SOLID HAZARDOUS WASTE DUMPING SITE SELECTION USING FUZZY-AHP AND MULTI-CRITERIA APPROACH: A CASE OF BAHIR DAR CITY, ETHIOPIA

EPHREM AZEZEW ABATE

A Thesis Submitted to

The Department of Geomatics Engineering,

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Geo-informatics

Office of Graduate Studies

Adama Science and Technology University

September, 2022

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled ‘‘Solid hazardous waste dumping site selection using fuzzy-AHP and multi-criteria approach: a case of Bahirdar city, Ethiopia” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Ephrem Azezew Abate __________________________ _________________

Name of the student Signature Date

RECOMMENDATION

I the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled ‘‘Solid hazardous waste dumping site selection using fuzzy-AHP and multi-criteria approach: a case of Bahirdar city, Ethiopia” prepared under my guidance by Ephrem Azezew Abate submitted in partial fulfillment of the requirements for the degree of Mater’s of Science in Geo-informatics Engineering.

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Dejene Tesema (PhD)______	____________________	__________________
Major Advisor	Signature	Date

APPROVAL

I the advisors of the thesis entitled ‘‘Solid hazardous waste dumping site selection using fuzzy-AHP and multi-criteria approach: a case of Bahirdar city, Ethiopia” and developed by Ephrem Azezew Abate hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Dejene Tesema (PhD)	____________________	________________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Ephrem Azezew Abate have read and evaluated the thesis entitled ‘‘Solid hazardous waste dumping site selection using fuzzy-AHP and multi-criteria approach: a case of Bahirdar city, Ethiopia” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geo-informatics Engineering.

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LISTS OF ACRONYMS

AHP	Analytic Hierarchy Process
CI	Consistency index
CR	Consistency ratio
DEM	Digital Elevation Model
ENVI	Environment for Visualizing Images
ETM	Enhanced Thematic Mapper
FAHP	Fuzzy analytic hierarchal structure
GSE	Geological Survey of Ethiopia
GIS	Geographic Information System
GPS	Global Positioning System
LULC	Land Use Land Cover
MCDA	Multi Criteria Decision Analysis
MCE	Multi Criteria Evaluation
MSWM	Municipal Solid Waste Management
RI	Random inconsistency indices
USGS	United States geological survey
UTM	Universal Transverse Mercator
WLC	Weight Linear Combination
WSS	Water supply and sanitary

ABSTRACT

Disposal is the ultimate step in waste management strategy and requires an adequate site to successfully control its consequences. Rapid urbanization and technological developments have been acknowledged as reasons for increased hazardous waste generation in urban settings. Prior waste management studies in Ethiopia have mostly concentrated on managing non-hazardous solid waste in general, leaving hazardous waste unconsidered. As the population grows, there is a growing demand for landfills to be located in a more organized manner. Choosing the ideal location for a new dump site is a challenging choice given the cost and difficulties of both the initial implementation and any necessary future changes. This study aims to determine the optimal hazardous waste landfill site for the rapidly growing Bahir Dar city, taking a range of alternative evaluation criteria into account. Determinant environmental, social, and economic factors for hazardous waste disposal site location were selected based on a literature review and expert interview. The factors were developed through remote sensing and conventional data and were standardized based on suitability rankings. A Fuzzy Analytical Hierarchy Process (FAHP) was employed to determine the relative importance of each factor, as well as fuzzy logic for standardizing the Factors Map. Suitable landfill sites were determined through weighted spatial overlay analysis in a GIS environment. The results reveal that 2%, 6%, and 30% of the study area are considered extremely suitable, highly suitable, and moderately suitable landfill sites for hazardous waste disposal, respectively. In line with efforts being made to ensure the sustainable growth of Bahir City, this study would provide planners and stakeholders with important information regarding appropriate alternative sites for hazardous waste disposal in the future in Bahir Dar City.

Keywords: *Waste Management, Multi-criteria approach, Fuzzy logic, Fuzzy-AHP.*

CHAPTER I: INTRODUCTION

1.1 Background of the study

Waste is a material discharged from daily human activities that has adverse impacts on human health and the environment. These include spoiled food, papers, textiles, bones, ash, dust, and stones, as well as the remains of dead animals, human and animal excreta, construction and demolition waste, bio-medical waste, leftover electrical or mechanical equipment, furniture, and more. Hazardous waste means any unwanted or discarded material (excluding radioactive material), which because of its physical, chemical, or infectious characteristics can cause significant hazards to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed. Hazardous waste can also be produced through different manufacturing methods and discarded substances like unused commercial products (i.e., pesticides and cleaning fluids) and used materials and may come in many forms, including liquids, solids, gases, and sludge. The US Environmental Protection Agency (EPA) stated that the characteristics of hazardous waste should be detectable by using a standardized test method or by applying general knowledge of the waste's properties. Given these criteria, the EPA established four hazardous waste characteristics: ignitability, reactivity, corrosivity, and toxicity (EPA 2018).

In recent years, population growth and urban and technological development have led to changes in lifestyles, industrialization of cities, and the production and accumulation of large volumes of hazardous waste (Afzali et al. 2014). These problems and effects are exaggerated in most developing countries around the world, where hazardous waste is disposed of in an unplanned manner, causing problems, particularly for the poor who have direct exposure to them. The most common problems occurring as the result of improper planning and management of hazardous wastes can lead to pollution of surface and underground water sources, soil and air pollution, and emissions of greenhouse gases such as CO_2 and methane (Nishanth et al. 2010).

If hazardous waste is not dealt with properly, there can be potential long-term and catastrophic effects on the water, the atmosphere, the soil, and the environment. Therefore, hazardous waste environmental management, which involves waste generation, collection, storage, transportation, utilization, and disposal, is an indispensable part of environmental pollution prevention and control.

Hazardous waste management is the most difficult and expensive aspect of modern waste disposal and waste reduction in the environment. Municipal hazardous waste management has become a top priority for urban planners, municipal authorities, and decision-makers due to a growing population, industrialization, and urban sprawl. In developing countries, problems are becoming more serious where the non-scientific method of solid waste management is practiced due to population growth, urbanization, and low human awareness (Gorsevski et al. 2012). It has become one of the main challenges in urban planning, particularly in developing countries, due to increased waste generation and high handling costs (Idowu et al. 2019). The rapid increase in municipal waste from urban sprawl causes severe water, air, and environmental pollution, particularly in urban areas (Hereher et al. 2020). Not only does the pace of urbanization and population growth generate large volumes of hazardous waste, but it also leads to the improper disposal of such wastes, which are now a major environmental problem facing people.

In managing and planning the hazardous waste systems, multiple goals, such as socioeconomic and environmental control goals, have to be properly addressed. Thus, a preliminary screening exercise based on field observations and various site attributes is required to be carried out to avoid the huge costs involved in a detailed environmental assessment. Therefore, proper landfill site selection is a critical issue in the urban planning process because of its enormous impact on the economy, ecology, and environment as well as the health of the region. Therefore, hazardous waste management is becoming a major public health and environmental concern in urban areas of many African countries, like Ethiopia, especially in Bahirdar city. Various waste management techniques are available, such as reduction, reuse, recycling, composting, energy recovery, disposal, or landfill (Ayilara et al. 2020). The low cost of landfilling has turned it the first priority in comparison to other disposal methods in many countries.

Hazardous waste of Bahir Dar City includes wastes from hospitals and medical laboratories, chemically contaminated containers and trimmings from agriculture, pesticide retailer shops, university and school laboratories, tanneries, textiles, printing enterprises and expired drugs, biological wastes from hospitals and biological research facilities, the dry cells from each sources and car batteries from garages, used condoms from hotels and pensions and fluorescent lamps(Tassie & Endalew, 2020). Residential hazardous waste amounts to 156.6 kg/d (0.3% of total residential waste stream), commercial hazardous waste was recorded to be 124.8 kg/d (0.5% of commercial waste). Institutional hazardous waste was 120.7 kg/d (0.7%) and street sweeping hazardous waste was zero. This makes a total of 402.1 kg of hazardous waste generated per day, which is 0.4% of the total municipal solid waste in Bahir (UNEP, 2010a).

In view of this, this study presents a model to assist city authorities in identifying suitable sites for hazardous waste disposal considering geo-environmental, economic, and social factors. The specific purpose of this study was to identify criteria suitable for siting a hazardous landfill site and then use the identified criteria in conjunction with available data to determine suitable locations for a hazardous waste landfill in the study area using a fuzzy hierarchical modeling approach. The appropriate siting of hazardous waste disposal facilities is the most important consideration in hazardous waste management.

The multi-criteria decision-making (MCDM) method can integrate expert opinion with real information. These methods evaluate different criteria and cover all possible and contradictory objectives and results of analysis. GIS techniques and fuzzy analysis hierarchical process (AHP) have combined to select the best disposal location, and an environmental approach was applied to provide the disposal measures.

1.2 Problem Statement

Open dumps are well known to release large amounts of hazardous and otherwise deleterious chemicals to nearby groundwater, surface water, soil, and air, via leachate, liquid waste, and landfill gas. It is known that such releases contain a large variety of potential carcinogens, potentially toxic chemicals, and bacteriological contaminants that represent a threat to public health.

To date, the hazardous waste generated by various social, medical, and industrial units is disposed of in municipal landfills or dumped adjacent to roads, river banks, and any open spaces, and the dumping site is a common location for disposal of all types of waste. Although there is a large amount of hazardous waste in this province, there is no properly engineered landfill for managing such kinds of waste. It is an open field disposal site close to rural settlements and is not covered with soil daily, which causes nuisance and health hazards for the people living nearby. Furthermore, no environmental impact assessment has been carried out the selection of a location as a waste disposal site.

The rapid growth in hazardous waste is directly related to increased urbanization and technological development. Even though hazardous waste management has a significant impact on the economy and the environment, most previous waste management research has focused on general non-hazardous solid waste management, and hazardous waste management has recently not commenced in Bahirdar city.

In previous studies, the selected disposal sites were only for non-hazardous waste. However, the criteria for non-hazardous wastes are different from those for hazardous wastes, so hazardous waste disposal sites are not well studied. However, the previously selected landfill sites were not thoroughly investigated in order to select a highly suitable disposal site, necessitating more hydro-geological inquiry in order to minimize the spread of leachate naturally, both at the time of moving into ground water or when moving laterally along the ground water, and also to reduce the pollution of ground water, surface water, and drinking water sources.

The previous study mostly used traditional weighting assign method due to the complexities involved in siting landfills, the use of traditional methods is inappropriate, since this could result in undesirable results. As a result, the primary goal of this study is to select hazardous-waste landfill sites using the Fuzzy-AHP method for hazardous medical waste, hazardous industrial waste, and hazardous social waste. Therefore, the siting of landfills has become a necessary issue for waste management in growing and developing areas of the city.

1.3 Objectives

1.3.1 General objectives

The general objective of the study is to select a solid hazardous waste dumping site using fuzzy-AHP and a multi-criteria decision-making analysis (MCDA) approach.

1.3.2 Specific objectives

The specific objectives of the study were to: -

- ✓ Identify environmental, social, and economic factors for selecting suitable dumping sites.
- ✓ Produce a constraints map to determine the restricted areas for dumping site in Bahir Dar city.
- ✓ Determine the optimal hazardous waste dumping site for Bahir Dar City.

1.4 Research Questions

- ❖ What are the factors that are necessary in solid hazardous waste dumping optimal site selection?
- ❖ How to differentiate areas that can be considered restricted from those that can be considered suitable for a waste dumping site?
- ❖ How can optimal sites suitable for solid hazardous waste dumping be identified?

1.5 Scope of the study

The scope of the study is confined to suitable solid hazardous waste dumping site selection in Bahir Dar city. It focuses on technical aspects of solid waste disposal site selection. The issues under consideration in the study are only solid hazardous wastes. Sanitary wastes area, engineering and design part of the construction are not included.

1.6 Significant of study

From this study, the result is optimal hazardous waste landfill sites and a map of optimal hazardous waste disposal sites to protect the environment and the economic, political, and social safety of Bahir Dar city. Unsuitable hazardous waste landfill sites affect the social and economic activities of the communities as well as the health of the people.

