25,0.33 (0.14,0.17,0.2 (0.17,0.2,0.25 (0.13,0.14,0.17 (0.14,0.17,0.2	(0.13,0.14,0.17 (0.11,0.13,0.14 (0.13,0.14,0.17 (0.11,0.11,0.13 (0.14,0.17,0.2
A3	(2.00,3.00,4.00) (4.00,5.00,6.00) (2.00,3.00,4.00) (3.00,4.00,5.00) (4.00,5.00,6.00)	(3.00,4.00,5.00) (5.00,6.00,7.00) (4.00,5.00,6.00) (6.00,7.00,8.00) (5.00,6.00,7.00)	(1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(0.14,0.17,0.2 (0.13,0.14,0.17 (0.11,0.13,0.14 (0.13,0.14,0.17 (0.11,0.13,0.14

A4	(6.00,7.00,8.00) (8.00,9.00,9.00) (7.00,8.00,9.00) (6.00,7.00,8.00) (8.00,9.00,9.00)	(6.00,7.00,8.00) (7.00,8.00,9.00) (6.00,7.00,8.00) (8.00,9.00,9.00) (5.00,6.00,7.00)	(5.00,6.00,7.00) (6.00,7.00,8.00) (7.00,8.00,9.00) (6.00,7.00,8.00) (7.00, 8.00, 9.00)	(1.00, 1.00,1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00), (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)

Where A1, A2, A3 and A4 are alternative 1, 2, 3 and 4 (location one, location two, location three, and location four. Respectively)

Table 10: Combined comparison matrix of location I with respect to criteria 1 from five decision makers.

C1	A1			A2			A3			A4			W_i	CR
A1	1.00	1.00	1.00	0.19	0.23	0.31	0.13	0.15	0.18	0.13	0.15	0.18	0.04	0.07
A2	3.25	4.28	5.30	1.00	1.00	1.00	0.19	0.23	0.30	0.17	0.20	0.25	0.11	
A3	5.50	6.52	7.53	3.37	4.37	5.38	1.00	1.00	1.00	0.18	0.22	0.28	0.27	
A4	5.50	6.52	7.53	3.95	5.01	6.04	3.52	4.54	5.55	1.00	1.00	1.00	0.58	

Where A1, A2, A3 and A4 are alternative 1, 2, 3 and 4 (location one, location two, location three, and location four. Respectively)

Table 11: Combined comparison matrix of location I with respect to criteria 2 from five decision makers

C2	A1			A2			A3			A4			w	CR
A1	1.00	1.00	1.00	0.22	0.28	0.39	0.17	0.20	0.25	0.13	0.14	0.16	0.05	0.05
A2	0.71	0.21	0.27	1.00	1.00	1.00	3.95	4.96	5.97	4.74	5.75	6.76	0.26	
A3	0.15	0.17	0.21	0.12	0.13	0.15	1.00	1.00	1.00	2.55	3.57	4.57	0.09	
A4	6.09	7.11	7.95	6.52	7.53	8.36	3.73	4.74	5.75	1.00	1.00	1.00	0.60	

Where A1, A2, A3 and A4 are alternative 1, 2, 3 and 4 (location one, location two, location three, and location four. Respectively)

Table 12: Combined comparison matrix of location I with respect to criteria 3 from five decision makers

C3	A1			A2			A3			A4			w	CR
A1	1.00	1.00	1.00	6.19	7.19	8.19	6.15	7.16	8.16	5.50	6.52	7.53	0.66	0.09
A2	1.43	1.82	2.27	1.00	1.00	1.00	0.18	0.22	0.29	0.12	0.14	0.16	0.07	
A3	6.94	7.95	8.59	3.44	4.48	5.50	1.00	1.00	1.00	0.13	0.15	0.18	0.23	
A4	0.44	0.55	0.70	0.12	0.13	0.14	0.12	0.14	7.53	1.00	1.00	1.00	0.04	

Where A1, A2, A3 and A4 are alternative 1, 2, 3 and 4 (location one, location two, location three, and location four. Respectively)

Table 13: Combined comparison matrix of location I with respect to criteria 4 from five decision makers

C4	A1			A2			A3			A4			w	CR
A1	1.00	1.00	1.00	0.16	0.19	0.23	0.20	0.26	0.35	0.12	0.13	0.15	0.04	0.092
A2	4.28	5.30	6.32	1.00	1.00	1.00	0.15	0.18	0.22	0.12	0.14	0.16	0.10	
A3	2.86	3.90	4.92	4.48	5.50	6.52	1.00	1.00	1.00	0.12	0.14	0.16	0.22	
A4	6.94	7.95	8.59	6.32	7.33	8.16	6.15	7.16	8.16	1.00	1.00	1.00	0.64	

Where A1, A2, A3 and A4 are alternative 1, 2, 3 and 4 (location one, location two, location three, and location four. Respectively)

Table 14: All priority weights for each level

Wc(i)	CR	WL(I,j)	CR	W(i)
Wc(1)=0.08		W(1,1)= 0.04 W(2,1)= 0.11 W(3,1)=0.27 W(4,1)=0.58	0.07	0.3
Wc(2)=0.11	0.03	W(1,2)= 0.05 W(2,2)= 0.26 W(3,2)=0.09 W(4,2)=0.60	0.05	0.24
Wc(3)=0.50		W(1,3)= 0.66 W(2,3)= 0.07 W(3,3)=0.23 W(4,3)=0.04	0.09	0.17
Wc(4)=0.31		W(1,4)=0.04	0.092	0.29

		W(2,4)=0.10 W(3,4)=0.22 W(4,4)=0.64		

Where Wc is criteria weight and Wl is weight of location i

4.2 Compute the optimal solution for solid waste transfer station with the Facility location Problem model Result

After selectin of solid waste transfer station based on the experts view, mathematical modelling is presented. There are four potential sites for transfer stations but to establish waste transfer station, the volume of the waste must be greater than 158m cub per day in that station. The inner part of the city was unsuitable due to density population and environmental cost. So, It must be selected the three sites after desiccation with the city authority. Then the following mathematical results was presented where it should be opened from the given four alternatives. The objective of the model was to minims the sum of allocation, operation and transportation cost of the system.

To obtain the optimal solution for the lowest total cost, the FLP model was used to solve the problem. Currently Dream light Plc. Company used rental vehicle, which is rental cost is 3500 per trip for 16m3 loading capacity in7km distance. So transport cost of one unite cubic meter per km (1m3/k) is equal to (3500birr/16m3)/7k=31.25ETB. The demand and real distance matrix of four candidate locations and 26 kebele are shown in Table 15 as *dj* and *dtij*. The value of unit transportation cost is 31.25 birr/km. Facility cost is for each 12,000 ETB per day including the operation cost (the description of these are: The solid waste workers spent for 4:00 hour per day and the working time is 96 hour per month (4 hour *26 dais per month). Monthly fee is 2500 birr per month, hence 2500 birr/ 96 hour = 26.04 birr/ hour and based on the current situation, the required number of solid waste worker is 369.66≈370. So operation cost is 370*26.04=9626.2ETB. According to city land administration, cost of land is 291423.28ETB/m2 for 90 years. Each location requires 267.59m2 which is, during observation for processing 1m3 solid waste requires 1.7m2 area. Then (1.7*472.22)/3=267.59m2/day for each location hence (291423.28/267.59)/365=8.8 birr per day. This implies that 267.59*8.8birr per day =2,373.88 ETB per a day. So 2373.88+9626.2(land cost plus operational cost) = 12000ETB/day. After that, LINGO18 was used, and the optimal solution is shown in Table 17

Table 15: Distances between potential locations for establishing transfer stations and solid waste generated kebeles in each district.

	Kebeles ID	L_1	L_2	L_3	L_4	Waste. A
Atse Tewodiros	01	4.6	2	6	3.5	19.24
	02	4.2	1.8	5.8	3.8	20
	03	3.9	1.5	5.5	4	18
	04	3.5	1	5.2	4	18
	05	4.1	1.7	5	4.1	21
Gish Abay	06	3.5	3	4.5	1.8	22
	07	3	3.6	4.3	1.5	20
	08	3.2	3.3	4	2	20.5
	9	2.7	4	3.8	0.8	21
Fasilo	10	2	4	3.7	3	12
	11	1.9	4.5	3.5	2.7	10.6
	12	1.6	4	3.6	2.5	9
	13	2	3.8	3.9	2.5	11
Tana	14	1.2	5	4.3	3.8	19.41
	15	0.8	4.5	4.1	3.5	19
	16	1.5	4	3.7	3	18.5
	17	1.5	3.5	3.2	2.7	21
	18	2.7	5.2	2.2	3	18.8

Dagmawi Menilke	19	2.5	5	2	2.6	20
	20	2	5	2	2.4	19
	21	2	4.7	1.8	2.2	17
	22	2.2	4.5	1.5	2.6	19.43
Belay Zelek	23	3.5	5.5	2	3	16
	24	3	5.5	1.7	3	17.5
	25	3.4	5.2	1.5	2.8	20
	26	2.8	4.8	1.5	2.5	19

Where L1= potential location of site one L2= potential location of site two, L3= potential location of site three, and L4= potential location of site four.

