SITE SUITABILITY ANALYSIS OF MUNICIPAL SOLID WASTE DISPOSAL FACILITIES USING DECISION MAKING MULTI-MODELS AND GEOSPATIAL TECHNIQUES IN MULTAN DISTRICT, PAKISTAN

By

SAMRA FATIMA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

I dedicate this dissertation to my loving husband Muhammad Abdul Basit, my son, my daughter and my parents for all their love, care, support, and sacrifices during this PhD program. Without you, none of this would have been possible. Thank you for always believing in me.

Samra Fatima
March 2021

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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March 2021

Chairman : Zulfa Hanan binti Ash'aari, PhD
Faculty : Forestry and Environment

Proper solid waste management is essential for the sustainable development of underdeveloped countries. The district of Multan, located in the southern part of Punjab province, Pakistan currently experiencing poor solid waste management due to weak urban planning, infrastructure, technology, and insufficient funding. With 1,800 tons/day of Municipal Solid Waste (MSW) generation, the district had only one landfill site at Habiba Sial, which has already been filled up; thus, solid waste is being dumped in open places. Hence, there is an urgent need to identify a new solid waste disposal site that considers not only impacts on human health but also to the surrounding environment. However, identifying a new landfill site for the Multan district is challenging. It needs to be carefully done due to the main agricultural area and an increase in the city area because of the rapidly growing population. Conventional Geographical Information System (GIS)-based method regarding landfill siting always lead to decisional uncertainty and imprecision in data. Therefore, in this study, main aim was to enhance the quality of decision making in the management of municipal solid waste facilities in the study area by integrating the GIS with decision-making multi-models.

Ecological, socioeconomic and infrastructure factors like groundwater level, soil type, land cover, slope; and distance to settlement, road, airport, railway line and surface water source, electric powerlines and wells which affect on landfill site selection process, were evaluated by experts. Geospatial data such as district boundary map, city map, soil map, digital elevation model (DEM) and topographic maps were obtained from various government agencies in Pakistan to produce different criteria maps. Two decision-making multi-models named; Analytical Hierarchy Process (AHP) and integrated Fuzzy AHP were used to generate landfill site suitability maps of the Multan district. A total of 100 random locations/sites from whole district were selected based on the stratified random sampling method to verify the accuracy of applied models. For this purpose,

field visits and screening using other satellite data (quickbird image of 0.6m resolution) were carried out. Furthermore, the decision on selecting the landfill sites was improved by integrating waste collection and transportation routes analysis to find the shortest or minimum impedance path. Nonetheless, a regression model was also applied to find the most significant variables that affect waste truck travel time.

Evaluation of the accuracy of multi-models using area under the curve (AUC) where, value for Fuzzy AHP (0.86) was higher than AHP (0.77), with a *p*-value of <0.0001 was achieved at a 95% confidence interval. These findings also confirmed that the application of an integrated Fuzzy set and AHP for landfill site suitability assessment had better accuracy as compared with the conventional AHP. It showed that the integrated fuzzy set and AHP was an effective model for landfill site suitability assessment to support the decision. In addition, the results of waste disposal route optimization indicated that the length of routes, the population in the routes, two-way route, and the number of stops were the important variables that influenced transportation time. From the holistic analysis that has been carried out, the most suitable landfill site is located at Old Shuhjabad road, which not only meet all the important criteria but also involved minimal cost and time. In conclusion, landfill site selection criteria have been evaluated and accuracy of landfill site suitability model has been improved by integrated Fuzzy AHP technique. The regression analysis found the most significant factors which effect on waste transportation time and optimal routes were selected based on different parameters. The applied models and methods have been able to identify landfills and optimal waste transportation routes that can help city planners and stakeholders to reduce cost of managing solid waste.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ANALISIS KESESUAIAN FASILITI PELUPUSAN SISA PERBANDARAN MENGGUNAKAN MULTI-MODEL MEMBUAT KEPUTUSAN DAN TEKNIK GEOSPATIAL DI DAERAH MULTAN, PAKISTAN