There could be multiple implications for this study. First, it might provide some guidelines and information on the current state of municipal solid waste management issues in Bahir Dar city to decision-makers, solid waste managers, and environmental protection agencies. Second, the study may be useful in providing baseline data for those who want to conduct detailed and comprehensive studies in Bahir Dar or other areas in the future. Therefore, the final result of this research is expected to solve problems caused by hazardous waste related to the health, environment, and economy of the local people. Finally, by addressing issues with disease transmission, fire hazards, offensive odors, water and air pollution, as well as urban aesthetic issues, the Bahirdar City community will be the primary beneficiary of this research.

1.7 Organization of the Thesis

This thesis is divided into five chapters. The first chapter provides the introduction to the study, including background of the study, a statement of the problem, the objectives of the study, research questions, scope, and significance. The second chapter presents a review of related literature, mainly including definition waste, type waste, solid waste management, dump site selection, the role of GIS and remote sensing for landfill site selection, multi-criteria decision analysis (MCDA) for landfill site selection, fuzzy multi-criteria hierarchy process (FMHP), empirical review, research and knowledge gaps, and conceptual framework. The third chapter deals with the description of the study area as well as the materials, methods, and analysis employed in the study. The fourth chapter presents the result and discussion of the study area, and Chapter five presents conclusions and recommendations.

CHAPTER II: LITERATURE REVIEW

2.1 An Overview of Urban Planning

The urban areas in developing countries have witnessed tremendous changes in terms of population growth and urbanization. In the absence of proper urban management practice, uncontrolled and rapid increase in population pose enormous challenges to governments in providing adequate shelter to the millions of homeless and poor in urban areas (Raghunath, 2006). This has also posed great concern among urban planners. Random urban growth leads to the change of land use and land cover in many urban areas around the world, especially in developing countries (Hauser et al, 1982). This is resulting in deterioration of infrastructure facilities, loss of agricultural lands, water bodies, open spaces, and diminution of ground water aquifer zones, water contamination, air pollution, health hazards and many micro-climatic changes.

Urban land-use planning is a multi-component and multi-disciplinary process, which requires more than a single method for reasonable results. The main concern of urban land use planning is the allocation of suitable sites for the appropriate land uses. It is the fundamental work and the essential content of overall land use planning, which requires a scientific approach, in addition to guide development, avoidance of errors in decision-making and over-investment, for sustainable utilization of land resources. Most urban growth falls outside formal planning controls, thus increasing economic and social pressures and exacerbating health and hygiene problems.

In the preparation of environmentally compatible urban development plan it is a prerequisite to understand linkages and interactions that exist between different components of the urban environment. Secondly, the data collected on different aspects of the urban environment has to be translated into useful information for the purpose of urban development. Thirdly, there is also a need to aggregate this information according to administrative/natural and hierarchical units (Das et al, 2013). Basic requirement for this is the availability of systematic, detailed, reliable, timely and accurate information on various facets of urban environment (Bhavana, 2013). Urban planning should concern the use of land and design of the urban environment, including air and water and infrastructure passing into and out of urban areas with it.

Planning is a widely accepted way to handle complex problems of resources allocation and decision-making. It involves the use of collective intelligence and foresight to chart direction, order harmony and make progress in public activity relating to human environment and general welfare. In order to provide more effective and meaningful direction for better planning and development necessary support of the organization has become essential. Hence, the need for a suitable information system is increasingly being felt in all planning and developmental activities, whether these are for urban or rural areas. The modern technology of remote sensing which includes both aerial as well as satellite based systems, allow us to collect lot of physical data rather easily, with speed and on repetitive basis, and together with GIS helps us to analyze the data spatially, offering possibilities of generating various options (modeling), thereby optimizing the whole planning process.

2.2 Urban Development Planning Exercise in Ethiopia

Almost all Ethiopian towns and cities were established without proper plans (Tadesse, et al, 1997). It was only in the late 1950's that Ethiopia first started giving attention to urban development planning by formulating appropriate development strategies (Solomon, 1999). This means that the history of urban development planning in Ethiopia can be estimated to be only half a century old. The emphasis at that time was largely on the issue of land use control.

A series of three different types of 5-year plans were prepared between 1958 and 1974. The focus of these plans in general was (Solomon, 1999) development of infrastructure, expansion of agriculture and manufacturing industry, and maximization of growth and attainment of better standard of living. In 1964 the first huge planning project with the aim of preparing master plan for forty towns of the country was commenced and completed in 1967. The responsible government arm was Ministry of Interior and the contract was given to three Italian Companies (Tadesse, et al, 1997). Later the development and planning aspect of the urban sector was handled by the Ministry of Urban Development and Housing, which was established through proclamation No. 126/1977.

The various plans prepared, however, were not responsive as expected due mainly to lack of integration of the various aspects of urban development planning (such as social, economic, cultural and physical concerns of the towns). Neglect of the interactions of the towns with their corresponding immediate hinterlands was also important factor (Ibid). As urban problems in the country got more and more complex, the concern of the government and the importance of having sound urban planning practice became notable. To that end, the Military Government of Ethiopia established the present National Urban Planning Institute (NUPI), in 1987 (PMGE, 1987).

The proclamation empowers the institute: to prepare different types of plans for towns and cities of the country based on appropriate study and research; to prepare plans for regional urbanization, metropolitan area and urban centers; and; to recruit the required manpower necessary for executing the above mentioned responsibilities.

2.3 Solid Waste

Waste is generated as a direct consequence of human activities. Wastes are generally classified into solid, liquid and gaseous. Solid wastes, the subject of this study, are mainly disposed of to landfill as it is the simplest, cheapest and most cost-effective method of disposing of waste. Such wastes are generated by the full extent of human activities that range from relatively innocuous substances such as food and paper waste to toxic substances such as paint, chemicals used batteries, healthcare waste, and sewage sludge derived from wastewater treatment (Zhag et al., 2010).

Numerous classifications of solid wastes have been proposed and the following represents a simple classification of waste into broad categories according to its origin and risk to human and environmental health. These include household waste, municipal waste, commercial and nonhazardous industrial wastes, hazardous (toxic) industrial wastes, construction and demolition waste, healthcare wastes generated in health care facilities (e.g. hospitals, medical research, and laboratory), human and animal wastes and incinerator wastes (Sivasankar and Kuppu, 2017). Household waste represents waste generated at home and usually in city and townships collected by municipal waste collection services. Municipal solid waste includes wastes collected from shops, homes and offices, food waste from restaurants, waste derived from street cleaning and green (organic) waste generated in parks and garden (Debishree and Samadder, 2014)

2.4 Types of wastes

Solid waste can be divided into different types of groups based on their source: (Eberchi and Godwill, 2016). 2.2.1 Urban solid waste The urban solid waste contains construction waste, household and destruction debris, healthcare wastes, and waste from roads. This waste is generated mainly from settlements and profitable complexes. With increasing urban expansion and revolution in life and food habits, the amount of municipal solid waste has been increasing rapidly and varying its composition (Eberchi and Godwill, 2016).

2.4.1 Urban solid waste

The urban solid waste contains construction waste, household and destruction debris, healthcare wastes, and waste from roads. This waste is generated mainly from settlements and profitable complexes. With increasing urban expansion and revolution in life and food habits, the amount of municipal solid waste has been increasing rapidly and varying its composition (Eberchi and Godwill, 2016).

2.4.2 Hazardous waste

Hospital and industrial wastes are considered as harmful as they may also include poisonous substances. Same types of household waste are also hazardous. Dangerous wastes could be extremely toxic to animals, humans and plants. Domestic wastes that can be classified as hazardous waste include used materials like, car batteries, shoe polish, clinical instrument, paint materials, and medical instruments. Human and animal healthcare waste with chemical substances are also dangerous. These chemicals include formaldehyde and phenols, which are used as antiseptics and mercury, which is used in thermometers or instrument that measure blood pressure. In the industrial sector, the major producers of risky waste are the metal, chemical, paper, insecticide, dye, purifying and plastic industries. Direct contact with chemicals such as dangerous such as cyanide and mercury can be fatal (Eberchi and Godwill, 2016).

2.4.3 Hospital waste

Hospital waste is generated during the diagnosis, treatment and injection of human beings or animals or in exploration activities in these fields or in the production or laboratory testing. It may contain wastes like scissors edge material, disposables, dry waste, culture medicinal wastes, anatomical waste, discarded medicines and chemicals. These are in the form of wastes such as syringes, swabs, bandages, body fluids and excreta. These are highly infectious and can be a serious threat to human health if not managed in a scientific and discriminate manner (Eberchi and Godwill, 2016).

2.5 Solid Waste Management System

Solid waste management is the discipline associated with the control of generation, storage, collection, transfer, transport, processing and disposal of solid wastes in a manner that is in agreement with the best principles of public health, engineering, economics, aesthetics, conservation and environmental considerations, and to change the attitude of people (Zhag et al., 2010). Scientific management of solid waste around human habitat reduces its adverse impacts on the environment and human health and supports economic development and improved quality of life. The main methods of solid waste management systems are a waste reduction, waste reuse and recycling. There are many environmental benefits that can be derived from the reuse, reduction and recycling methods. They reduce or prevent greenhouse gas emission, conserve resources, reduce the release of pollutants, save energy, and reduce the demand for waste treatment technology and landfill space. Therefore, it is advisable that these methods be incorporated as part of the solid waste management plan (Debishiree, 2014). Poor waste management systems coupled with hot climatic conditions results in increasing environmental problems with significant local as well as global dimensions. In spite of the increasing stress towards the waste reduction at the source, as well as recovery and recycling of the solid waste, disposal of solid waste by landfilling remains the most commonly employed method (Debishiree, 2014).

2.5.1 Solid waste management in Ethiopia

Municipal Solid Waste Management (MSWM) is a problem that is experienced by all counties in the world. It is an issue mostly witnessed in urban areas as a result of a high surge in population growth rate and increase in per capita income, thus posing a danger to environmental quality and human health (Javaheri, 2006). Because of its nature, it has one of the major environmental problems man continues to face. Investigation of waste management is now becoming critical in developing countries (Kyessi and Mwakalinga, 2009). Waste management is understudied, in developing countries, but now receiving increasing attention. Municipal solid waste management problems have become more pronounced in recent years, as a result of inadequate collection and disposal of wastes. In most cities, wastes are not properly collected and where the proper collection is ensured, only a small fraction receives proper disposals. Urban waste management has been challenging for municipalities and urban governments in the developing world, largely due to poor infrastructure and limited institutional capacity. Municipalities throughout Ethiopia are not free of these problems as they have been facing major challenges with the solid waste collection and management (Issam et al., 2007). Per-capita waste generated in Ethiopia ranged from 0.11 to 0.35 kg/day for rural areas 0.17 to 0.48 kg/day for urban areas. The range depends on several factors such as income and season. In Ethiopia, the total municipal solid waste generation in 2003 was 2.8 to 8.8 million tonnes.

2.6 Dump site selection

Dump site selection is a difficult task to accomplish because the site selection process depends on different factors and regulations and also because it requires data from diverse social and environmental fields such as water supply sources, land-use, sensitive sites, and road network. These data often involve processing of a significant amount of spatial information, which can be used by GIS as an important tool for land-use/land-cover suitability analysis (Zeinhom et al., 2010). Dump site selection is becoming increasingly difficult due to growing environmental awareness, decreased amount of governmental and municipal funding with extreme political and social opposition. Increasing of the human population, public health concerns and a shortage of land available for landfill construction adds more difficulties to the problem to overcome. Environmental factors are very important to be considered in such work due to the fact that landfill might affect the biophysical environment and the ecology of the surrounding area. Several techniques are used in site selection of solid waste disposal. Such site selection techniques combine multiple criteria decision analysis (MCDA) and GIS. The result of these techniques is the evaluation of the suitability for the entire study region based on suitability index, which is useful in order to make an initial ranking of most suitable areas (Mohammad et al., 2014). Dump site selection in an urban area is a critical issue because of its enormous impacts on the economy and the environmental health of the region, and many site selection factors and criteria should be carefully organized and analyzed. One of the complicated steps is locating of waste dump sites have precise steps including site selection and preparation of waste dump site. If these dump sites are near the individual's workplace or living places, it is considered as a negative outcome and it may cause irreparable consequences to human life (Seiied, 2015).