Table 16: Distance cost matrix table between i and j

2765.75	1202.50	3607.50	2104.38
2625.00	1125.00	3625.00	2375.00
2193.75	843.75	3093.75	2250.00
1968.75	562.50	2925.00	2250.00
2690.63	1115.63	3281.25	2690.63
2406.25	1375.00	3093.75	2062.50
1875.00	2250.00	2687.50	937.50
2050.00	2114.06	2562.50	1281.25
1771.88	2625.00	2493.75	525.00
750.00	1500.00	1387.50	1125.00
629.38	1490.63	1159.38	894.38
450.00	1125.00	1012.50	703.13
687.50	1306.25	1340.63	859.38
727.88	3032.81	2608.22	2304.94
475.00	2671.88	2434.38	2078.13

867.19	2312.50	2139.06	1734.38
984.38	2296.88	2100.00	1771.88
1762.50	3055.00	1292.50	1586.25
1625.00	3125.00	1250.00	1562.50
1425.00	2968.75	1187.50	1187.50
1168.75	2496.88	956.25	1062.50
1335.81	2732.34	910.78	1578.69
1750.00	2750.00	1000.00	1500.00
1640.63	3007.81	929.69	1367.19
2125.00	3250.00	937.50	1750.00
1662.50	2850.00	890.63	1484.38

To calculate the total cost of transporting wastes, the amounts of shipment, the transportation Distance and the cost of fuel are considered for each pair of the nodes in the network. The defined problem has been solved using the lingo18software Table 17 summarizes the results for the best obtained solution. At this solution, establishment of 3 transfer stations, 1 geter menged, 1 Abay mado and 1sebatamit were the selected locations center are suggested. Table 18 represents the suggested locations for these facilities. As can be seen, the model results in the minimum possible number of each of the facilities and utilizing the capacity of facilities at the maximum extent.

See the result of lingo software at appendixes.

Table 17: optimal solution of FLP model from lingo softwair.

Number of kebeles covered by location i	Generated Waste amount /day	Locations
Kebele 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, and 17	182.01	1ocation 1
Kebele 1,2,3, 4, 5,6,	166.73	1ocation 2
		1ocation 3
Kebele 19, 20, 21, 22, 24, 25, 26	118.24	Location 4
Objective value	62847.44 Birr/day	

Where k_i is kebeles

4.3 Compute the suitable locations for solid waste transfer station using FAHP couple GP model.

After calculating the FAHP and FLP model in sections three, the next step was minimize the unwanted deviations di^-, di^+ in Equation (23), so the tow objective set as Wtc = 0.5 and WFAHP = 0.5 according to experts' opinions. The minimum total cost based on the FLP model was substituted into Equation (24) as the target of total cost in the FAHP-GP model. Similarly, the final priority weights were substituted into Equation (25), and the target of FAHP was equal to 1. Like the MSLP model, Equations (17)-(23) were the same constraints for this model.

See the result with lingo software at appendixes.

The optimal solution of the integrated of FAHP-GP model is the same as the FLP model.

After that, LINGO18 was used, and the optimal solution was compared with FAHP-only and FLP models, as shown in Table 18

Table 18: comparison of FAHP, FLP and FAHP-GP models

Location (i)	Final priority weight	FAHP	FLP model	FAHP-GP
L1	0.3	Selected	Selected	Selected
L2	0.24	selected	Selected	selected
L3	0.17	Not selected	Selected	selected
L4	0.29	Selected	Not selected	Not selected
Total cost (birr/day)		69,285	63,375.34	63,375.34

Where FLP= facility location, FAHP=fuzzy analytical hierarchy process

As seen in Table 18, based on the FAHP method, the results show that L1, L2 and L4, namely geter menged, Abay mado and sebatamit were the selected locations. The final priority weights of L1, L2 and L4 are 0.3, 0.24, and 0.29 respectively, and the total cost is 69,285 ETB/day. Next, based on the facility location model, L1, L2, and L3 namely geter menged site, Abay mado site and selam argiw site, were selected by consideration of the minimum total cost, about 62,847 ETB/day. The final priority weights of L1, L2 and L3 are equal to 0.3, 0.24, and 0.17 respectively.

Finally, the combined model of FAHP&GP was formulated to solve this problem because this model can be considered as multi-objective at the same time. Like the FLP model, the results show that the suitable candidate municipalities were L1, L2 and L3. It can decrease the total cost by selection of FAHP-only by about 6432 ETB/day. Although the weight of L2 was slightly lower than the weight of L4 (selected by FAHP-only, L1, L2 and L4), by about 0.12, the total cost objective was achieved using the new proposed model. Therefore, this model can lead to the selection of new suitable locations for solid waste transfer station by considering both tangible factors and intangible factors simultaneously. Moreover, the proposed model is realistic and feasible, since it considers resource limitations that need to be solved in the location selection problem.

The sensitivity analysis of the FAHP-GP model was also performed for different levels of objective weights. The sensitivity analysis is conducted to evaluate the solid waste transfer stations weights on the MOFLP. The results are summarized in Table 19. It can be seen that by increasing W_{tc} and decreasing W_{FAHP} at the same time, the total cost goal has a decreasing trend (minimum total cost). On the other hand, it can also be seen that by decreasing w_{tc} and increasing W_{FAHP} at the same time, the number of locations and total cost have an increasing trend. Finally, the solutions from the sensitivity analysis for different values of objective weights were offered to the five decision makers. The decision makers confirmed that these locations (L1, L2 and L3) are appropriate as new locations for solid waste transfer stations, and they believed that the work can provide essential support for decision makers in the assessment of location of solid waste transfer stations problems, in this case study and other areas of the city.

Table 19 Sensitivity analysis for different values of objective weights

	Wtc=0.6,WFAHP=0.4	Wtc=0.5,WFAHP=0.5	Wtc=0.4,WFAHP=0.6
L1	Selected	Selected	Selected
L2	selected	selected	selected
L3	not selected	not selected	selected
L4	Select	Select	Selected
Total cost ETB/day	62,847	62,847	69,285
Total priority	0.83	0.83	1

CHAPTER FIVE

5. Conclusion and Recommendation

5.1 Conclusion

Solid waste transfer station site selection is an important and difficult task which involves a high degree of complexity in balancing the morphological, geological, environmental and infrastructural perspectives. This study developed an MCDM technique with LFP environment to investigate the best location for waste transfer station sites in the four districts in Bahir dar city. A study gap was discovered from many earlier studies because researchers exclusively utilize quantitative objectives not qualitative objectives to solve the facility location problem for the lowest cost or smallest distance. The authors provide a paradigm for solving multi-objective issues having both quantitative and qualitative objectives in order to address this issue. A case study covering 26 kebeles and four potential facility locations in Bahir Dar City was used to test this approach. First, the, fuzzy analytical process was used to define the priority weights for each element in a three-level hierarchy. Second, the FLP model was developed to determine the ideal locations, and LINGO18 was used to solve the model's optimal solution, or minimum total cost. Subsequently, a multi-objective model comprising both the optimal solution of the FLP model and the priority weights of FAHP was developed to tackle this intricate problem. Ultimately, LINGO calculated the best option to choose appropriate sites for solid waste transfer stations. The results show that L1, L2 and L3 are the suitable locations.

The combined, fuzzy analytical process & goal programing, model produced the lowest overall cost and appropriate final priority weight, despite the fact that for one chosen location (L2), the final priority weight of L2 is marginally lower than the selection by , fuzzy analytical process (by roughly 0.12). The primary benefits of the proposed approach lie in its ability to direct the process of choosing a new, suitable location for the facility under a multi-criteria facility location problem. Both quantitative and qualitative considerations are taken into account at the same time.