Oleh

SAMRA FATIMA

Mac 2021

Pengerusi : Zulfa Hanan binti Ash'aari, PhD
Fakulti : Perhutanan dan Alam Sekitar

Pengurusan sisa pepejal yang betul adalah penting untuk pembangunan berterusan bagi negara-negara tidak membangun. Daerah Multan, yang terletak di bahagian selatan wilayah Punjab, Pakistan ketika ini sedang mengalami pengurusan sisa pepejal yang buruk berikutan kelemahan perancangan bandar, infrastruktur, teknologi, dan kekurangan dana. Dengan penjanaan 1,800 tan / hari sisa pepejal perbandaran (MSW), daerah ini hanya mempunyai satu tapak pelupusan sampah di Habiba Sial, yang telah penuh; oleh itu, sisa pepejal telah dibuang di tempat-tempat terbuka. Oleh itu, terdapat keperluan mendesak untuk mengenal pasti tapak pelupusan sisa pepejal baru yang mengambil kira bukan sahaja kesan kepada kesihatan manusia tetapi juga kepada persekitaran sekitarnya. Walaubagaimanapun, mengenalpasti tapak pembuangan yang baru di daerah Multan adalah mencabar. Ia perlu dibuat dengan teliti kerana ia adalah Kawasan utama pertanian dan peningkatan kawasan perbandaran yang disebabkan oleh peningkatan populasi yang pantas. Kaedah berasaskan Sistem Maklumat Geografi (GIS) konvensional berkaitan pemilihan tapak pembangan sampah selalu menyebabkan ketidakpastian keputusan dan ketidaktepatan data. Oleh yang demikian, penyelidikan ini, bermatlamat untuk meningkatkan kualiti membuat keputusan dalam pengurusan fasiliti sisa pepejal perbandaran di kawasan kajian dengan mengintegrasi GIS dan multi-model membuat keputusan.

Ekologi, sosoiekonomi dan faktor infrustruktur seperti paras air bawah tanah, jenis tanah, litupan tanah, kecerunan dan jarak ke kawasan penempatan, jalan, lapangan terbang, landasan kereta api dan sumber permukaan air, talian elektrik dan perigi yang memberi kesan kepada proses pemilihan tapak pembuangan sampah telah dinilai oleh pakar. Data geospatial seperti peta sempadan daerah, peta bandar, peta tanah, model ketinggian digital (DEM) dan peta topografi diperoleh dari pelbagai agensi kerajaan di Pakistan untuk menghasilkan peta mengikut kriteria yang berbeza. Dua multi-model membuat keputusan iaitu Proses Analisis Hierarki (AHP) dan kaedah *AHP Fuzzy*

bersepadu. Sebanyak 100 lokasi / tapak rawak dari peta yang dihasilkan dipilih untuk mengesahkan ketepatan model yang digunakan. Untuk tujuan ini, lawatan tapak dan penyaringan menggunakan data satelit yang lain (imej *Quickbird* dengan resolusi 0.6m) telah dilaksanakan. Selanjutnya, keputusan memilih tapak pelupusan sampah ditingkatkan dengan mengintegrasikan analisis pengumpulan sampah dan laluan pengangkutan untuk mencari jalan terpendek atau minimum. Selain itu, model regresi juga telah dijalankan untuk mencari pemboleh ubah yang paling signifikan yang mempengaruhi masa perjalanan trak sampah.