Sanitary dump site selection requires an extensive evaluation process in order to identify the best available disposal location. Therefore, the site selection of a solid waste dump site must also involve processing of a significant amount of spatial data, regulations and acceptance criteria, as well as an efficient correlation between them. The geographic information system has been found to play a significant role in the domain of site selection of solid waste disposal sites. Many factors must be incorporated into dump site selection decisions and GIS is ideal for this kind of preliminary studies due to its ability to manage large volumes of spatial data from a variety of sources. The integration of GIS and Analytical Hierarchy Process (AHP) is a powerful tool to solve dump site selection problem because GIS provides efficient manipulation and presentation of the data and AHP supplies a consistent ranking of the potential dump areas based on a variety of criteria (Debishree et al., 2014).

2.7 The role of GIS and Remote Sensing for Landfill Site Selection

2.7.1 Application of Remote Sensing for Landfill Site Selection

Remote sensing is one of the excellent tools for inventory and analysis of environment and its resources, owing to its unique ability of providing the synoptic view of a large area of the earth's surfaces and its capacity of repetitive coverage. Its multispectral capability provides appropriate contrast between various natural features where as its repetitive coverage provides information on the dynamic changes taking place over the earth surface and the natural environment. (Nishanth, 2010) also states remote sensing as one of the excellent tools for inventory and analysis of environment and its resources, owing to its unique ability of providing the synoptic view of a large area of the earth's surface and its capacity of repetitive coverage. The use of remote sensing is becoming increasingly frequent in environmental studies. In the recent years, no serious research of the environment performed without advanced image processing and analysis. One of the most important applications of remote sensing can be found in the case of solid waste landfill site selection where remote sensing data (satellite images) are used for extracting most of the site selection criteria used for siting landfill (Oštir et al.,2003) (example, mapping land use/land cover, geology and surface water), time and cost effectively. Moreover, remote sensing can provide digital data as an input for GIS.

2.7.2 Application of Geographic information system for Landfill Site Selection

GIS is a set of software tools that is used to input, store, manipulate, analyze and display geographical information. Strategically, GIS may be a philosophy, a way of making decisions within an organization where all information is held centrally and is related by its location. Technological development in computer science has introduced geographic information system (GIS) as an innovative tool in landfill process. GIS combines spatial data (maps, aerial photographs, satellite images) with the other quantitative, qualitative and descriptive information databases. GIS combines spatial data (maps, aerial photographs, satellite images) with the other quantitative, qualitative and descriptive information databases. This technology offers an analytical frame work for data synthesis that combines a system capable of data capture, storage, management, retrieval, analysis and display. When remotely sensed data are combined with other landscape variables organized with in a GIS environment provide an excellent frame work for data capture, storage, synthesis, measurement and analysis. The GIS aided methodology presented here utilizes to create the digital geo-database as a spatial clustering process and easily understood way for land filling process.

One of the benefits of GIS is its capability for landfill site selection. Landfill sitting is complex, tedious and costly as it requires multiple criterions from environment, social and economic point of view. GIS application can help in determining the landfill location in accordance with the technical requirements, with overlay the thematic map to get an appropriate landfill. GIS is a tool that not only reduces time and cost of the site selection but also provides digital data bank for future monitoring program of the site. Therefore, the GIS offers the spatial analytical capabilities to quickly eliminate parcel of land unsuitable for landfill site and hence reduce cost and time of siting processes.

The advantage of a GIS based approach for sitting arises from the fact that it not only reduces time and cost of site selection, but also provides a digital data inventory for long-term monitoring of the site (Kontos, 2005). Application of it can help in determining the landfill location in accordance with the technical requirements, with overlay the thematic map to get an appropriate landfill.

2.8 Multi-Criteria Decision Analysis for Landfill Site Selection

Multi-criteria analysis is a set of mathematical tools and methods allowing the comparison of different alternatives according to many criteria, often conflicting, to guide the decision maker towards a judicious choice. MCDA consists of a series of techniques (such as weighted summation or concordance analysis) that permit a range of criteria relating to a particular issue to be scored, weighted and then ranked by, for example, experts, interest groups and/or stakeholders according to their degree of suitability or importance for locating/siting a particular facility/service like landfills. Furthermore, Multi-criteria approaches have the potential to reduce the costs and time involved in siting facilities by narrowing down the potential choices based on predefined criteria and weights while also permitting sensitivity analysis of the results from these procedures (Kabite G, 2012)

2.9 Fuzzy Analytical Hierarchy Process (FAHP)

The Analytical Hierarchy Process (AHP) is one of the methods of multi-criteria decision making (MCDM) developed by Saaty (1980). AHP is a structured technique for organizing and analyzing complex decisions or issues which involves subjective judgments. In other words, an AHP is a traditional powerful decision making technique in order to determining priorities among different criteria, comparing the decision alternatives for each criterion and determining an overall ranking of the decision alternatives. The main advantages of AHP are handling multiple criteria, easy to understand and effectively dealing with both qualitative and quantitative data. In the real world, most of the information or data obtained from experts included uncertainty and vagueness because of the incomplete information, impreciseness of human judgments and uncertainty of decision environment. The combine effect of fuzzy set theory and analytical hierarchy process gives fuzzy analytical hierarchy process (Fuzzy AHP) as a more powerful methodology for multi-criteria decision making (MCDM). Hence, it can be concluded that Fuzzy AHP will find more applications than conventional AHP in the near future. There are many scientific approaches for deriving the weights (crisp or fuzzy) from fuzzy pairwise comparison matrices. Since fuzzy weights are not as easy to compute as crisp weights, then the majority of Fuzzy AHP applications use a simple extent analysis method proposed by Chang (1992). Likewise an AHP, fuzzy AHP provides a hierarchical structure, facilitates the decompositions and pairwise comparisons, reduces the inconsistency and generates the priority vectors. Also, a fuzzy AHP can solve and support spatial reasoning problems in a number of different context such as: locating convenience stores and other facilities (Partovi, 2006), hospital site selection (Alesheikh, 2009), screening potential landfill sites and local park planning (Zucca, 2008). Criterion weights used in the selection of a suitable site for solid waste are expressed in linguistic terms. Therefore, integrating decision analysis with fuzzy logic enables more accurate approaches (Torabi-Kaveh, 2016). The fuzzy AHP method converts precise values to fuzzy numbers and membership functions and ensures more reasonable weight evaluation of criteria (Aryafar, 2013). In the present study, the Fuzzy AHP method will be employed for landfill site selection.

2.10 Empirical Review

Hailu Zewdie (2017): Select a Suitable Solid Waste Disposal Site in Ambo Town. The results show that the importance of environmental factors like geology and soil permeability, such as proximity to groundwater wells and streams/rivers, and topographic factors, such as slope and land uses, for determining waste disposal sites are not the same. The weight assignment analysis reveals that ground- and surface-water related factors such as soil permeability and proximity to wells and streams/rivers are more influential than the other factors, as they are critical in protecting water pollution from dumping leachate.The weighted linear combination result showed four classes of suitability levels. As the overall suitability result shows, there is no area that fulfills the more suitable criteria. This indicates that there are no very highly suitable items in all the ten (10) criteria considered. Furthermore, the suitability map shows that the dumping site is located in an environmentally and socially unsuitable area that does not satisfy the unacceptable.

Ahmed Mussa (2018) Identify suitable solid waste disposal sites in Logia Town, Ethiopia. Used Criteria Land Use Land cover, geological structures, lithology, slope, distance to river built-up, road, soil, drainage, well points, and weight derivation model Analytical Hierarchy Process pairwise comparison model The results show that ground- and surface-water-related criteria are more influential than the rest of the criteria, as they need protection against leachate contamination from dump sites. On the other hand, a groundwater well points to an important environmental criterion in the dump site selection, and bare land in the study area was identified as the best option for solid waste dump sites. Comparisons of the different positions based on environmental, social, and economic impacts were done. Out of the total study area, about 5.93% (499.43 ha) fall under highly suitable categories due to the area satisfying environmental, social, and economic criteria such as fault, built-up area, surface water, land-use/land-cover, soil, slope, and road network.

Genemo Berisa (2016) Municipal solid waste disposal site selection of Jigjiga Town Road networks, residences, and built-up areas; rivers, boreholes, and reservoirs were used as integrated environmental and socioeconomic criteria.The result shows Areas identified as highly suitable for landfill sites are reevaluated for different purposes, such as socio-economic criteria like size of the site, distance from nearby settlements, and access to transportation. Out of five candidate landfill sites, a site with reasonable size (24 ha), at an optimum distance from residences (4.8 km), and accessible to the major roads (1 km), was nominated as the most suitable site. The second result shows that the most suitable site for solid waste disposal in the town is because it’s the largest, located at an optimum distance from human settlements, and the most accessible.

Gizachew Kabite (2015) identifies an appropriate solid waste disposal system in Addis Ababa, Ethiopia. Used Criteria such as lithology, groundwater depth, water supply well points, land-use/ landcover, slope, drainage pattern (water bodies), roads, airport locations were used for selecting a suitable landfill within the study area and used AHP pair-wise comparison technique in the Analytic Hierarchy Process (AHP). Sites identified as highly suitable for landfills are based on their size, distance from the center, and distance from nearby settlements. The results showed that highly suitable locations, with 12 candidate sites having an extent of >0.5 km, were evaluated in terms of size of the landfill, distance from the city center, and distance from nearby settlements. Multi-criteria evaluation results showed that groundwater-related factors are more important in landfill site selection as ground water needs protection from leachates arising from landfills.

Dereje Biru Debalke and Tesfahun Endalew Admas (2021): Solid waste dumping site analysis in Bonga Town, Southwestern Ethiopia. Out of the area of the study site, about 0.3% (4.15 ha) comprise highly suitable categories, given that the realm satisfies environmental, social, and economic criteria such as fault, settlement, river, geology, LULC, soil, slope, and road network. For each model, weights were determined using AHP methods. The result of using the stated criteria is that the acceptable area for solid waste dumping may facilitate transportation and reduce the cost of transport. The result also shows that the ability to use inaccessible geological information frameworks and detection innovations for mandatory discrimination evidence for a reasonably robust waste dump will minimize opportunities and natural human well-being problems.

Tirusew Ayisheshim and Amare Sewnet (2013), "Solid waste dumping site suitability analysis for Bahir Dar Town, North Western Ethiopia. used criteria such as land use Distance from urban settlement, rural settlement, protected area, Road, Distance from road, Distance from River, Distance from lake and slope. Out of the total area of the study site, about 11.9% (or 2528 ha) fall under the category of highly suitable area. Using the criteria stated, the suitable areas for a solid waste dumping site are located to the east and south-west of the town.The selected site areas are significantly at the optimum distance from Lake Tana and the River Abay and from major roads. The areas were most suitable for solid waste dumping sites. Moreover, suitability analyses for slope had shown that slopes lower than 10% were more suitable in order to minimize environmental impacts.

2.11 Research and knowledge gaps

Tirusew and Amare (2013) presented a study for Bahirdar city using traditional Analytical Hierarchy Process (AHP) approaches to select the suitable site only for non-hazardous waste disposal. The major criteria involved in the study are land use, slope, water sources, settlement, and transport facilities. The study's weakness was the lack of further investigation of hydro-geological issues.When using a traditional weighting system (AHP), the risk of making wrong decisions is greater than with other methods (Freselam M and Masdi M, 2014). In addition, the decision-maker's preference and personal judgment affect the AHP result enormously (Smith and Winterfeldt, 2004). Since fuzziness is a common characteristic of decision-making problems, the FAHP method has been developed to address this problem (Mikhailov and Tsvetinov, 2004). Despite the fact that managing hazardous waste has a significant impact on the economy and the environment, most prior research on waste management has concentrated on managing non-hazardous solid waste in general, and managing hazardous waste has not recently begun in Bahirdar city.

The majority of earlier studies did not consider constraints when determining criteria for solid waste dumping site suitability. However, constraints should have to be considered in suitability analysis as they are a restriction set up by legal framework. hence this study uses the multi-criteria methods integrated a larger amount of evaluation criteria (ten factors and constraints) than in previous studies to determine the suitability index of urban land for future solid waste dumping site. Almost all of the previous studies did not validate the suitability index of their analysis by comparing with proposed land use plan of their study areas which would have prepared by authorized body for city's spatial development and regulation. From principles of land use suitability analysis, the final results of suitability analysis for land use should be validated. This research tried to fill this gap of knowledge by confirming the final suitability map with existing land use to validate its suitability. This is not experienced well before in suitability analysis of urban land uses for some particular.