As a result, it is thought that this strategy will be more beneficial and useful than independent optimization methods and independent, fuzzy analytical process methodology. The research's contribution is the creation of a novel, adaptable method that decision-makers may use to choose acceptable sites for municipal solid waste transfer stations based on both quantitative and qualitative factors. This flexible strategy, which is straightforward yet effective, helps decision-makers control expenses and their impact on the environment.

Therefore, the findings of this study are likely to be capable of resolving issues relating to potential solid waste transfer stations sites in the future since the method adopted in this study is scientific in its approach and is an effective tool for decision makers, planners and stakeholders in deciding where to site solid waste transfer stations. The model's outcomes demonstrate that it may effectively reduce environmental impact and serve as a guide for choosing the place with the lowest cost. The advantage of this research is that decision makers can select the optimal location network and give significant weights as needed.

5.2 Recommendation

The author recommends that the municipally solid waste management system should have considered for a city with proper waste transfer stations (waste segregation and packaging) and treatment facility locations along with the environmental, social and economical basic factors. So, the transfer station facility used as Intermediate/Central sorting facility. This is the basic mater that provides from where recyclable material to be sent for recycling and Revenue can be earned by selling the recyclables from recycling facility. And also Treatment and disposal of wastes will have be done as per its characteristics, like high calorific value of waste may go for incineration, biodegradable organic waste for composting and Inert, process rejects and residues from transfer station will have to go to engineered landfill.

According to the research finding, the environmental aspects are consider as the economical in equal or more for the better municipality solid waste management system. The research's contribution is the creation of a novel, adaptable method that decision-makers can use to choose acceptable sites for the solid waste transfer stations based on both quantitative and qualitative factors. This flexible strategy, which is simple but powerful, helps decision-makers to control expenses and their impact on the environment. The model's outcomes demonstrate that it is capable of directing the process of choosing the place with the lowest costs while also successfully reducing its environmental impact. This research has the benefit of enabling decision makers to choose the best location network and assign major weights as necessary.

Reference

Abbasi, G., Khoshalhan, F., & Javad Hosseininezhad, S. (2022). Municipal solid waste management and energy production: A multi-objective optimization approach to incineration and biogas waste-to-energy supply chain. *Sustainable Energy Technologies and Assessments*, *54*, 102809. https://doi.org/10.1016/J.SETA.2022.102809

Abou Najm, M., El-Fadel, M., Ayoub, G., El-Taha, M., & Al-Awar, F. (2002). An optimisation model for regional integrated solid waste management I. Model formulation. *Waste Management and Research*, *20*(1), 37–45. https://doi.org/10.1177/0734242x0202000105

Ağaçsapan, B., & Çabuk, S. N. (2020). Determination of suitable waste transfer station areas for sustainable territories: Eskisehir case. *Sustainable Cities and Society*, *52*. https://doi.org/10.1016/j.scs.2019.101829

Ahmadi-Javid, A., Seyedi, P., & Syam, S. S. (2017). A survey of healthcare facility location. *Computers and Operations Research*, *79*, 223–263. https://doi.org/10.1016/j.cor.2016.05.018

Akbarpour Shirazi, M., Samieifard, R., Abduli, M. A., & Omidvar, B. (2016). Mathematical modeling in municipal solid waste management: Case study of Tehran. *Journal of Environmental Health Science and Engineering*, *14*(1), 1–12. https://doi.org/10.1186/s40201-016-0250-2

Arribas, C. A., Blazquez, C. A., & Lamas, A. (2010). Urban solid waste collection system using mathematical modelling and tools of geographic information systems. *Waste Management and Research*, *28*(4), 355–363. https://doi.org/10.1177/0734242X09353435

Asmare, M. (2019). Bahir Dar City Municipal Solid Waste Potential Assessment for Clean Energy. *American Journal of Energy Engineering*, *7*(1), 28. https://doi.org/10.11648/j.ajee.20190701.14

Ayalew, D. W., Jianfu, Z., Tao, W., & Lu, S. (2020). Characterization of Municipal Solid Waste Management in Bahir Dar City, Ethiopia. *International Journal of Scientific and Research Publications (IJSRP)*, *10*(4), p10011. https://doi.org/10.29322/ijsrp.10.04.2020.p10011

Ayvaz-Cavdaroglu, N., Coban, A., & Firtina-Ertis, I. (2019). Municipal solid waste management via mathematical modeling: A case study in İstanbul, Turkey. *Journal of Environmental Management*, *244*(February), 362–369. https://doi.org/10.1016/j.jenvman.2019.05.065

Badri, M. A. (2001). A combined AHP-GP model for quality control systems. *International Journal of Production Economics*, *72*(1), 27–40. https://doi.org/10.1016/S0925-5273(00)00077-3

Bakeshlou, E. A., Khamseh, A. A., Asl, M. A. G., Sadeghi, J., & Abbaszadeh, M. (2017). Evaluating a green supplier selection problem using a hybrid MODM algorithm. *Journal of Intelligent Manufacturing*, *28*(4), 913–927. https://doi.org/10.1007/s10845-014-1028-y

Barbosa, L. C., & Gomes, L. F. A. M. (2015). Assessment of efficiency and sustainability in a chemical industry using goal programming and AHP. *Procedia Computer Science*, *55*(Itqm), 165–174. https://doi.org/10.1016/j.procs.2015.07.027

Benítez, S. O., Lozano-Olvera, G., Morelos, R. A., & Vega, C. A. de. (2008). Mathematical modeling to predict residential solid waste generation. *Waste Management*, *28*(SUPPL. 1), 7–13. https://doi.org/10.1016/j.wasman.2008.03.020

Bertanza, G., Ziliani, E., & Menoni, L. (2018). Techno-economic performance indicators of municipal solid waste collection strategies. *Waste Management*, *74*, 86–97. https://doi.org/10.1016/j.wasman.2018.01.009

Biruk, A. F. (2017). Waste management in the case of Bahir Dar City near Lake Tana shore in Northwestern Ethiopia: A review. *African Journal of Environmental Science and Technology*, *11*(8), 393–412. https://doi.org/10.5897/ajest2017.2340

Boadi, K., Kuitunen, M., Raheem, K., & Hanninen, K. (2005). Urbanisation without development: Environmental and health implications in African cities. *Environment, Development and Sustainability*, *7*(4), 465–500. https://doi.org/10.1007/s10668-004-5410-3

Bosompem, C., Stemn, E., & Fei-Baffoe, B. (2016). Multi-criteria GIS-based siting of transfer station for municipal solid waste: The case of Kumasi Metropolitan Area, Ghana. *Waste Management and Research*, *34*(10), 1054–1063. https://doi.org/10.1177/0734242X16658363

Chalkias. (2015). *Optimizing municipal solid waste collection using GIS Optimizing municipal solid waste collection using GIS*. *January 2015*, 45–50.

Chalkias, C., & Lasaridi, K. (2009). A GIS based model for the optimisation of municipal solid waste collection: The case study of Nikea, Athens, Greece. *WSEAS Transactions on Environment and Development*, *5*(10), 640–650.

Chatzouridis, C., & Komilis, D. (2012). A methodology to optimally site and design municipal solid waste transfer stations using binary programming. *Resources, Conservation and Recycling*, *60*, 89–98. https://doi.org/10.1016/j.resconrec.2011.12.004

Chaudhary, P., Chhetri, S. K., Joshi, K. M., Shrestha, B. M., & Kayastha, P. (2016). Application of an Analytic Hierarchy Process (AHP) in the GIS interface for suitable fire site selection: A case study from Kathmandu Metropolitan City, Nepal. *Socio-Economic Planning Sciences*, *53*, 60–71. https://doi.org/10.1016/j.seps.2015.10.001

Chen, C. Y., & Huang, J. J. (2022). Deriving Fuzzy Weights from the Consistent Fuzzy Analytic Hierarchy Process. *Mathematics*, *10*(19). https://doi.org/10.3390/math10193499

Cobos-Mora, S. L., Guamán-Aucapiña, J., & Zúñiga-Ruiz, J. (2023). Suitable site selection for transfer stations in a solid waste management system using analytical hierarchy process as a multi-criteria decision analysis: a case study in Azuay-Ecuador. *Environment, Development and Sustainability*, *25*(2), 1944–1977. https://doi.org/10.1007/s10668-022-02134-8

Dai, C., Li, Y. P., & Huang, G. H. (2011). A two-stage support-vector-regression optimization model for municipal solid waste management - A case study of Beijing, China. *Journal of Environmental Management*, *92*(12), 3023–3037. https://doi.org/10.1016/j.jenvman.2011.06.038