Penilaian tentang ketepatan pelbagai model dinilai menggunakan kawasan di bawah nilai lekuk (AUC) di mana, untuk *Fuzzy AHP* (0.86) adalah lebih tinggi berbanding AHP (0.77), dengan nilai p <0.0001 dicapai pada selang keyakinan 95%. Keputusan pengesahan ini menunjukkan bahawa aplikasi set Fuzzy bersepadu dengan AHP untuk penilaian kesesuaian tapak pelupusan mempunyai ketepatan yang lebih baik berbanding dengan AHP konvensional. Ini menunjukkan bahawa set *Fuzzy* dan AHP adalah model yang berkesan untuk penilaian kesesuaian tapak pelupusan sampah yang dapat menyokong keputusan. Sebagai tambahan, hasil kajian ini menunjukkan bahawa panjang laluan, populasi di laluan, laluan dua arah, dan jumlah pemberhentian adalah pemboleh ubah penting yang mempengaruhi masa perjalanan. Daripada analisis holisitik yang telah dilaksanakan, lokasi paling sesuai untuk tapak pelupasan adalah terletak di Jalan Old Shuhjabad, di mana ia bukan sahaja memenuhi kesemua kriteria pening tetapi juga melibatkan kos dan masa yang minimum. Kesimpulannya, kriteria pemilihan tapak pembuangan sampah telah dinilai dan ketepatan model dalam memilih tapak yang sesuai telah ditambah baik menggunakan Teknik integrasi Fizzy-AHP. Analisis regrasi telah menemui faktor-faktor paling penting yang memberi kesan kepada masa pengangkutan sampah dan jalan yang optimum dipilih berdasarkan parameter berbeza. Model dan teknik yang telah diaplikasikan berupaya mengenalpasti tapak pelupusan dan jalan pengangkutan optimum yang membantu perancang bandar dan pihak berkepentingan membuat keputusan yang lebih efektif.

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The process of writing this thesis was a wonderful learning experience in my academic life, which was filled with challenges and rewards. The completion of the present study leads a new beginning and a step forward towards my future, and when writing this preface, a quotation by the famous **Scottish Physicist James Clark Maxwell** came to my mind. Maxwell once stated, **“What is done by what is called myself is, I feel, done by something greater than myself in me.”** The question is justifiable. Did I really do this? Did I really manage to get it all together?

I express my heartfelt thanks to my supervisor, **Dr. Zulfa Hanan Ashaari**, for her keen constructive comments, generous support of knowledge, and her critical review of successive drafts chapter by chapter. I also express my heartfelt thanks to co-supervisors, **Assoc. Prof. Dr. Mohammad Firuz Ramli, Dr. Amir Hamzah Sharaai, and Prof. Dr. Mohammad Nawaz Chaudhry** for their advice, guidance, encouragement, and providing academic assistance during my study. Apart from wonderful supervisors, they all are great human beings, and I respect them from the depth of my heart.

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Samra Fatima
March 2021

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Zulfa Hanan binti Ash'aari, PhD
Senior Lecturer
Faculty of Forestry and Environment
Universiti Putra Malaysia
(Chairman)

Mohammad Firuz bin Ramli, PhD
Associate Professor
Faculty of Forestry and Environment
Universiti Putra Malaysia
(Member)

Amir Hamzah bin Sharaai, PhD
Senior Lecturer
Faculty of Forestry and Environment
Universiti Putra Malaysia
(Member)

Muhammad Nawaz Chaudhry, PhD
Professor
Faculty of Basic Sciences
Lahore School of Economics, Pakistan
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 October 2021

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LIST OF ABBREVIATIONS

MSW	Municipal Solid Waste
GIS	Geographic Information System
RS	Remote Sensing
MWMC	Multan Waste Management Company
C & D	Construction and Demolition waste
MCDM	Multi-criteria Decision Making
PROMETHEE	Preference Ranking Organization Method for Enrichment of Evaluations
AHP	Analytical Hierarchy Process
MCDA	Multi-Criteria Decision Analysis
ROC	Receiver Operating Characteristic
EPA	Environmental Protection Agency
DSS	Decision Support System
DGBT	Data Ganj Baksh Town
NIMBY	not in my backyard
NIABY	not in anyone's backyard
FMIR	Fuzzy Medical Image Retrieval
ABC	Artificial Bee Colony
FCM	Fuzzy C-Means
ANP	Analytic Network Process
OWA	Ordered Weighted Average
SAW	Simple Additive Weighting
TOPSIS	Order Preferences by Similarity with the Ideal Solutions