2.12 Conceptual framework

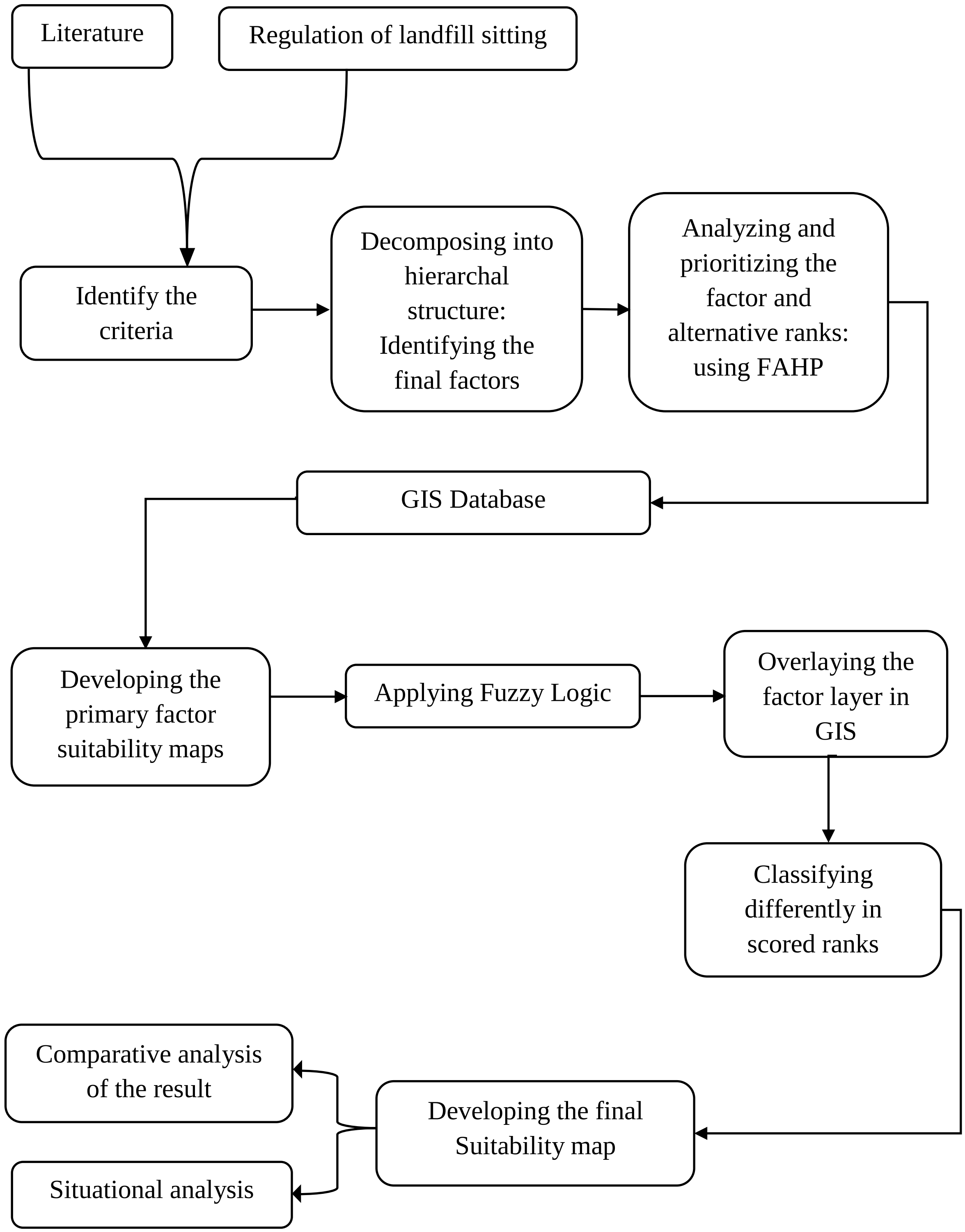

Figure 2:1 the study conceptual framework

CHAPTER III: MATERIALS AND METHODS

3.1 Study Area Description

Bahir Dar, originally inhabited by the Wayto people, is currently serving as the regional capital of Amhara National Regional State (ANRS) in the Federal Democratic Republic of Ethiopia. It is one of the few modern cities established as a gesture towards modern town development in the Imperial Period. Its historical establishment goes back to the period of the Italian invasion in the period 1936–41 (Municipality of Bahir Dar, 2003). It had a total population of 96,140 in 1994 and 230,344 in 2007 (CSA, 2007), and an estimated 297,749 in 2014 (FFE, 2010). The annual population growth of the town is about 6.6% (Ebistu et al., 2013). It has become one of the country's most popular tourist destinations, with numerous attractions in the nearby Lake Tana (Ethiopia's largest lake, famous for churches and monasteries on the lake's 37 islands) and Blue Nile River (FFE, 2010).The city has expanded rapidly throughout the 20th century and is the fastest growing city in the country (UNEP, 2010a).

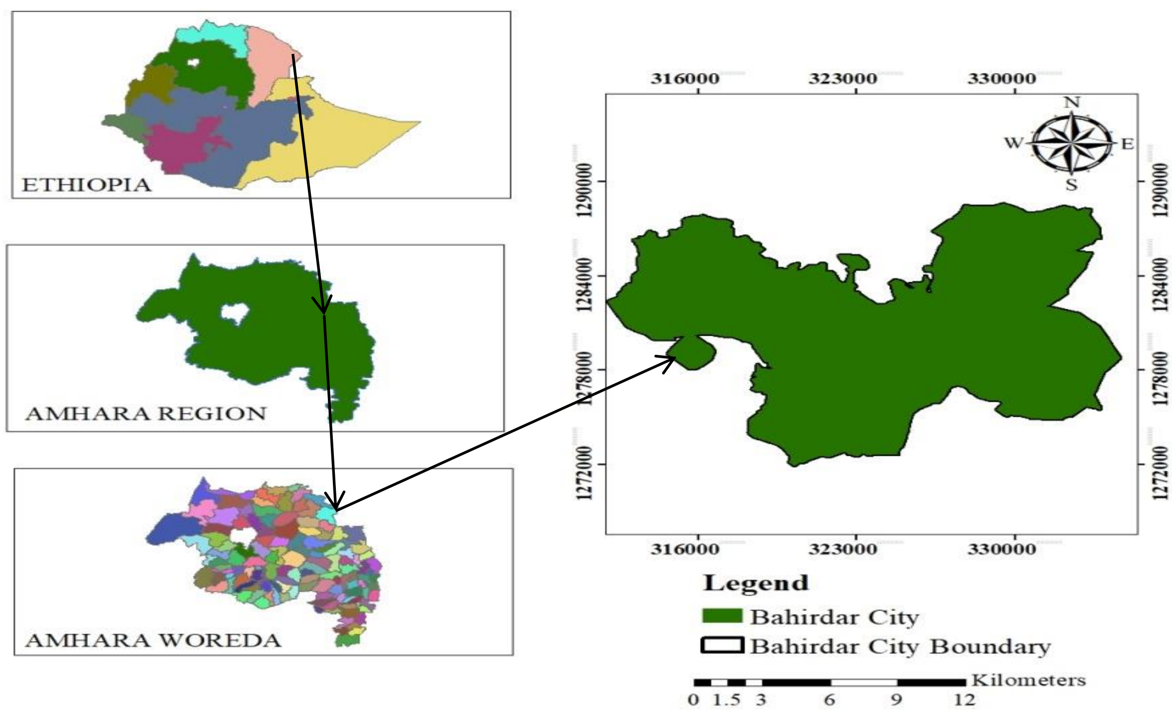

Figure 3:1 Study area map

3.1.1 Geographical

Bahir Dar City is located at 11° 38'N, 37° 25' E on the Southern end of Lake Tana which is the source of Blue Nile by its native name '*Abay'*. The study area is found in the North Western about 563kms away from the capital of Ethiopia, Addis Ababa, covering an area of about 229 square kilometers. It comprises 9 sub-cities and 11 rural kebeles. The mean annual rainfall in Bahir Dar City is 1384 mm. The rainy season extends from June to September. The mean annual temperature in the city is 27°C.

3.1.2 Topography

The topography of Bahir Dar city is characterized with an average altitude of 1830m above mean sea level. The city slopes down from the north eastern towards the center and towards the southern part of the city, with the steepest slopes mostly concentrated in the southern and north eastern borders of the study area, and continues flowing gently up towards the most western border of the city creating a saddle topography in the central part stretching towards the most northern, towards Lake Tana, and southern borders. These results in the occurrence of streams and drainages draining towards the river Nile (Abay), Lake Tana and other seasonal and permanent streams mostly from the north eastern and western parts of the study area.

3.2 Data Collection Techniques & Data Source

3.2.1 Primary Data

Survey data are the primary data types that were used in this study. During a field survey, points to identify public facilities like schools and health centers as well as protected areas like churches, public parks, and mosques were collected using GPS for the purpose of constraint and factor mapping. In addition, some sample points from different land use and cover types were also collected to update the current land use and cover type of the study area. Photographs and field observations were also used to show the existing landfill site. Satellite images were also some of the primary data types used to show the character of land use in this study.

3.2.2 Secondary Data

Table 3:1 Secondary Data, Source and Purpose

Data	Source	Purpose
Boundary of City	Bahirdar municipality	To determine the location of the study area.
Road Network	Bahirdar municipality	For road proximity constraint and factor mapping.
Lithology	Ethiopia Geologic survey	For Lithology factor mapping and fault line constraint and factor
Wells/springs	Bahirdar WSS Office	For Wells/springs proximity constraint and factor mapping.
LULC	Satellite image/Landsat 8/2022	For land use factor mapping.
Soil Texture	Ethiopia Ministry of agriculture	For soil texture factor mapping.
Slope	DEM	For slope factor mapping.
Surface	DEM and google earth	For Surface water proximity constraint and factor mapping.

3.3 Materials and Software Used

Table 3:2 Materials and Software needed with the possible sources and purpose

Material or Software Name	Purpose
Garmin GPS map 76CS	For collecting location data of existing dumping sites, and for ground truth data
Arc GIS 10.7	For data processing, main analysis, map preparation, etc.
ENVI	For Image processing and data analysis.
Google Earth Pre	Used as supplementary for accuracy of the classification and data extraction.

3.4 Methods

Generally, a siting process can be divided into six phases. The first phase is when all GIS spatial data is converted to the Adindan UTM Zone 37N Coordinate System and used in a transversal Mercator projection. The second phase feasibility analysis is aimed at selecting ‘‘unsuitable areas’’ the Exclusion of restricted areas for landfill siting defined by literature and legislation. The constraints based on the Boolean criteria were used to differentiate areas that can be considered suitable for a waste disposal site from those that cannot be considered suitable under any conditions. In the third phase of a GIS environment, fuzzy membership functions were used to standardize the factors to a continuous scale of suitability from zero (least suitable) to one (most suitable), then weighted and combined using the AHP methods. The fourth phase of suitability maps was created using the WLC aggregation method. Three scenarios were created by combining the suitability maps for each set of factors to enable selection of the most appropriate sites. Fifth Phase: Landfill suitability is classified in five equally scored classes: high, suitable, moderate, low, and very low suitability areas. Sixth and final phase: evaluating alternative landfill sites and comparing them to preferred landfill sites based on 10 used factor maps.

3.4.1 Classification of Exclusion Criteria

Exclusion criteria are constraints with the goal of limiting research to suitable sites that do not tolerate competition (Sahnoun H et al. 2012).The classification process involves choosing various areas that represent a new plan of information for a required condition. Maps were divided into two categories: zones verifying the condition were given a ranking of 1, and all other zones received a ranking of 0. The resulting image is a Boolean image. The last step consisted of combining, by superposition, the information contained in Boolean layers relative to the exclusion criteria. The logical operator "AND" has been used in this part; it translates the intersection between conditions that must be absolutely satisfied.