Dai, F., & Chen, Y. (2022). Integrated dynamic municipal solid waste transfer station location decision study based on the dynamic MSW generation. *Environment, Development and Sustainability*, *0123456789*. https://doi.org/10.1007/s10668-022-02292-9

Das, S., & Bhattacharyya, B. K. (2015). Optimization of municipal solid waste collection and transportation routes. *Waste Management*, *43*, 9–18. https://doi.org/10.1016/j.wasman.2015.06.033

Das, S., Lee, S. H., Kumar, P., Kim, K. H., Lee, S. S., & Bhattacharya, S. S. (2019). Solid waste management: Scope and the challenge of sustainability. *Journal of Cleaner Production*, *228*, 658–678. https://doi.org/10.1016/j.jclepro.2019.04.323

Desa, A., Ba'yah Abd Kadir, N., & Yusooff, F. (2011). A study on the knowledge, attitudes, awareness status and behaviour concerning solid waste management. *Procedia - Social and Behavioral Sciences*, *18*, 643–648. https://doi.org/10.1016/j.sbspro.2011.05.095

Dhokhikah, Y., Trihadiningrum, Y., & Sunaryo, S. (2015). Community participation in household solid waste reduction in Surabaya, Indonesia. *Resources, Conservation and Recycling*, *102*, 153–162. https://doi.org/10.1016/j.resconrec.2015.06.013

Dong, J., Wan, S., & Chen, S. M. (2021). Fuzzy best-worst method based on triangular fuzzy numbers for multi-criteria decision-making. *Information Sciences*, *547*, 1080–1104. https://doi.org/10.1016/j.ins.2020.09.014

Erkisi-Arici, S., Hagen, J., Cerdas, F., & Herrmann, C. (2021). Comparative LCA of Municipal Solid Waste Collection and Sorting Schemes Considering Regional Variability. *Procedia CIRP*, *98*, 235–240. https://doi.org/10.1016/j.procir.2021.01.036

Fereja, W. M., & Chemeda, D. D. (2022). Status, characterization, and quantification of municipal solid waste as a measure towards effective solid waste management: The case of Dilla Town, Southern Ethiopia. *Journal of the Air and Waste Management Association*, *72*(2), 187–201. https://doi.org/10.1080/10962247.2021.1923585

Ferronato, N., Portugal Alarcón, G. P., Guisbert Lizarazu, E. G., & Torretta, V. (2021). Assessment of municipal solid waste collection in Bolivia: Perspectives for avoiding uncontrolled disposal and boosting waste recycling options. *Resources, Conservation and Recycling*, *167*(June). https://doi.org/10.1016/j.resconrec.2020.105234

Gholipour, R., Jandaghi, G., & Rajaei, R. (2014). Contractor selection in MCDM context using fuzzy AHP. *Iranian Journal of Management …*, *7*(1), 151–173. http://journals.ut.ac.ir/?_action=showPDF&article=36206&_ob=32a5d505bac002540f2caf0475360394&fileName=full_text.pdf&rb=1

Griffin, C. E. (2009). What you should know about. *Compendium: Continuing Education For*

Veterinarians, *31*(11), 535–536. https://doi.org/10.1097/00152193-198712000-00022

Habibi, F., Asadi, E., Sadjadi, S. J., & Barzinpour, F. (2017). A multi-objective robust optimization model for site-selection and capacity allocation of municipal solid waste facilities: A case study in Tehran. *Journal of Cleaner Production*, *166*, 816–834. https://doi.org/10.1016/j.jclepro.2017.08.063

He, L., Huang, G. H., & Lu, H. (2011). Greenhouse gas emissions control in integrated municipal solid waste management through mixed integer bilevel decision-making. *Journal of Hazardous Materials*, *193*, 112–119. https://doi.org/10.1016/j.jhazmat.2011.07.036

He, T., Ho, W., Man, C. L. K., & Xu, X. (2012). A fuzzy AHP based integer linear programming model for the multi-criteria transshipment problem. *International Journal of Logistics Management*, *23*(1), 159–179. https://doi.org/10.1108/09574091211226975

Höke, M. C., & Yalcinkaya, S. (2021). Municipal solid waste transfer station planning through vehicle routing problem-based scenario analysis. *Waste Management and Research*, *39*(1), 185–196. https://doi.org/10.1177/0734242X20966643

Jabbarzadeh, A., & Jabalameli, Ms. (2016). A Multi-objective Model for Location of Transfer Stations: Case Study in Waste Management System of Tehran. *Journal of Industrial and Systems Engineering*, *9*(1), 109–125. http://www.jise.ir/?_action=articleInfo&article=12664

Jaiswal, A., & Bharat, A. (2016). Exploring criteria to locate solid waste Transfer station in an urban area. *Journal of Solid Waste Technology and Management*, *42*(1), 58–65. https://doi.org/10.5276/JSWTM.2016.58

Jaunich, M. K., Levis, J. W., DeCarolis, J. F., Gaston, E. V., Barlaz, M. A., Bartelt-Hunt, S. L., Jones, E. G., Hauser, L., & Jaikumar, R. (2016). Characterization of municipal solid waste collection operations. *Resources, Conservation and Recycling*, *114*, 92–102. https://doi.org/10.1016/j.resconrec.2016.07.012

Kannan, D., Khodaverdi, R., Olfat, L., Jafarian, A., & Diabat, A. (2013). Integrated fuzzy multi criteria decision making method and multiobjective programming approach for supplier selection and order allocation in a green supply chain. *Journal of Cleaner Production*, *47*, 355–367. https://doi.org/10.1016/j.jclepro.2013.02.010

Kassahun, T., & Birara, E. (2018). Assessment of Solid Waste Management Practices in Bahir Dar City, Ethiopia. *Pollution*, *4*(2), 251–261. https://doi.org/10.22059/poll.2017.240774.311

Kawai, K., & Tasaki, T. (2016). Revisiting estimates of municipal solid waste generation per capita and their reliability. *Journal of Material Cycles and Waste Management*, *18*(1), 1–13. https://doi.org/10.1007/s10163-015-0355-1

Khorramrouz, F., Pourmahdi Kajabadi, N., Rahiminezhad Galankashi, M., & Mokhatab Rafiei, F. (2019). Application of fuzzy analytic hierarchy process (FAHP) in failure investigation of knowledge-based business plans. *SN Applied Sciences*, *1*(11). https://doi.org/10.1007/s42452-019-1394-3

Kilic, H. S., & Yalcin, A. S. (2020). Modified two-phase fuzzy goal programming integrated with IF-TOPSIS for green supplier selection. *Applied Soft Computing Journal*, *93*, 106371. https://doi.org/10.1016/j.asoc.2020.106371

Kolekar, K. A., Hazra, T., & Chakrabarty, S. N. (2017). Prediction of municipal solid waste generation for developing countries in temporal scale: A fuzzy inference system approach. *Global Nest Journal*, *19*(3), 511–520. https://doi.org/10.30955/gnj.002323

Kumar, G. S., Kar, S. S., & Jain, A. (2011). Health and environmental sanitation in India: Issues for prioritizing control strategies. *Indian Journal of Occupational and Environmental Medicine*, *15*(3), 93–96. https://doi.org/10.4103/0019-5278.93196

Lee, C. K. M., Yeung, C. L., Xiong, Z. R., & Chung, S. H. (2016). A mathematical model for municipal solid waste management – A case study in Hong Kong. *Waste Management*, *58*, 430–441. https://doi.org/10.1016/j.wasman.2016.06.017

Liu, J., Li, Y., Xiao, B., & Jiao, J. (2021). Coupling fuzzy multi-criteria decision-making and clustering algorithm for msw landfill site selection (Case study: Lanzhou, China). *ISPRS International Journal of Geo-Information*, *10*(6). https://doi.org/10.3390/ijgi10060403

Lohri, C. R., Camenzind, E. J., & Zurbrügg, C. (2014). Financial sustainability in municipal solid waste management - Costs and revenues in Bahir Dar, Ethiopia. *Waste Management*, *34*(2), 542–552. https://doi.org/10.1016/j.wasman.2013.10.014

Lu, H. W., Huang, G. H., He, L., & Zeng, G. M. (2009). An inexact dynamic optimization model for municipal solid waste management in association with greenhouse gas emission control. *Journal of Environmental Management*, *90*(1), 396–409. https://doi.org/10.1016/j.jenvman.2007.10.011

Luthra, S., Mangla, S. K., Xu, L., & Diabat, A. (2016). Using AHP to evaluate barriers in adopting sustainable consumption and production initiatives in a supply chain. *International Journal of Production Economics*, *181*, 342–349. https://doi.org/10.1016/j.ijpe.2016.04.001