DEMATEL	Decision Making Trial and Evaluation Laboratory
WLC	Weighted Linear Combination
LDR	Land Development and Redevelopment
SPSS	Statistical Package for the Social Sciences
TMA	Tehsil/Town Municipal Administration
UC	Union Council
MDA	Multan Development Authority
USGS	United States Geological Survey
WASA	Water and Sanitation Agency
DEM	Digital Elevation Model
IDW	Inverse Distance Weighted
CR	Consistency Ratio
CI	Consistency Index
RI	Random Index
MF	Membership Function
OA	Overall Accuracy
GPS	Global Positioning System
AUC	Area Under Curve
OD	Origin-Destination

CHAPTER 1

INTRODUCTION

1.1 Background

From the beginning of civilization, people have produced solid waste. Proper solid waste management is important for the sustainable development of underdeveloped nations. Waste management involves many operations, from waste generation to final disposal. However, one of the essential issues generally facing the solid waste management is the business of waste collection and transportation in most developing countries with rapid urbanization, poor planning, and limited resources (Rızvanoğlu et al., 2020). As the world evolves, waste quantities also increase, becoming a significant concern across the globe. In the current era, global solid waste generation is approximately 1,600 million metric tons produced annually and is expected to increase to around 2.2 billion tonnes/year by 2025 (Debnath et al., 2015; Hina, 2016).

Nevertheless, the global averages are only broad estimates as the rates vary significantly by country, region, city, or even cities (Hoornweg & Bhada-tata, 2012). It is dependable on many factors such as Population growth, economic growth, climate, the standard of living, technology, customs and culture, and economic status of the cities (Korai et al., 2017; Korai et al., 2020).

It is reported that more than 50% of the population in developing countries does not have access to waste collection services. In addition, between 40% and 70% of discarded materials in urban areas are not collected, and open dumping and open burning are common disposal methods (Yukalang et al., 2018). This leads to significant impacts on human health and the environment (Hoornweg & Bhada-tata, 2012).

Improper disposal sites cause negative impacts on the environment and also a burden to the government due to the socio-economic issues associated with it. It has become the primary source of mosquitoes, rodents, and flies that transmit diseases and affect the local population (Hina, 2016). Moreover, sanitary landfills in nearby residential areas are always feeding grounds for cats, stray dogs, and rodents that transmit the disease to the population near where they move. Such a situation can cause respiratory, gastric, genetic, dermatological diseases. Landfill leachate generally consists of a significant amount of contaminants like chloride, nitrate, ammonia, and heavy metals. These contaminants can get into the waterways, degrade water resources, and become dangerous to human health (Nas et al., 2010). Methane is also vital greenhouse gas produced in landfills, a by-product of the anaerobic decomposition of organic waste. Also, air pollution caused by open burning in landfills will lead to bad odors and litters of wind (Amuda et al., 2014).

Due to the limitation of budget and lack of sufficient resources, poor government policies, improper handling, storage, and processing of MSW have caused many urban environmental issues in Pakistan (Korai et al., 2015). Only a few cities have an adequate solid waste management system, from the collection to final disposal. On the other hand, no proper route is designed to collect MSW from different waste collection points, even in the major cities of the country. Burning and dumping of waste on roadsides is frequently sighted. MSW issues in Pakistan involved lack of source segregation, improper design of collection routes, insufficient waste collection, lack of equipment, and the unavailability of funds (Masood & Barlow, 2014).

The storage and collection of solid wastes in Pakistan is carried out in two stages i.e., primary and secondary with an open discharge of more than 85% of the waste collected (Sharholy et al., 2008; Adila & Nawaz, 2009). Primary collection is collection of waste from door to door collection or the collection points. Primary collection is carried out by two wheels hand carts and mini compactors, while the secondary collection points are those storage points where the municipal waste is being temporarily stored. The tractors trolleys, arm rolls, hoist trucks are working for secondary collection from collection points. Pakistan generates 55,000 tons/day of solid waste in its urban area, increasing 2.4% annually (Hina, 2016). However, its proper disposal is a seriously challenging issue for Pakistan, which has caused serious environmental degradation (Adeel et al., 2012).