3.4.2 Standardization of Appreciation Criteria

MCE demands that the values in the various criterion map layers be transformed to similar units (Moeinaddini M et al. 2010). A number of approaches can be used to make criterion map layers comparable. The "fuzzy membership approach" is one of the standardization methods that have been proposed (Sahnoun H et al. 2012). For this reason, fuzzy sets were used in this study. To apply fuzzy functions in the GIS environment in this case study, all the map layers are transformed to a raster format with a 100-m pixel size. Seven fuzzy membership functions are provided in GIS: Gaussian, MS Small, Linear, Large, Small, Near, and MS Large. Our choice has been made relying on geo-environmental and socio-economic data that has been standardized into one common interval ranging from zero to one.

3.4.3 Fuzzy-AHP Weighting factors method

The purpose of criterion weighting is to express the importance of each criterion relative to other criteria. AHP is one of the most convenient methodologies for dealing with complex problems where both qualitative and quantitative aspects need to be considered. However, some researchers claim that there are some weaknesses in Saaty's AHP method (e.g. Costa and Vansnick, 2008). The AHP method, which is used effectively in the solution of many decision-making problems, has been criticized for the use of real numbers in the process of pairwise comparisons. Therefore, using fuzzy numbers was proposed to overcome this problem (Lee et al. 2013).

In the present study, FAHP was applied in order to evaluate and weight criteria in relation to the landfill site selection. Ten criteria selected in this site selection process were classified into three main classes. Fuzzy numbers were used as a useful tool for quantifying the uncertainty of comparison judgments. A triangular fuzzy number is a special class of fuzzy number whose membership is defined by three real numbers, expressed as (l, m, u). In addition, the membership function is described mathematically in the following form (Cox, 1995).

$$\mu_A(\chi)\begin{cases} \dfrac{(\chi - l)}{(m - l)}, l \leqslant \chi \leqslant m \\ \dfrac{(u - \chi)}{(u - m)}, m \leqslant \chi \leqslant u \\ 0 \qquad \text{otherwise} \end{cases}$$

Where l, m, and u are the lower, mean, and upper bounds of the triangular fuzzy number, respectively. The membership function μ represents the degree to which any given element χ in the domain X belongs to the fuzzy number A. In this study, because of simple calculation in comparison with other FAHP approaches, fuzzy extent analysis (Chang, 1996) was employed for calculation of criteria weights. In this approach when the expert judgments are expressed as triangular fuzzy numbers, the triangular fuzzy comparison matrix is

$$\tilde{A} = \left(\tilde{a}_{ij}\right)_{n\times n} = \begin{bmatrix} (1,1,1) & (l_{12},m_{12},u_{12})\ldots & (l_{1n},m_{1n},u_{1n}) \\ (l_{21},m_{21},u_{21}) & (1,1,1) \quad \ldots & (l_{2n},m_{2n},u_{2n}) \\ \vdots & \vdots & \vdots \\ (l_{n1},m_{n1},u_{n1}) & (l_{n2},m_{n2},u_{n2})\cdots & (1,1,1) \end{bmatrix}$$

$$\text{where } \tilde{a}_{ij} = \left(l_{ij},m_{ij},u_{ij}\right) \quad \text{and} \quad \tilde{a}_{ij}^{-1} = \left(1/u_{ji},1/m_{ji},1/l_{ji}\right)$$
$$\text{for } i,j,=1,\ldots,n \quad \text{and} \quad i \neq j.$$

Chang’s fuzzy extent analysis has steps as follows.

1. Sum each row of the fuzzy comparison matrix Ã and then normalize the row sums by the fuzzy arithmetic operation

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{a}_{ij} \otimes \left[\sum_{k=1}^{n}\sum_{j=1}^{n} \tilde{a}_{kj}\right]^{-1}$$
$$= \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}}\right)$$
$$i = 1,\ldots,n$$

Where ⨂ denotes the extended multiplication of two fuzzy numbers. Depending on the total objective, these fuzzy triangular numbers (as the relative weights for each alternative under a given criterion) are used to represent the weight of each criterion. A weighted summation is then used to obtain the overall performance of each alternative.

2. Compute the degree of possibility for $\tilde{s}_i \widetilde{\geq s_j}$ by the following equation

$$V\left(\tilde{S}_i \geqslant \tilde{S}_j\right) = \sup_{y \geqslant \chi}\left[\min\left(\tilde{S}_i(x), \tilde{S}_j(y)\right)\right]$$

This formula can be equivalently expressed as

$$V\left(\tilde{S}_i \geqslant \tilde{S}_j\right) = \begin{cases} 1 & m_i \geqslant m_j \\ \dfrac{u_i - l_i}{\left(u_i - m_i\right) + \left(m_j - l_j\right)} & l_i \leqslant u_i \quad i, j = 1, \ldots, n; j \neq i \\ 0 & \text{otherwise} \end{cases}$$

$$\text{where} \quad \tilde{S}_i = \left(l_i, m_i, u_i\right) \quad \text{and} \quad \tilde{S}_j = \left(l_j, m_j, u_j\right)$$

Estimation of the priority vector (W =(w1, … , wn)^T) of the fuzzy comparison matrix Ã as follows

$$w_i = \frac{V\left(\tilde{S}_i \geqslant \tilde{S}_j \quad j = 1, \ldots, n; j \neq i\right)}{\sum_{k=1}^{n} V\left(\tilde{S}_k \geqslant \tilde{S}_j \quad j = 1, \ldots, n; j \neq k\right)}, \qquad i = 1, \ldots, n$$

In order to perform a pairwise comparison among fuzzy parameters, linguistic variables have been defined for several levels of preference (Table 3.3).

Table 3:3 Triangular fuzzy numbers pairwise comparisons (Taibi and Atmani 2017)

Linguistic variables	**Triangular fuzzy numbers**	**Reciprocal triangular fuzzy numbers**
Extreme strongly preferred	(7,9,9)	(1/7,1/9,1/9)
Intermediate	(6,8,9)	(1/6,1/8,1/9)
Very strongly preferred	(5,7,9)	(1/5,1/7,1/9)
Intermediate preferred	(4,6,8)	(1/4,1/6,1/8)
Strongly preferred	(3,5,7)	(1/3,1/5,1/7)
Intermediate	(2,4,6)	(1/2,1/4,1/6)

Moderately preferred	(1,3,5)	(1,1/3,1/5)
Intermediate	(1,2,4)	(1,1/2,1/4)
Equally preferred	(1,1,1)	(1,1,1)

3.4.4 Multi-criteria Evaluation by Weighted Linear Combination Method

A multi-criteria evaluation consists of combining a set of criteria (constraints and factors) to build a single suitability map according to a specific category (set of factors). WLC is a technique based on the concept of a weighted average in which continuous criteria are standardized to a common numeric range, and then combined by means of a weighted average to produce a continuous mapping of suitability (Mahini AS, Gholamalifard M. S 2006). The suitability index for a site is the sum of the products of the standardized score for each criterion multiplied by the weight of each criterion; the following equation is given by Eastman (Eastman JR. 2001):

$$S = \sum_{i=1}^{n} wi\ xi$$

where S is the suitability index for area i; w1 , w2 ,…,wn are the weights of the criteria constrained to sum to 1; x1 , x2 ,…,xn are the standardized scores of the criteria i and n is the total number of criteria. As the sum of the weights is constrained to one, the final combined estimate is presented on the same scale.

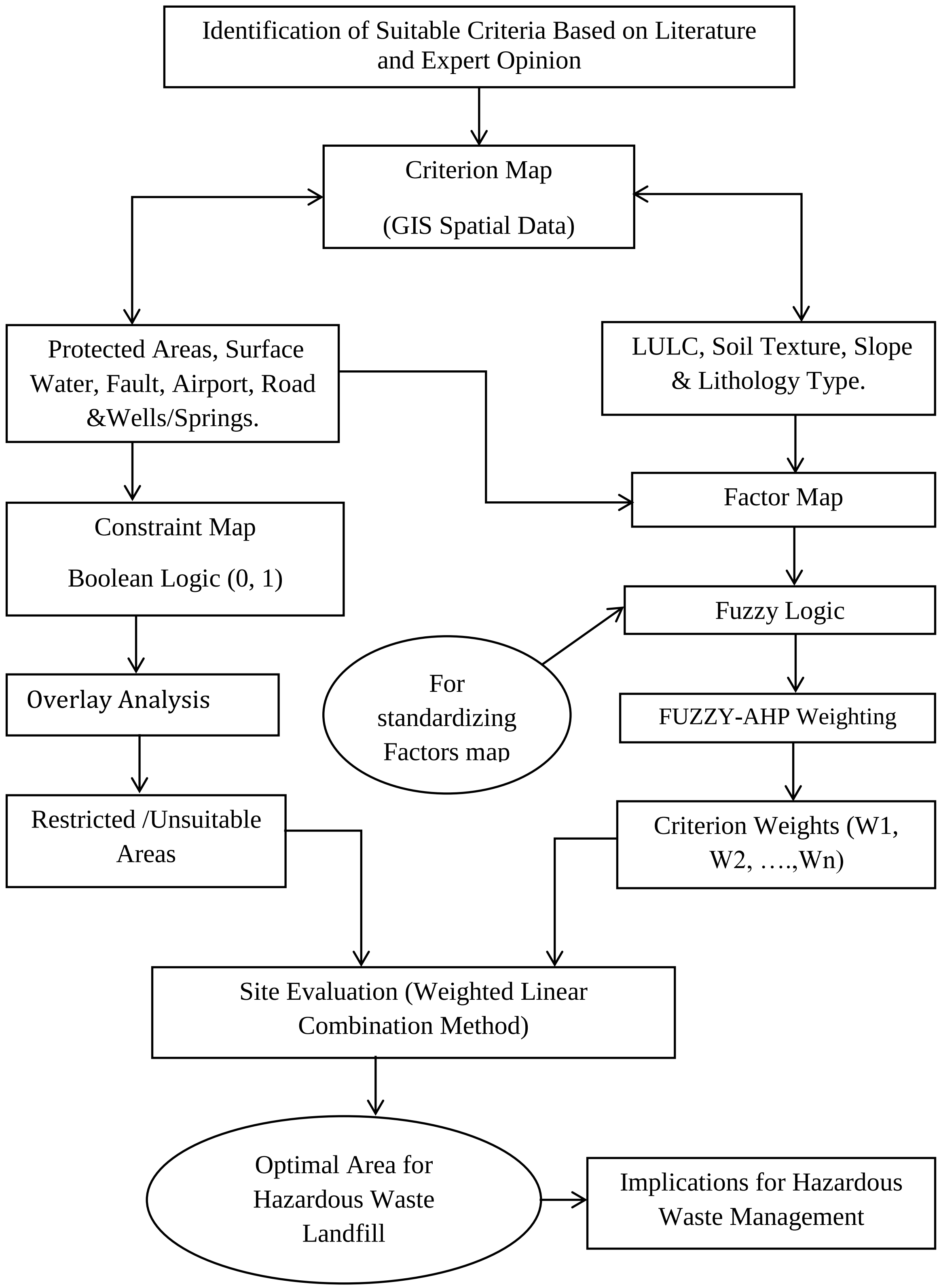

Figure 3:2 Technological schemes of hazardous waste landfill site selection.

3.5 Data Analysis Techniques

3.5.1 Constraints maps

The constraints maps are generated according to Eric S. and Bernard K. (2019), Danesh G. & Monavari,S. (2019) and MSW guidelines and are shown in Figures 3.3 to 3.9. The constraint maps are used to exclude areas in the study area that are considered restricted. Maps were classified into two categories:

1 -Was ranked to zones verifying the condition (restricted) and

0 - Was ranked to the other zones.