Marshall, R. E., & Farahbakhsh, K. (2013). Systems approaches to integrated solid waste management in developing countries. *Waste Management*, *33*(4), 988–1003. https://doi.org/10.1016/j.wasman.2012.12.023

McAllister, J. (2015). Factors influencing solid-waste management in the developing world. *A Plan B Report Submitted i Partial Fulfillmrnt of the Requirements for the Degree of Master of Science in Geography*, *299*, 1–95. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1537&context=gradreports

Moh, Y. C., & Abd Manaf, L. (2017). Solid waste management transformation and future challenges of source separation and recycling practice in Malaysia. *Resources, Conservation and Recycling*, *116*(2017), 1–14. https://doi.org/10.1016/j.resconrec.2016.09.012

Monzambe, G. M., Mpofu, K., & Daniyan, I. A. (2021). Optimal location of landfills and transfer stations for municipal solid waste in developing countries using non-linear programming. *Sustainable Futures*, *3*(September 2020). https://doi.org/10.1016/j.sftr.2021.100046

Mora, C., Manzini, R., Gamberi, M., & Cascini, A. (2014). Environmental and economic assessment for the optimal configuration of a sustainable solid waste collection system: A kerbside case study. *Production Planning and Control*, *25*(9), 737–761. https://doi.org/10.1080/09537287.2012.750386

Moslem, S., Ghorbanzadeh, O., Blaschke, T., & Duleba, S. (2019). Analysing Stakeholder Consensus for a Sustainable Transport Development Decision by the Fuzzy AHP and Interval AHP. *Sustainability*, *11*(12), 3271. https://doi.org/10.3390/su11123271

Nanda, S., & Berruti, F. (2021). A technical review of bioenergy and resource recovery from municipal solid waste. *Journal of Hazardous Materials*, *403*(September 2020), 123970. https://doi.org/10.1016/j.jhazmat.2020.123970

Omran, A., Mahmood, A., Abdul Aziz, H., & Robinson, G. M. (2009). Investigating households attitude toward recycling of solid waste in Malaysia: A case study. *International Journal of Environmental Research*, *3*(2), 275–288.

Önüt, S., & Soner, S. (2008). Transshipment site selection using the AHP and TOPSIS approaches under fuzzy environment. *Waste Management*, *28*(9), 1552–1559. https://doi.org/10.1016/j.wasman.2007.05.019

Panepinto, D., & Zanetti, M. (2021). Technical and environmental comparison among different municipal solid waste management scenarios. *Sustainability (Switzerland)*, *13*(6). https://doi.org/10.3390/su13063167

Paul, K., Chattopadhyay, S., Dutta, A., Krishna, A. P., & Ray, S. (2019). A comprehensive optimization model for integrated solid waste management system: A case study. *Environmental Engineering Research*, *24*(2), 220–237. https://doi.org/10.4491/EER.2018.132

Press, A. I. N. (2005). *Results from a pilot-scale air quality study in Addis Ababa , Ethiopia*. *39*, 7849–7860. https://doi.org/10.1016/j.atmosenv.2005.08.033

Quezada, L. E., & López-Ospina, H. A. (2014). A method for designing a strategy map using AHP and linear programming. *International Journal of Production Economics*, *158*, 244–255. https://doi.org/10.1016/j.ijpe.2014.08.008

Raut, R. D., Bhasin, H. V., Kamble, S. S., & Banerjee, S. (2011). An integrated fuzzy-AHP-LP (FAHLP) approach for supplier selection and purchasing decisions. *International Journal of Services and Operations Management*, *10*(4), 400–425. https://doi.org/10.1504/IJSOM.2011.043464

Razil, F., Abdul, A., Saleh, S., Asma, N., & Abdul, F. (2017). ScienceDirect ScienceDirect ScienceDirect Higher Heating Value of Torrefied Palm from Proximate Analysis Assessing the feasibility of using the heat demand-outdoor Abdul for Abdul forecast temperature function a long-term district heat Fazli. *Energy Procedia*, *138*, 307–312. https://doi.org/10.1016/j.egypro.2017.10.102

Rousta, K., Bolton, K., Lundin, M., & Dahlén, L. (2015). Quantitative assessment of distance to collection point and improved sorting information on source separation of household waste. *Waste Management*, *40*(2015), 22–30. https://doi.org/10.1016/j.wasman.2015.03.005

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

Saaty, T. L. (2002). Decision making with the Analytic Hierarchy Process. *Scientia Iranica*, *9*(3), 215–229. https://doi.org/10.1504/ijssci.2008.017590

Sajjad Ashfaq, M. (2018). A Tribute to Father of Fuzzy Set Theory and Fuzzy Logic (Dr. Lotfi A. Zadeh). *International Journal of Swarm Intelligence and Evolutionary Computation*, *07*(02). https://doi.org/10.4172/2090-4908.1000170

Saxena, S., Rajendran, C., Sanjeevi, V., & Shahabudeen, P. (2021). Optimization of solid waste management in a metropolitan city. *Materials Today: Proceedings*, *46*(xxxx), 8231–8238. https://doi.org/10.1016/j.matpr.2021.03.219

Schwartzman, A., Dougherty, R. F., & Taylor, J. E. (2010). Group comparison of eigenvalues and eigenvectors of diffusion tensors. *Journal of the American Statistical Association*, *105*(490), 588–599. https://doi.org/10.1198/jasa.2010.ap07291

Şener, Ş., Şener, E., Nas, B., & Karagüzel, R. (2010). Combining AHP with GIS for landfill site selection: A case study in the Lake Beyşehir catchment area (Konya, Turkey). *Waste Management*, *30*(11), 2037–2046. https://doi.org/10.1016/j.wasman.2010.05.024

Sharholy, M., Ahmad, K., Mahmood, G., & Trivedi, R. C. (2008). Municipal solid waste management in Indian cities - A review. *Waste Management*, *28*(2), 459–467. https://doi.org/10.1016/j.wasman.2007.02.008

Sukholthaman, P., & Sharp, A. (2016). A system dynamics model to evaluate effects of source separation of municipal solid waste management: A case of Bangkok, Thailand. *Waste Management*, *52*, 50–61. https://doi.org/10.1016/j.wasman.2016.03.026

Syauqi, A., & Purwanto, W. W. (2020). Mixed-integer non-linear programming (MINLP) multi-period multi-objective optimization of advanced power plant through gasification of municipal solid waste (MSW). *Chemical Product and Process Modeling*, *15*(4). https://doi.org/10.1515/cppm-2019-0126

Tassie, K., Endalew, B., & Mulugeta, A. (2019). Composition, Generation and Management Method of Municipal Solid Waste in Addis Ababa City, Central Ethiopia: A Review. *Asian Journal of Environment & Ecology*, *April*, 1–19. https://doi.org/10.9734/ajee/2019/v9i230088

Tassie Wegedie, K. (2018). Households solid waste generation and management behavior in case of Bahir Dar City, Amhara National Regional State, Ethiopia. *Cogent Environmental Science*, *4*(1), 1–18. https://doi.org/10.1080/23311843.2018.1471025

Teshome, F. B. (2020). *Municipal solid waste management in Ethiopia ; the gaps and ways for improvement*. *0123456789*. https://doi.org/10.1007/s10163-020-01118-y

Torfi, F., Farahani, R. Z., & Rezapour, S. (2010). Fuzzy AHP to determine the relative weights of evaluation criteria and Fuzzy TOPSIS to rank the alternatives. *Applied Soft Computing Journal*, *10*(2), 520–528. https://doi.org/10.1016/j.asoc.2009.08.021

Tsaura, S. H., Chang, T. Y., & Yen, C. H. (2002). The evaluation of airline service quality by fuzzy MCDM. *Tourism Management*, *23*(2), 107–115. https://doi.org/10.1016/S0261-5177(01)00050-4

Varma, V. S., & Kalamdhad, A. S. (2018). Solid Waste. In *Environmental Pollutants and Their Bioremediation Approaches*. https://doi.org/10.1201/b22171-12

Vitorino de Souza Melaré, A., Montenegro González, S., Faceli, K., & Casadei, V. (2017). Technologies and decision support systems to aid solid-waste management: a systematic review. *Waste Management*, *59*, 567–584. https://doi.org/10.1016/j.wasman.2016.10.045