According to Anifowose et al. (2011), an ideal site for waste disposal is the location close to the waste source, a suitable road network. It must not on an alluvial plain and is supported by geologically stable and have competent and strong rock material. Considering the large amount of data involved, limitation of time and resources, the site selection studies need to consider using geospatial technologies to help better visualization and make timely decisions. This research is based on two different spatial techniques; dynamic and quantitative, within a GIS environment. Being a computer-based system, the reason behind the Geographic Information System (GIS) is that it is one of the most advanced technologies for geographers, which provides support for decision making by using spatial data. It can manage the data on the road network and solve the waste transportation problems. It also provides network-based spatial analysis and application of ArcGIS Network Analyst. This makes the user able to dynamically model realistic network conditions, including turns and height restrictions, speed limits, one-way streets, and variable travel speeds based on the local traffic (Malakahmad et al., 2014; Hemidat et al., 2017).

1.2 Problem Statement

The weakness of waste management is obvious in an area with high development, diversity of activities, and increasing population, such as the Multan district. Currently, solid waste management in Multan has improved over time due to a strong commitment from local authorities. However, a landfill located in Habiba Sial, dedicated to the Multan district, is already full, and solid waste is being dumped in open places (Multan Waste Management Company, 2017). Landfill site selection needs to be carefully done due to the main agricultural area and an increase in the city area because of the rapidly growing population.

The provision of the sanitary landfill is a critical element of infrastructure that the city provides to its citizens and is vital for the safe, solid waste management according to integrated solid waste management practices. A sanitary landfill is necessary for the safe disposal of non-combustible MSW, Construction, and Demolition waste (C & D).

The use of an optimal method, i.e., Multi-criteria Decision Making (MCDM), can bring efficiency and performance to the selection process (Ertuğrul & Karakaşoğlu, 2008). Methods that do not limit the analysis to only a few alternative locations are more appropriate than those who give little options for selecting a new landfill (Hanine et al., 2016). The main concern in the decision process of selecting a landfill is related to the difficulty of the time, which refers to the time in which an algorithm is performed (Chang, 1996). The difficulty of time varies from one method to another depending on the number of input variables, which in the case of selection of landfill, refers to the number of alternative locations and criteria.

Moreover, due to the condition of the traffic and the organic nature of the waste, selection of best routes to protect the nearby community and reducing the cost of transportation are imperative. The waste transportation process occupies an extensive amount of the total budget, so if the transport system is not efficient, it can cause a great loss of funds. Regular waste transportation is crucial to ensure that waste bins are not overflowed and should not be visible on the streets. Such regular transport could maintain hygienic conditions in cities/towns (Ohri & Singh, 2010). The expenditures consisted of high costs to operate and maintain the municipal fleet, the fuel consumed, the number of miles driven, and emissions of exhaust gases such as carbon dioxide, which in turn leave a negative impact on the environment.

Nonetheless, the respective municipal authorities have to make effective decisions that can positively affect the service quality offered to people. In return, the environment can be protected in the future. These positive decisions will come from optimizing the waste collection routes by integrating geospatial analysis with different mathematical algorithms. The optimal route can be defined as the route with the lowest impedance, for example, time or cost, we choose to solve for. To measure the path, routing algorithms mainly use length to find an optimized route to a defined destination. However, little attention has been paid to waste transportation in most of the city areas in Multan (Urban Unit, 2016). This provides a great and immense perspective for the current study to be carried out and generate better and lower-cost solutions for solid waste management.