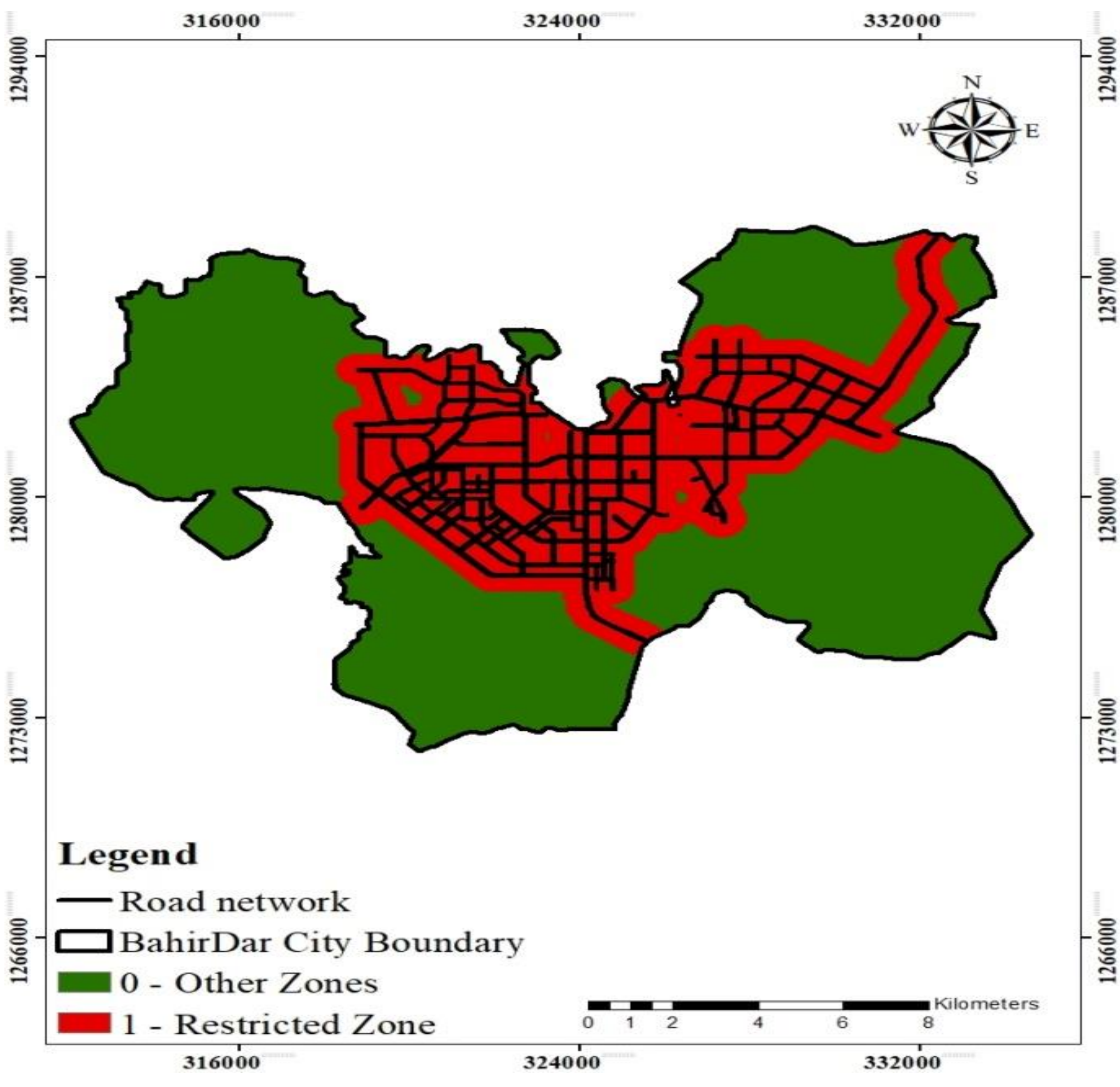

Figure 3:3 Road Network with 500m

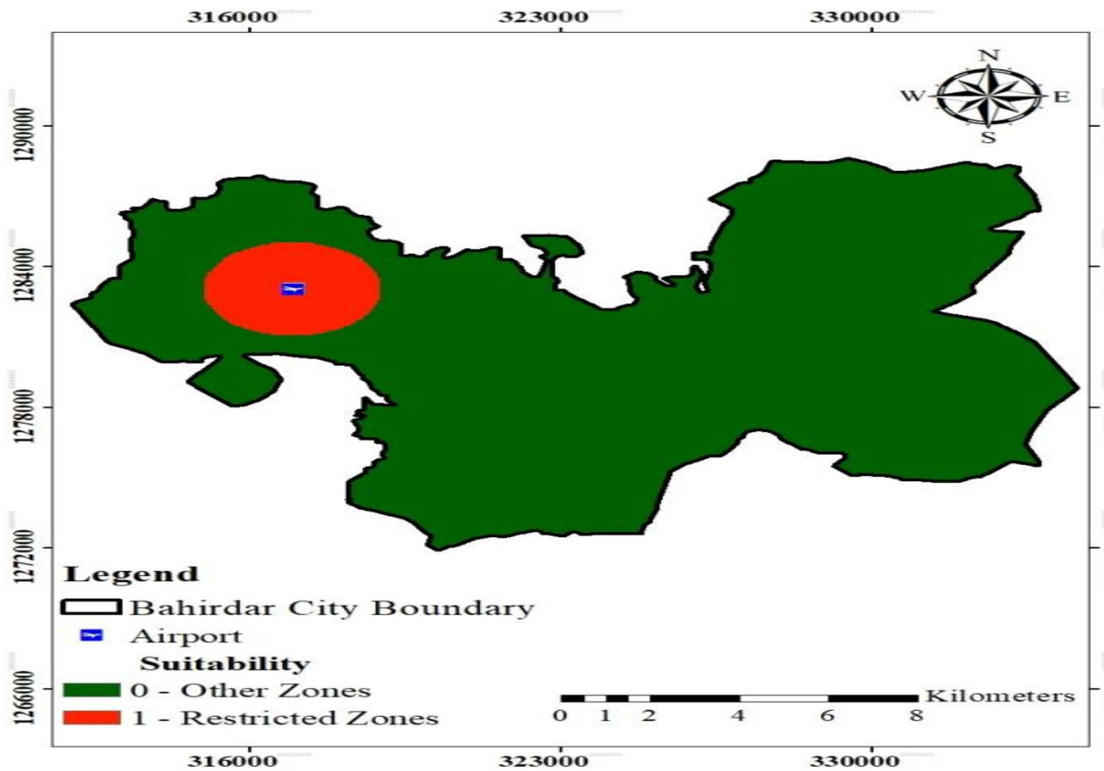

Figure 3:4 Airport with 2km

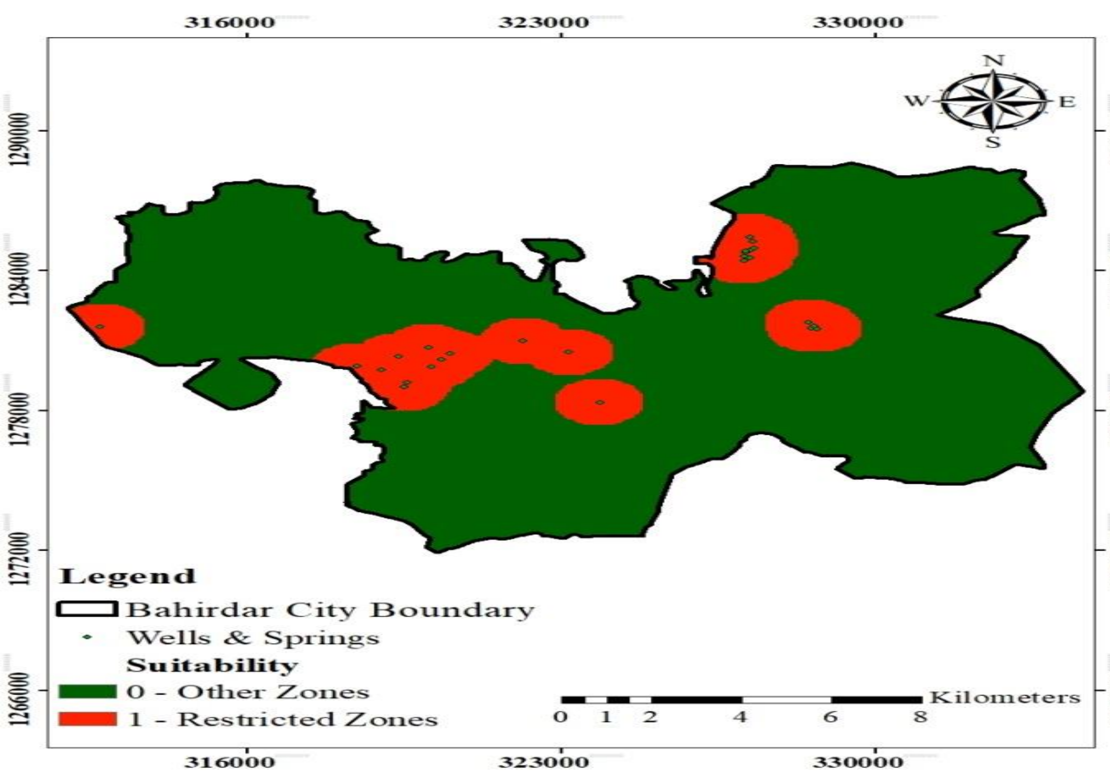

Figure 3:5 Wells/springs with 500m

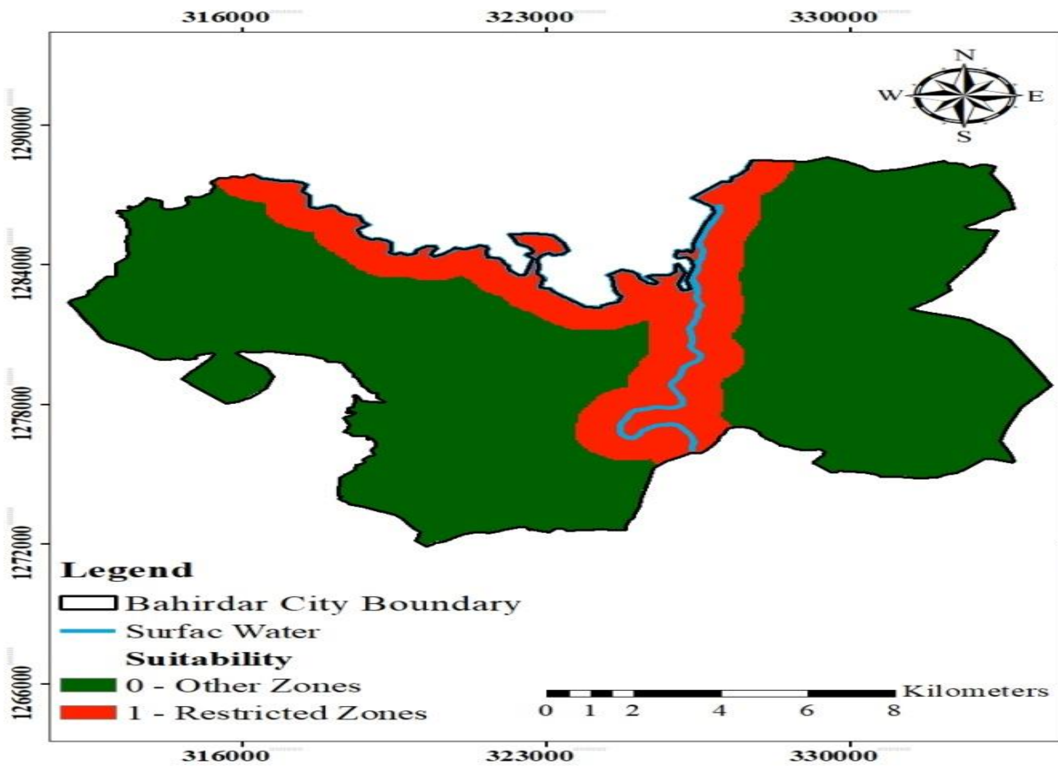

Figure 3:6 Surface water with 1km

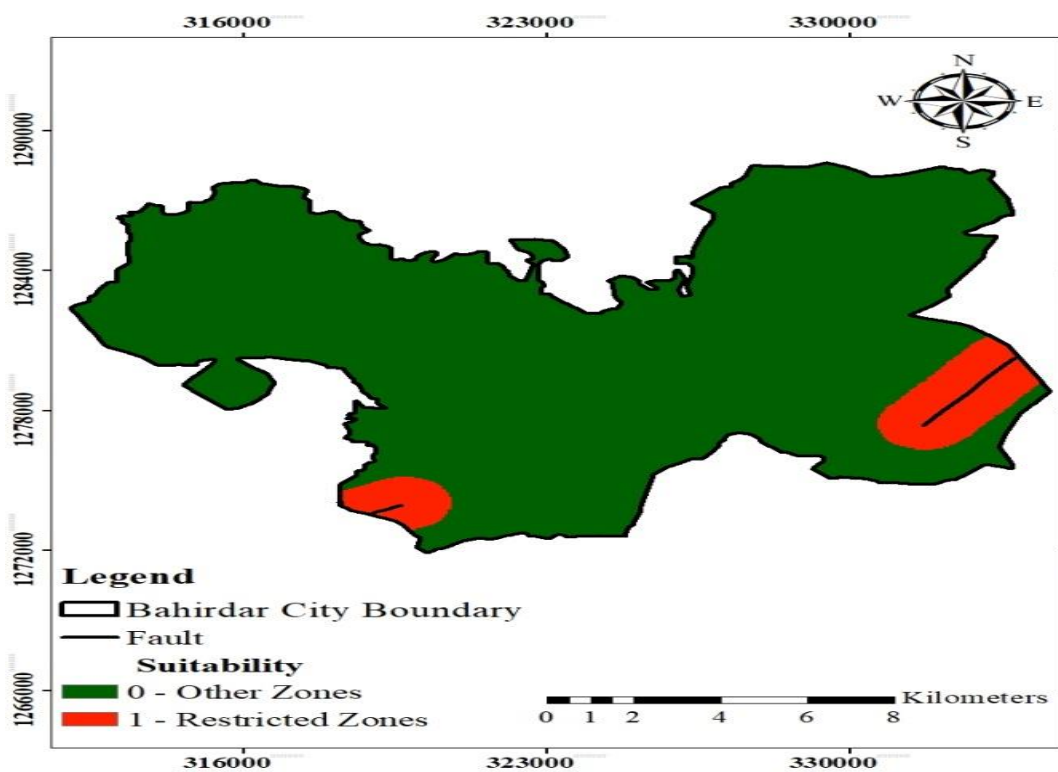

Figure 3:7 faults with 500m

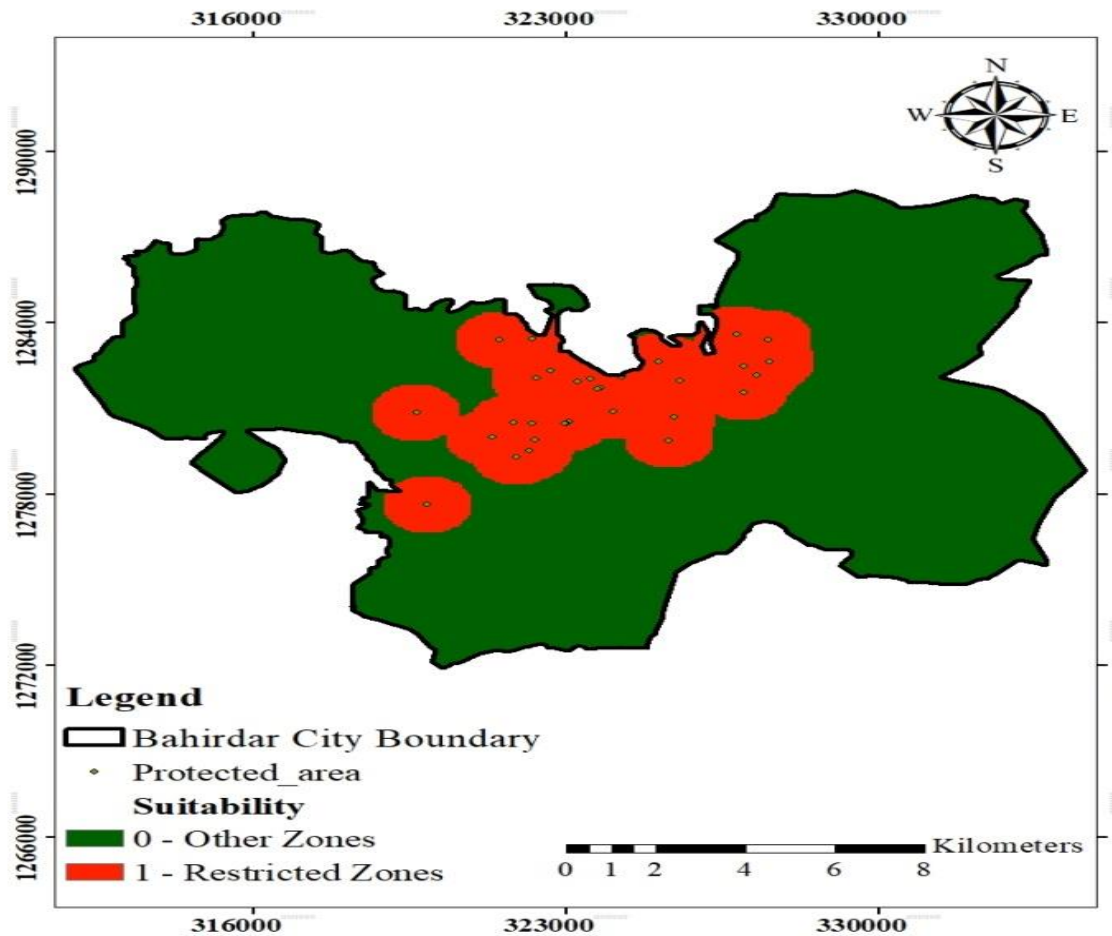

Figure 3:8 protected area with 1km

3.5.2 Fuzzy logic model

A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to scalar output data. In a fuzzy expression (formula), a fuzzy proposition can have its truth value in the interval [0, 1]. The fuzzy membership function, constrained to be between zero and one, reflects the degree of similarity between the data value at that location.

The suitability of land is mapped by pixels of causal factor layers in a fuzzy approach. Pixel values are numeric and range from zero to one, from not suitable to very suitable. Values can be chosen to reflect the degree of membership of a set based on subjective judgment (Amato et al., 2018). Fuzzy logic is preferred for land suitability evaluation due to its ability to estimate land use suitability on a continuous scale, which helps to cope with vagueness and uncertainty (Elaalem, 2012).

In this study, the evaluation criteria were determined and classified into four main categories according to how they are considered to affect the landfill site suitability. These are (1) hydrogeological, (2) Geo-environmental (3) morphologic and (4) socioeconomic criteria. The first category includes the constraining criteria that limit the analyses to particular geographic areas. The second category includes factors relevant to environmental parameters, whereas the third and fourth categories comprise factors relevant to the design and the construction of the landfill and the social case of the region, respectively. In the four main categories, ten criteria such as lithology, lineament/Fault, surface water, wells/spring, airport, protected area, soil texture slope, distance to roads, and land use were selected for the computation process.

3.5.3 Standardization of land characteristics using fuzzy set models

Fuzzy logic helps the user determine the likelihood that a site is suitable or unsuitable. This step assigns values from zero to one, with zero being not likely or unsuitable and one being most likely or suitable. Thus, the higher fuzzy value implies the ideal site. When assigning fuzzy values, four types of membership need to be understood to choose the best fits for the analysis criteria. There are four types of membership functions in fuzzy systems: linear, small, large, and Gaussian. In this study, the linear membership function was used to normalize the parameters due to its dependence on input parameters. If the input parameters seem chaotic, similar to a time series, the Gaussian type of membership function would be suggested; otherwise, the linear type is recommended (Qiu et al., 2014). High Fuzzy Membership is assigned to large or small values, and Fuzzy Membership decreases at a constant rate. In this study, linear functions were used to represent the reality function.