Ward, M. N., Wells, B., & Diyamandoglu, V. (2014). Development of a framework to implement a recycling program in an elementary school. *Resources, Conservation and Recycling*, *86*, 138–146. https://doi.org/10.1016/j.resconrec.2014.02.013

Yadav, V., Kalbar, P. P., Karmakar, S., & Dikshit, A. K. (2020). A two-stage multi-attribute decision-making model for selecting appropriate locations of waste transfer stations in urban centers. *Waste Management*, *114*, 80–88. https://doi.org/10.1016/j.wasman.2020.05.024

Yadav, V., & Karmakar, S. (2020). Sustainable collection and transportation of municipal solid waste in urban centers. *Sustainable Cities and Society*, *53*, 101937. https://doi.org/10.1016/j.scs.2019.101937

Yadav, V., Karmakar, S., Dikshit, A. K., & Vanjari, S. (2016). A feasibility study for the locations of waste transfer stations in urban centers: A case study on the city of Nashik, India. *Journal of Cleaner Production*, *126*, 191–205. https://doi.org/10.1016/j.jclepro.2016.03.017

Yagmur, L. (2016). Multi-criteria evaluation and priority analysis for localization equipment in a thermal power plant using the AHP (analytic hierarchy process). *Energy*, *94*(2016), 476–482. https://doi.org/10.1016/j.energy.2015.11.011

Yang, L., Li, Z. S., & Fu, H. Z. (2011). Model of municipal solid waste source separation activity: A case study of Beijing. *Journal of the Air and Waste Management Association*, *61*(2), 157–163. https://doi.org/10.3155/1047-3289.61.2.157

Zhang, H., & Wen, Z. G. (2014). Residents' Household Solid Waste (HSW) source separation activity: A case study of suzhou, China. *Sustainability (Switzerland)*, *6*(9), 6446–6466. https://doi.org/10.3390/su6096446

Zhang, W., Che, Y., Yang, K., Ren, X., & Tai, J. (2012). Public opinion about the source separation of municipal solid waste in Shanghai, China. *Waste Management and Research*, *30*(12), 1261–1271. https://doi.org/10.1177/0734242X12462277

Appdix A1- Mathematical equation of FLP model

MinZ=2765.75X11+1202.50X12+3607.50X13+2104.38X14+2625.00X21+1125.00X22+3625.00X23+2375.00X24+2193.75X31+843.75X32+3093.75X33+2250.00X34+1968.75X41+562.50X42+2925.00X43+2250.00X44+2690.63X51+1115.63X52+3281.25X53+2690.63X54+2406.25X61+2250.00X62+3093.75X63+937.50X64+1875.00X71+2250.00X72+2687.50X73+937.50X74+2050.00X81+2114.06X82+2562.50X83+1281.25X84+1771.88X91+2625.00X92+2493.75X93+525.00X94+750.00X101+1500.00X102+1387.50X103+1125.00X104+629.38X111+1490.63X112+1159.38X113+894.38X114+450.00X121+1125.00X122+1012.50X123+703.13X124+687.50X131+1306.25X132+1340.63X133+859.38X134+727.88X141+3032.81X142+2608.22X143+2304.94X144+475.00X151+2671.88X152+2434.38X153+2078.13X154+867.19X161+2312.50X162+2139.06X163+1734.38X164+984.38X171+2296.88X172+2100.00X173+1771.88X174+1762.50X181+3055.00X182+1292.50X183+1586.25X184+1625.0X191+3125.00X192+1250.00X193+1562.50X194+1425.0X201+2968.75X202+1187.50X203+1187.50X204+1168.75X21+2496.88X212+956.25X213+1062.50X214+1335.81X221+2732.34X222+910.78X223+1578.69X224+1750.00X231+2750.00X232+1000.00X233+1500.00X234+1640.63X241+3007.81X242+929.69X243+1367.19X244+2125.00X251+3250.00X252+937.50X253+1750.00X254+1662.50X261+2850.00X262+890.63X263+1484.38X264+12000y1+12000y2+12000y3+12000y3.

Subject to:

X11+X12+X13+X14=1

X21+X22+X23+X24=1

X31+X32+X33+X34=1

X41+X42+X43+X44=1

X51+X52+X53+X54=1

X61+X62+X63+X64=1

X71+X72+X73+X74=1

X81+X82+X83+X84=1

X91+X92+X93+X94=1

X101+X102+X103+X104=1

X111+X112+X113+X114=1

X121+X122+X123+X124=1

X131+X132+X133+X134=1

X141+X142+X143+X144=1

X151+X152+X153+X154=1

X161+X162+X163+X164=1

X171+X172+X173+X174=1

X181+X182+X183+X184=1

X191+X192+X193+X194=1

X201+X202+X203+X204=1

X211+X212+X213+X214=1

X221+X222+X223+X224=1

X231+X232+X233+X234=1

X241+X242+X243+X244=1

X251+X252+X253+X254=1

X261+X262+X263+X264=1

X11+ X21+ X31+X41+ X51+X61+X71+ X81+X91+X101+ X111+ X121+ X131+ X141+ X151+ X161+ X171+X181+ X191+ X201+ X211+ X221+ X231+ X241+ X251+ X261<=26*Y1

X12+X22+X32X42X52+X62+X72+X82+X92+X102+X112+X122+X132+X142+X152+X162+ X172+X182+X192+X202+X212+X222+ X232+X242+X252+X262<=26*Y2

X13+X23+X33+X43+X53+X63+X73+X83+X93+X103+X113+X123+X133+X143+X153+X163+X173+X183+X193+X203+X213+X223+ X233+ X243+X253+ X263<=26*Y3

X14+X24+X34+X44+X54+X64+X74+X84+X94+X104+X114+X124+X134+X144+X154+X164+X174+X184+X194+X204+X214+X224+X234+X244+X254+X264<=26*Y4

X11+ X21+ X31+X41+ X51+X61+X71+ X81+X91+X101+ X111+ X121+ X131+ X141+ X151+ X161+ X171+X181+ X191+ X201+ X211+ X221+ X231+ X241+ X251+ X261>Y1

X12+X22+X32X42X52+X62+X72+X82+X92+X102+X112+X122+X132+X142+X152+X162+ X172+X182+X192+X202+X212+X222+ X232+X242+X252+X262>Y2

X13+X23+X33+X43+X53+X63+X73+X83+X93+X103+X113+X123+X133+X143+X153+X163+X173+X183+X193+X203+X213+X223+ X233+ X243+X253+ X263>Y3

X14+X24+X34+X44+X54+X64+X74+X84+X94+X104+X114+X124+X134+X144+X154+X164+X174+X184+X194+X204+X214+X224+X234+X244+X254+X264>Y4

Y1+Y2+Y3+Y4>=3

Y1+Y2+Y3+Y4<=6

Appdix A2-equation of goal programing model

Minis Z=$W_{tc.}$*d1plus +W_{FAHP}*d2minus

Subject to:

0.103x11+0.045x12+0.134x13+0.078x14+0.098x21+0.042x22+0.135x23+0.088x24+0.082x31+ 0.031x32+0.115x33+0.084x34+0.073x41+0.021x42+0.109x43+0.084x44+0.100x51+0.042x52+ 0.122x53+0.100x54+0.090x61+0.051x62+0.115x63+0.077x64+0.070x71+0.084x72+0.100x73+ 0.035x74+0.076x81+0.079x82+0.095x83+0.048x84+0.066x91+0.098x92+0.093x93+0.020x94+ 0.028x101+0.056x102+0.052x103+0.042x104+0.023x111+0.056x112+0.043x1130.033x114+0.017x121+0.042x12+0.038x123+0.026x124+0.026x131+0.049x132+0.050x133+0.032x134+0.027x141+0.113x142+0.097x143+0.086x144+0.018x151+0.100x152+0.091x153+0.077x154+0.032x161+0.086x162+0.080x163+0.065x164+0.037x171+0.086x172+0.078x173+0.066x174+0.066x181+0.114x182+0.048x18+0.059x184+0.061x191+0.116x192+0.047x193+0.058x194+0.05

3x201+0.111x202+0.044x203+0.044x204+0.044x211+0.093x212+0.036x213+0.040x214+0.050x221+0.102x222+0.034x223+0.059x224+0.065x231+0.102x232+0.037x233+0.056x234+0.061x241+0.112x242+0.035x243+0.051x244+0.33y1+0.33y2+0.33y3+0.33y4+0.5d1plus-0.5d2minus=1;