1.3 Research Objective

The main aim of this study is to strengthen the quality of decision making in the landfill site suitability analysis and in optimizing waste transportation routes by using improved Multi-Criteria Decision Analysis (MCDA), which can be achieved by specific objectives as follow:

1. To evaluate the criteria that affect the selection of a landfill site.
2. To develop the multi-criteria decision-making model for landfill site suitability.
3. To identify suitable locations of landfill sites for the Multan district.
4. To determine the optimal waste collection routes for reducing operation cost and saving time.

1.4 Research Questions

This research will be supported by the following main research questions:

1. What are the main influencing factors in the landfill site selection process?
2. How can decision-making models for landfill site selection be improved for better results?
3. How useful will it be to develop optimization routes for economic and time-saving purposes for decision-makers / policymakers?

1.5 Significance of the Research

This study demonstrates the benefits of using advanced comprehensive techniques, such as remote sensing and GIS integrated with quantitative methods, to identify the suitable location of the landfill site and find the best waste disposal routes for Multan district, Pakistan. Results from this study will benefit policymakers in preparing the manual and guidelines for the MSW disposal facility project. Furthermore, decision making authorities can link this scientific and technical knowledge with strategic policies and programme formulation that are related to municipal solid waste disposal. The development of spatial database will overcome the paucity of geographic data which hinders appropriate waste management. Nonetheless, all the techniques, methods, and approaches used in this study guide researchers, city planners, decision-makers, and local authorities to manage solid waste in a better and cost-effective way. This research can be a useful source of reference for future study of site selection and can provide useful feedback and inputs. Further, output of the study will propose different maps showing the optimal routes for decision makers to select and minimise the drive time. In relation to the literature and with the best knowledge of the researcher, this study is considered the first study of its kind for the Multan district that uses these techniques to analyze and identify the location of landfills with the optimization of the waste disposal routes and includes different types of quantitative, physical and environmental data, factors, models, software-based approaches and techniques. Other than that, this research will also contribute to choosing the best statistical validation methods for landfill site suitability models and integrate spatial data (land-use) and social data (population) in the development of a comprehensive spatial database management system for waste planning. All the efforts will reduce environmental risks and human health problems.

1.6 Research Scope and Limitation

This research is based on two different spatial techniques; dynamic and quantitative, within a GIS environment. These include a comprehensive and critical review of landfill site modeling, spatial and quantitative geospatial analysis to evaluate the best landfill site, and also to validate the results of evaluation models. For this purpose, the first important step is to identify the criteria that affect the selection process of the landfill site. This study considers ecological, socioeconomic and infrastructure factors when evaluating a suitable location for landfills that could have less impact on the environment and the overall ecosystem. Two geospatial techniques AHP and Fuzzy set theory are used to produce landfill site suitability maps in GIS environment. The generated suitability maps are then validated by two statistical methods named overall accuracy and Receiver Operating Characteristic (ROC). Moreover, the scope of study also includes selecting the best waste disposal routes with the application of regression analysis and network analyst tool in ArcGIS software. This study also includes the development of spatial database to solve waste management problems.

The main limitation in criteria selection is that selected criteria cannot be applied to all places. This restriction is due to the different rules for the determination of the waste disposal site by the respective local authorities. Criteria like landuse and roads are dynamic and can change due to the local development plan. Moreover, any GIS analysis is limited to data availability and accuracy. There is a lack of geospatial data in the Multan district, and current available geospatial information is not automized and is not updated both in terms of quantity and quality. In the analysis, twelve different thematic layers were considered for the analysis of landfill site suitability, such as land use/land covers, surface water source, tube-wells, groundwater level, roads network, railways, airport, environmentally sensitive areas, electric powerlines, urban settlements, and slope. Certainly, some other factors like aspects, industrial areas, soil permeability, wind direction, hydrological parameters, underlying geology, and other socio-economic factors can be considered. Therefore, the availability of the latest data (2019-2020) always becomes a challenge. For route optimization, traffic data was not available for all types of roads in Multan city.