3.5.4 Generation of the criteria map layers

Before the spatial analysis is performed to identify suitable landfill sites, objectives, criteria, and factors are set and evaluated for their suitability for the study area. Thus, related legislation, restrictions, rules, experience, which several researchers have used, and local expertise are considered. This step assigns values from zero to one, with zero being unsuitable and one being most suitable. The range between zero and one for the membership function corresponds to the intensity of importance of each criterion, which is obtained from the literature and experts' opinions.

3.5.4.1 Land Use/land cover

Land use has great importance in sustainable watershed management, and especially surface waters, wetlands, and forests should be distant from environmental pollutants. In the present study, the land use and land cover of the study area were obtained from a Landsat OLI satellite image with a spatial resolution of 30 m x 30 m from March 2022, downloaded from the official website of the United States Geological Survey (www.usgs.gov), using a supervised classification technique with landfill using ENVI software. As a result, the study area was divided into several land use and land cover classes, including settlement, wetland, lagoon, forest, "planted cover," mosaic of thicket of grass, herb, shrub, and bare land.As per international practices for the selection of landfill sites, landfill sites may not be chosen for certain land uses, including agriculture and forestry. The maximum likelihood classification (MLC) (supervised classification) was used to create the LULC map. The uncertainty or error matrix is used to verify the results of the classification and has been established with good agreement (overall accuracy and Kappa coefficient of 91.32 and 0.8915, respectively).

Table 3:4 Potential Sites Land Use Fuzzy value and FAHP weight

Land Use Type	Fuzzy Value	Suitability	Weight
Settlement/ water/ forest	0.00-0.228	Unsuitable	0.358
Agriculture	0.228-0.470	Low suitable	
thicket of grass	0.470-0.727	Moderate suitable	
Bar land shrub herb	0.727-1.000	High suitable	

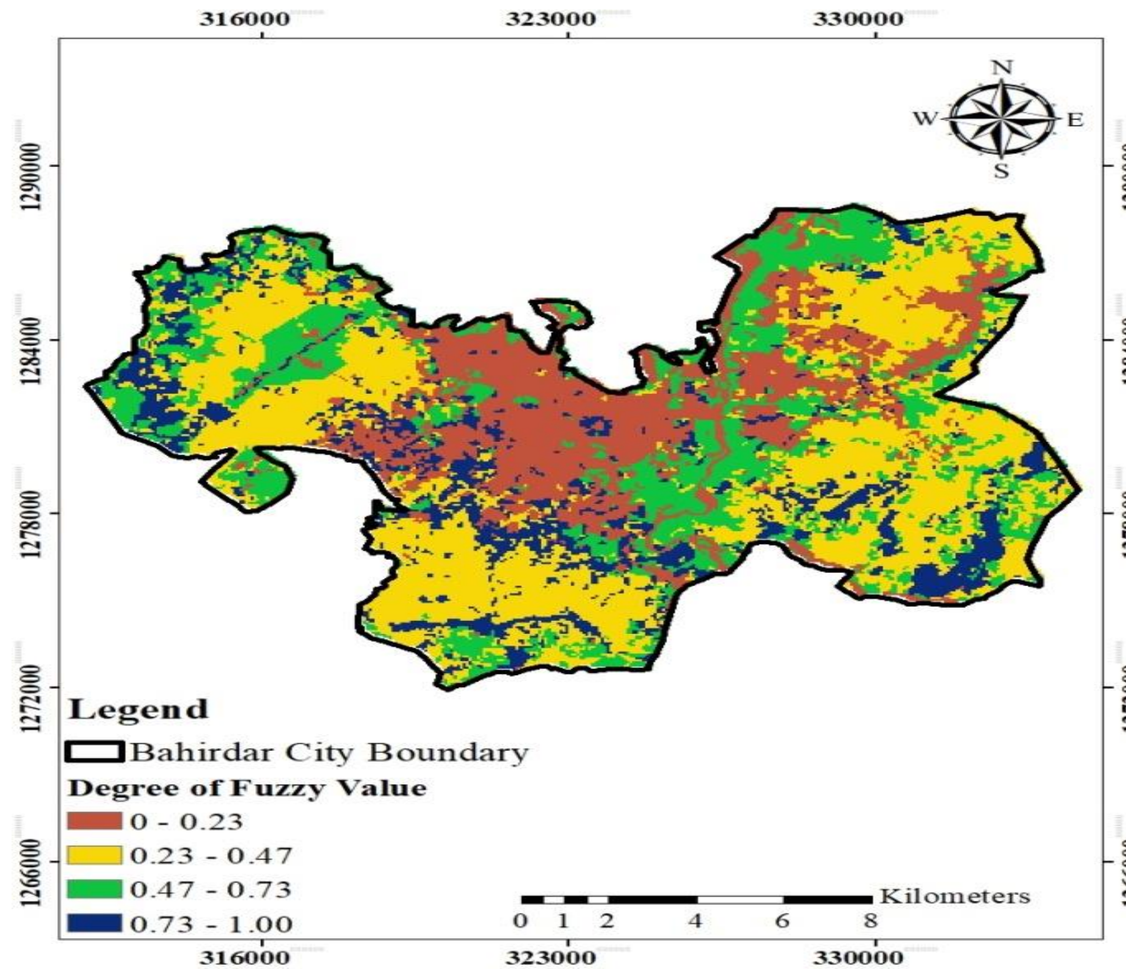

Figure 3:9 Land use Fuzzy value and suitability map

3.5.4.2 Lithology

The geology of an area will directly control the soil types created from the parent material, the load-bearing capacity of the landfill's foundation soil, and the migration of leachate. Lithology is one of the important environmental factors that should be considered for waste disposal site selection processes. The Lithology Map of the Study Area was obtained from the Ethiopian Geological Survey. The study area of the map was geo-referenced and digitized in a GIS environment. The study area has three lithology classes, as shown in the fig below. The suitability classification is based on the permeability of the soil and lithology structure (Ismail et al., 2016).