0.3y1+0.24y2+0.17y3+0.29y4+d2minus-d2plus=1

Other constraints are the same as FLP in Appdix A1

Appdix B1-result of optimal solution for FLM

```
Global optimal solution found.
Objective value:                              69285.04
Objective bound:                              69285.04
Infeasibilities:                              0.000000
Extended solver steps:                               0
Total solver iterations:                           124
Elapsed runtime seconds:                          0.26

Model Class:                                      MILP

Total variables:                    109
Nonlinear variables:                  0
Integer variables:                  108

Total constraints:                   37
Nonlinear constraints:                0

Total nonzeros:                     434
Nonlinear nonzeros:                   0
```

Variable	Value	Reduced Cost
X11	0.000000	2765.750
X12	1.000000	1202.500
X13	0.000000	3607.500
X14	0.000000	2104.380
X21	0.000000	2625.000
X22	1.000000	1125.000
X23	0.000000	3625.000
X24	0.000000	2375.000
X31	0.000000	2193.750
X32	1.000000	843.7500
X33	0.000000	3093.750
X34	0.000000	2250.000
X41	0.000000	1968.750
X42	1.000000	562.5000

X43	0.000000	2925.000
X44	0.000000	2250.000
X51	0.000000	2690.630
X52	1.000000	1115.630
X53	0.000000	3281.250
X54	0.000000	2690.630
X61	0.000000	2406.250
X62	1.000000	1375.000
X63	0.000000	3093.750
X64	0.000000	2062.500
X71	1.000000	1875.000
X72	0.000000	2250.000
X73	0.000000	2687.500
X74	0.000000	937.5000
X81	1.000000	2050.000
X82	0.000000	2114.060
X83	0.000000	2562.500
X84	0.000000	1281.250
X91	1.000000	1771.880
X92	0.000000	2625.000
X93	0.000000	2493.750
X94	0.000000	525.0000
X101	1.000000	750.0000
X102	0.000000	1500.000
X103	0.000000	1387.500
X104	0.000000	1125.000
X111	1.000000	629.3800
X112	0.000000	1490.630
X113	0.000000	1159.380
X114	0.000000	894.3800
X121	1.000000	450.0000
X122	0.000000	1125.000
X123	0.000000	1012.500
X124	0.000000	703.1300
X131	1.000000	687.5000
X132	0.000000	1306.250
X133	0.000000	1340.630
X134	0.000000	859.3800
X141	1.000000	727.8800
X142	0.000000	3032.810
X143	0.000000	2608.220
X144	0.000000	2304.940
X151	1.000000	475.0000
X152	0.000000	2671.880
X153	0.000000	2434.380
X154	0.000000	2078.130
X161	1.000000	867.1900
X162	0.000000	2312.500
X163	0.000000	2139.060
X164	0.000000	1734.380
X171	1.000000	984.3800
X172	0.000000	2296.880
X173	0.000000	2100.000
X174	0.000000	1771.880
X181	0.000000	1762.500
X182	0.000000	3055.000
X183	1.000000	1292.500

X184	0.000000	1586.250
X191	0.000000	1625.000
X192	0.000000	3125.000
X193	1.000000	1250.000
X194	0.000000	1562.500
X201	0.000000	1425.000
X202	0.000000	2968.750
X203	1.000000	1187.500
X204	0.000000	1187.500
X211	0.000000	1168.750
X212	0.000000	2496.880
X213	1.000000	956.2500
X214	0.000000	1062.500
X221	0.000000	1335.810
X222	0.000000	2732.340
X223	1.000000	910.7800
X224	0.000000	1578.690
X231	0.000000	1750.000
X232	0.000000	2750.000
X233	1.000000	1000.000
X234	0.000000	1500.000
X241	0.000000	1640.630
X242	0.000000	3007.810
X243	1.000000	929.6900
X244	0.000000	1367.190
X251	0.000000	2125.000
X252	0.000000	3250.000
X253	1.000000	937.5000
X254	0.000000	1750.000
X261	0.000000	1662.500
X262	0.000000	2850.000
X263	1.000000	890.6300
X264	0.000000	1484.380
Y1	1.000000	12000.00
Y2	1.000000	12000.00
Y3	1.000000	12000.00
Y4	0.000000	12000.00
X32X42X52	1.000000	0.000000

Row	Slack or Surplus	Dual Price
1	62847.44	-1.000000
2	0.000000	0.000000
3	1.000000	0.000000
4	0.000000	0.000000
5	0.000000	0.000000
6	0.000000	0.000000
7	0.000000	0.000000
8	0.000000	0.000000
9	0.000000	0.000000
10	0.000000	0.000000
11	0.000000	0.000000
12	0.000000	0.000000
13	0.000000	0.000000
14	0.000000	0.000000
15	0.000000	0.000000
16	0.000000	0.000000
17	0.000000	0.000000

18	0.000000	0.000000
19	0.000000	0.000000
20	0.000000	0.000000
21	0.000000	0.000000
22	0.000000	0.000000
23	0.000000	0.000000
24	0.000000	0.000000
25	0.000000	0.000000
26	0.000000	0.000000
27	0.000000	0.000000
28	0.000000	0.000000
29	0.000000	0.000000
30	15.00000	0.000000
31	20.00000	0.000000
32	17.00000	0.000000
33	0.000000	0.000000
34	10.00000	0.000000
35	3.000000	0.000000
36	8.000000	0.000000
37	0.000000	0.000000

Appdix B2 -result of optimal location using FAHP only

```
Global optimal solution found.
Objective value:                              63375.34
Objective bound:                              63375.34
Infeasibilities:                              0.000000
Extended solver steps:                               0
Total solver iterations:                           113
Elapsed runtime seconds:                          1.49

Model Class:                                      MILP

Total variables:                  109
Nonlinear variables:                0
Integer variables:                108

Total constraints:                 37
Nonlinear constraints:              0

Total nonzeros:                   434
Nonlinear nonzeros:                 0
```

Variable	Value	Reduced Cost
X11	0.000000	2765.750
X12	1.000000	1202.500
X13	0.000000	3607.500
X14	0.000000	2104.380
X21	0.000000	2625.000
X22	1.000000	1125.000
X23	0.000000	3625.000

X24	0.000000	2375.000
X31	0.000000	2193.750
X32	1.000000	843.7500
X33	0.000000	3093.750
X34	0.000000	2250.000
X41	0.000000	1968.750
X42	1.000000	562.5000
X43	0.000000	2925.000
X44	0.000000	2250.000
X51	0.000000	2690.630
X52	1.000000	1115.630
X53	0.000000	3281.250
X54	0.000000	2690.630
X61	0.000000	2406.250
X62	0.000000	2062.000
X63	0.000000	3093.750
X64	1.000000	1375.000
X71	0.000000	1875.000
X72	0.000000	2250.000
X73	0.000000	2687.500
X74	1.000000	937.5000
X81	0.000000	2050.000
X82	0.000000	2114.060
X83	0.000000	2562.500
X84	1.000000	1281.250
X91	0.000000	1771.880
X92	0.000000	2625.000
X93	0.000000	2493.750
X94	1.000000	525.0000
X101	1.000000	750.0000
X102	0.000000	1500.000
X103	0.000000	1387.500
X104	0.000000	1125.000
X111	1.000000	629.3800
X112	0.000000	1490.630
X113	0.000000	1159.380
X114	0.000000	894.3800
X121	1.000000	450.0000
X122	0.000000	1125.000
X123	0.000000	1012.500
X124	0.000000	703.1300
X131	1.000000	687.5000
X132	0.000000	1306.250
X133	0.000000	1340.630
X134	0.000000	859.3800
X141	1.000000	727.8800
X142	0.000000	3032.810
X143	0.000000	2608.220
X144	0.000000	2304.940
X151	1.000000	475.0000
X152	0.000000	2671.880
X153	0.000000	2434.380
X154	0.000000	2078.130
X161	1.000000	867.1900
X162	0.000000	2312.500
X163	0.000000	2139.060
X164	0.000000	1734.380