1.7 Conceptual Research Framework of the Study

The conceptual framework was designed, which is a systematic view of how different components of the research have interaction with the system and functions that they can use and apply, and finally outcome will help in reducing the cost of managing solid waste in Multan district (Figure 1.1). The two geospatial techniques were used for landfill site suitability analysis and selection of most suitable landfill site. GIS combines digital maps with traditional databases and provides visual representations of information. The proposed model was also used to overcome the problems of the waste transportation according to time, vehicle speed, distance, population, and land use parameters. The regression analysis was applied to select the most significant variables which affect waste transportation time. Finally, the optimal waste transportation routes were developed based on the parameters stored in the database system.

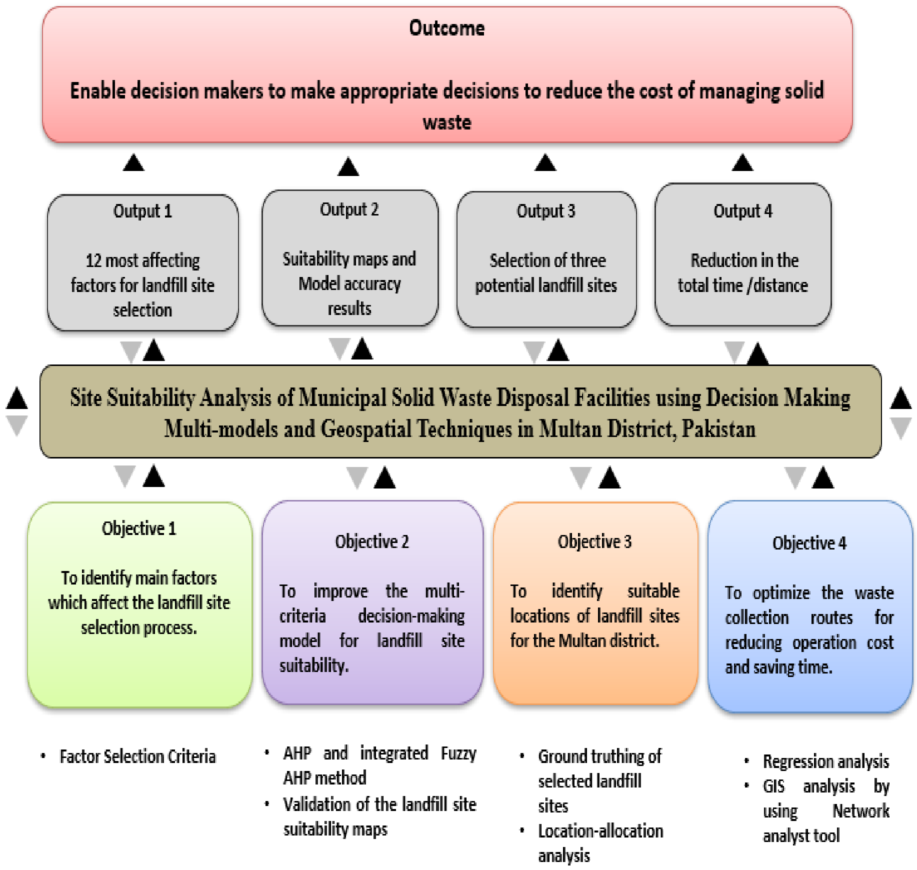

Figure 1.1 : Conceptual Research Framework

1.8 Organization of Thesis

This thesis emphasizes five main chapters to provide a better understanding and explanation of how the study was conducted and the priority set to it.

Chapter 2 focuses on a literature review that explains the general characteristics of suitability assessment models, methods, and approaches for landfill site suitability and waste collection routes. Various approaches adopted in the design of these models are also presented. The strength and weaknesses of different models are indicated based on the analysis and discussion of characteristics of the model.

Chapter 3 explain the study area and the materials and methods used. It describes how the study was organized and conducted.

Chapter 4 present the results and discussion summarized in text, tables, and figures from data acquired throughout the entire analyses.

Chapter 5 concludes all the important data and findings and specify a suggestion for future work proposed concerning the research study.

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