X171	1.000000	984.3800
X172	0.000000	2296.880
X173	0.000000	2100.000
X174	0.000000	1771.880
X181	1.000000	1586.000
X182	0.000000	3055.000
X183	0.000000	1292.500
X184	0.000000	1762.500
X191	0.000000	1625.000
X192	0.000000	3125.000
X193	0.000000	1250.000
X194	1.000000	1562.500
X201	1.000000	1187.500
X202	0.000000	2968.750
X203	0.000000	1187.500
X204	0.000000	1425.000
X211	1.000000	1062.500
X212	0.000000	2496.880
X213	0.000000	956.2500
X214	0.000000	1168.750
X221	1.000000	1335.810
X222	0.000000	2732.340
X223	0.000000	910.7800
X224	0.000000	1578.690
X231	0.000000	1750.000
X232	0.000000	2750.000
X233	0.000000	1000.000
X234	1.000000	1500.000
X241	0.000000	1640.630
X242	0.000000	3007.810
X243	0.000000	929.6900
X244	1.000000	1367.190
X251	0.000000	2125.000
X252	0.000000	3250.000
X253	0.000000	937.5000
X254	1.000000	1750.000
X261	0.000000	1662.500
X262	0.000000	2850.000
X263	0.000000	890.6300
X264	1.000000	1484.380
Y1	1.000000	12000.00
Y2	1.000000	12000.00
Y3	0.000000	12000.00
Y4	1.000000	12000.00
X32X42X52	1.000000	0.000000

Row	Slack or Surplus	Dual Price
1	63375.34	-1.000000
2	0.000000	0.000000
3	1.000000	0.000000
4	0.000000	0.000000
5	0.000000	0.000000
6	0.000000	0.000000
7	0.000000	0.000000
8	0.000000	0.000000
9	0.000000	0.000000
10	0.000000	0.000000

11	0.000000	0.000000
12	0.000000	0.000000
13	0.000000	0.000000
14	0.000000	0.000000
15	0.000000	0.000000
16	0.000000	0.000000
17	0.000000	0.000000
18	0.000000	0.000000
19	0.000000	0.000000
20	0.000000	0.000000
21	0.000000	0.000000
22	0.000000	0.000000
23	0.000000	0.000000
24	0.000000	0.000000
25	0.000000	0.000000
26	0.000000	0.000000
27	0.000000	0.000000
28	0.000000	0.000000
29	0.000000	0.000000
30	14.00000	0.000000
31	21.00000	0.000000
32	0.000000	0.000000
33	17.00000	0.000000
34	11.00000	0.000000
35	2.000000	0.000000
36	0.000000	0.000000
37	8.000000	0.000000

Appdix B3 -result of optimal location using FAHP only

```
Global optimal solution found.
Objective value:                          0. 6337534
Objective bound:                          0. 6337534
Infeasibilities:                           0.000000
Extended solver steps:                            0
Total solver iterations:                         55
Elapsed runtime seconds:                       0.10

Model Class:                                   MILP

Total variables:                  113
Nonlinear variables:                0
Integer variables:                108

Total constraints:                 39
Nonlinear constraints:              0

Total nonzeros:                   442
Nonlinear nonzeros:                 0
```

Variable	Value	Reduced Cost
Z	0.9905633	0.000000

F 0.2400000 0.000000
X11 0.000000
0.5337637E-01
X12 1.000000
0.2320712E-01
X13 0.000000
0.6962135E-01
X14 0.000000
0.4061246E-01
X21 0.000000
0.5066003E-01
X22 1.000000
0.2171144E-01
X23 0.000000
0.6995909E-01
X24 0.000000
0.4583526E-01
X31 0.000000
0.4233731E-01
X32 1.000000
0.1628358E-01
X33 0.000000
0.5970646E-01
X34 0.000000
0.4342288E-01
X41 0.000000
0.3799502E-01
X42 1.000000
0.1085572E-01
X43 0.000000
0.5644975E-01
X44 0.000000
0.4342288E-01
X51 0.000000
0.5192653E-01
X52 1.000000
0.2153051E-01
X53 0.000000
0.6332503E-01
X54 0.000000
0.5192653E-01
X61 0.000000
0.4643836E-01
X62 0.000000
0.3980431E-01
X63 0.000000
0.5970646E-01
X64 1.000000
0.2388258E-01
X71 0.000000
0.3618573E-01
X72 0.000000
0.4342288E-01
X73 0.000000
0.5186622E-01
X74 1.000000
0.1809287E-01

X81 0.000000
0.3956307E-01
X82 0.000000
0.4079941E-01
X83 0.000000
0.4945384E-01
X84 1.000000
0.2472692E-01
X91 0.000000
0.3419552E-01
X92 0.000000
0.5066003E-01
X93 0.000000
0.4812703E-01
X94 1.000000
0.1013201E-01
X101 1.000000
0.1447429E-01
X102 0.000000
0.2894859E-01
X103 0.000000
0.2677744E-01
X104 0.000000
0.2171144E-01
X111 1.000000
0.1214634E-01
X112 0.000000
0.2876766E-01
X113 0.000000
0.2237485E-01
X114 0.000000
0.1726060E-01
X121 1.000000
0.8684576E-02
X122 0.000000
0.2171144E-01
X123 0.000000
0.1954030E-01
X124 0.000000
0.1356965E-01
X131 1.000000
0.1326810E-01
X132 0.000000
0.2520939E-01
X133 0.000000
0.2587280E-01
X134 0.000000
0.1658513E-01
X141 1.000000
0.1404730E-01
X142 0.000000
0.5853042E-01
X143 0.000000
0.5033617E-01
X144 0.000000
0.4448312E-01

0.9167052E-02

0.5156467E-01

0.4698115E-01

0.4010586E-01

0.1673590E-01

0.4462907E-01

0.4128189E-01

0.3347180E-01

0.1899751E-01

0.4432752E-01

0.4052802E-01

0.3419552E-01

0.3061313E-01

0.5895862E-01

0.2494403E-01

0.3401459E-01

0.3015478E-01

0.6030956E-01

0.2412382E-01

0.3136097E-01

0.2291763E-01

0.5729408E-01

0.2291763E-01

0.2750116E-01

0.2050525E-01

0.4818734E-01

0.1845472E-01

0.2255577E-01

X151	1.000000
X152	0.000000
X153	0.000000
X154	0.000000
X161	1.000000
X162	0.000000
X163	0.000000
X164	0.000000
X171	1.000000
X172	0.000000
X173	0.000000
X174	0.000000
X181	1.000000
X182	0.000000
X183	0.000000
X184	0.000000
X191	1.000000
X192	0.000000
X193	0.000000
X194	0.000000
X201	1.000000
X202	0.000000
X203	0.000000
X204	0.000000
X211	1.000000
X212	0.000000
X213	0.000000
X214	0.000000

X221 0.000000

0.2577992E-01

X222 0.000000

0.5273166E-01

X223 0.000000

0.2250000E-01

X224 1.000000

0.2350000E-01

X231 0.000000

0.3377335E-01

X232 0.000000

0.5307241E-01

X233 0.000000

0.2800000E-01

X234 1.000000

0.1850000E-01

X241 0.000000

0.3166252E-01

X242 0.000000

0.5804795E-01

X243 0.000000

0.2550000E-01

X244 1.000000

0.2550000E-01

X251 0.000000

0.4101050E-01

X252 0.000000

0.6272194E-01

X253 0.000000

0.3515000E-01

X254 1.000000

0.3700000E-01

X261 0.000000

0.3208468E-01

X262 0.000000

0.5500232E-01

X263 0.000000

0.1718822E-01

X264 1.000000

0.2864704E-01

Y1 1.000000 -

0.1500000E-01

Y2 1.000000

0.5000000E-01

Y3 0.000000

0.4000000E-01

Y4 1.000000

0.6500000E-01

M	0.000000	0.5000000
W	0.000000	0.5000000
X32X42X52	1.000000	0.000000

Row	Slack or Surplus	Dual Price
1	0.6152817	-1.000000
2	0.000000	0.5000000
3	0.000000	-0.5000000
4	0.000000	0.000000

5	1.000000	0.000000
6	0.000000	0.000000
7	0.000000	0.000000
8	0.000000	0.000000
9	0.000000	0.000000
10	0.000000	0.000000
11	0.000000	0.000000
12	0.000000	0.000000
13	0.000000	0.000000
14	0.000000	0.000000
15	0.000000	0.000000
16	0.000000	0.000000
17	0.000000	0.000000
18	0.000000	0.000000
19	0.000000	0.000000
20	0.000000	0.000000
21	0.000000	0.000000
22	0.000000	0.000000
23	0.000000	0.000000
24	0.000000	0.000000
25	0.000000	0.000000
26	0.000000	0.000000
27	0.000000	0.000000
28	0.000000	0.000000
29	0.000000	0.000000
30	0.000000	0.000000
31	0.000000	0.000000
32	14.00000	0.000000
33	23.00000	0.000000
34	0.000000	0.000000
35	17.00000	0.000000
36	11.00000	0.000000
37	2.000000	0.000000
38	0.000000	0.000000
39	8.000000	0.000000