Quaternary Basalt (QB): forming unevenly distributed cinder cones and sometimes broad-based gentle sloping circular to elliptical hills dark brown, reddish-grey fresh color and coarse grained texture. The Quaternary volcanic sequence comprises blocky and fractured vesicular basalt, with a porphyritic, glassy texture. The Quaternary volcanic are expected to be more than 100m thick and perhaps as much as 200-300m thick (Geologic Survey of Ethiopia 2012).

Taramber-Gussa Formation: dark-grey in fresh sample and reddish to yellowish brown weather sample medium to coarse grained texture and high productivity aquifer in the low topographic setting where it is moderately weathered and fractured(Geologic Survey of Ethiopia 2012).

Rhyolite: unevenly distributed domes and broad-based, gently sloping circular to elliptical hills, light gray to pink in fresh samples, and composed of alkali feldspar, quartz, and mica. It is light grey to pink in color and composed of alkali feldspar, quartz, and mica. It forms unevenly distributed small domes and broad-based, gently sloping circular to elliptical hills. Locally, the rock is joined weakly to strongly in both a vertical and horizontal orientation.In places, it shows intercalation of fine ash and unwedded tuffs (Geologic Survey of Ethiopia 2012). Based on the above and other considerations, the suitability set is below the table.

Table 3:5 Potential Sites geology type Fuzzy value and FAHP weight

Lithology type	Fuzzy Value	Suitability	Weight
Taramber-Gussa Formation	0.00-0.333	suitable	
Rhyolite	0.333-0.667	Moderate suitable	0.141
Quaternary Basalt (QB)	0.667-1.000	High suitable	

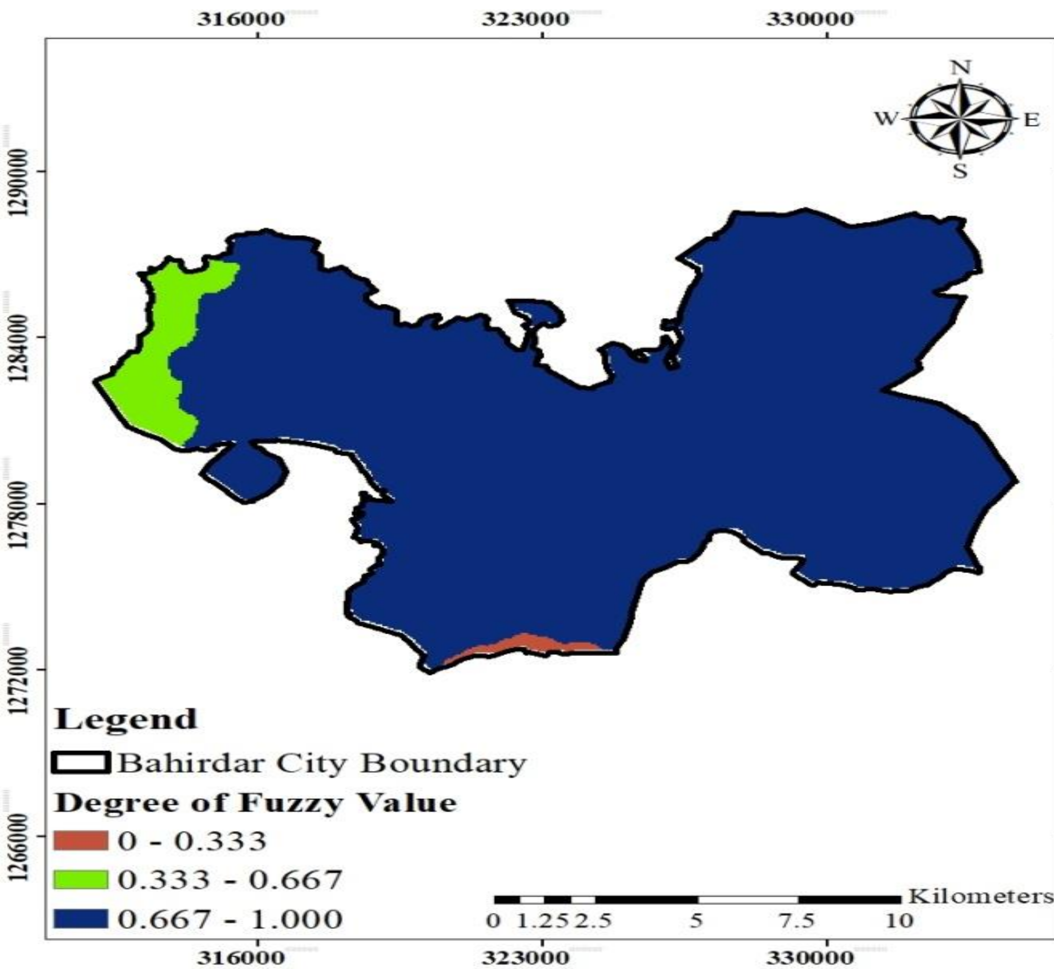

Figure 3:10 Lithology type Fuzzy value and suitability map

3.5.4.3 Surface water

Bahir Dar City is well known for its surface water resources. The city is located on the southern shore of Lake Tana. In addition to this, the River Nile (known by its local name, ABAY), which is thought to originate from Lake Tana, passes from north to south in the city, dividing the city area into two parts. The landfill site should not be placed within surface water or water resources protection areas to protect surface water from getting contaminated by leachate. Safe distances from meandering and non-meandering rivers should be achieved to prevent waste from eroding into rivers, major streams, and coastlines. Landfills are potential threats to lakes, wetlands, ponds, and rivers by generating leachate and gaseous pollutants; thus, a distance zone from surface waters is needed. According to Gbanie et al. (2013), Sharifi et al. (2009), and Wang et al. (2009), a distance of less than 1,000 m between a land fill and surface water is unsuitable for landfill siting, while a distance of more than 5 km is highly suitable for landfill siting.Based on the above and other considerations, the value is set below the table.

Table 3:6 Distance from Surface water Fuzzy value and FAHP weight

Distance from the Surface water(km)	Fuzzy Value	Suitability	Weight
<1	0.00-0.228	Unsuitable	
1-3	0.228-0.470	Low suitable	0.05
3 -5	0.470-0.727	Moderate suitable	
>5	0.727-1.000	High suitable	

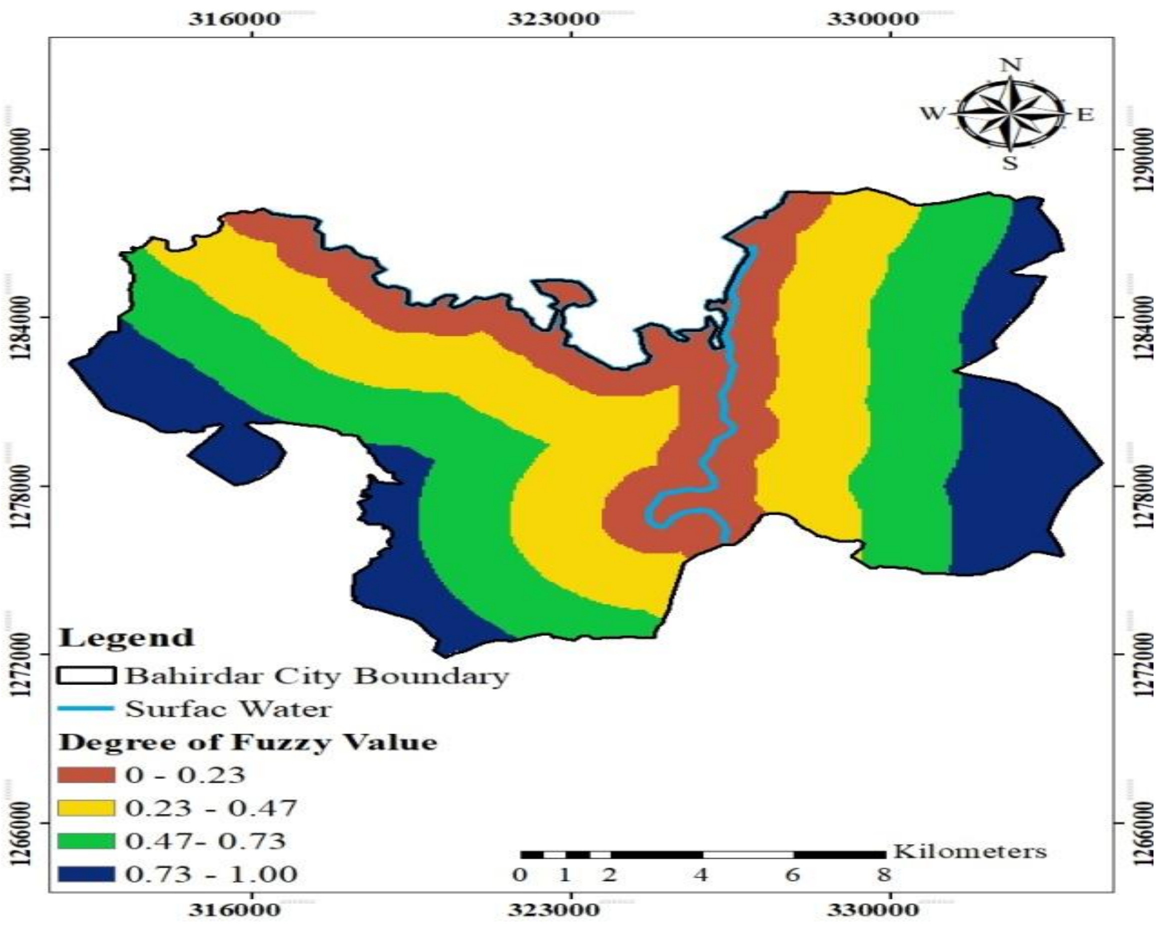

Figure 3:11 Surface water Fuzzy value and suitability map

3.5.4.4 Airport

In the selection of suitable waste landfill sites, airport areas should be considered restricted areas. The landfill site should not be located near an airport or airport base in order to protect potential hazards in flights caused by birds, other flying animals, and insects that are attracted to waste in disposal sites.Distance from airports Landfill sites are a hazard for airports due to smoke and haze, as well as the possibility of explosions and fires. In addition to this, it will help to reduce the effects on health and annoyance on passengers that arise from the unpleasant odors coming out of the landfill sites. According to Effat and Hegazy (2012), 5 km is not suitable, 5–10 km is suitable, and > 10 km is most suitable. According to Motlagh and Sayadi (2015), 3 km is not suitable, 7 km is suitable, and according to Moeinaddini et al. (2010), it is completely suitable 3 to 5 km: suitability is increasing from unsuitable to completely suitable. Based on the above and other considerations, the value is set below the table.

Table 3:7 Distance from Airport Fuzzy value and FAHP weight

Distance from the Airport(km)	Fuzzy Value	Suitability	Weight
<3	0.00-0.228	Unsuitable	
3-5	0.228-0.470	Low suitable	0.075
5-10	0.470-0.727	Moderate suitable	
>10	0.727-1.000	High suitable	

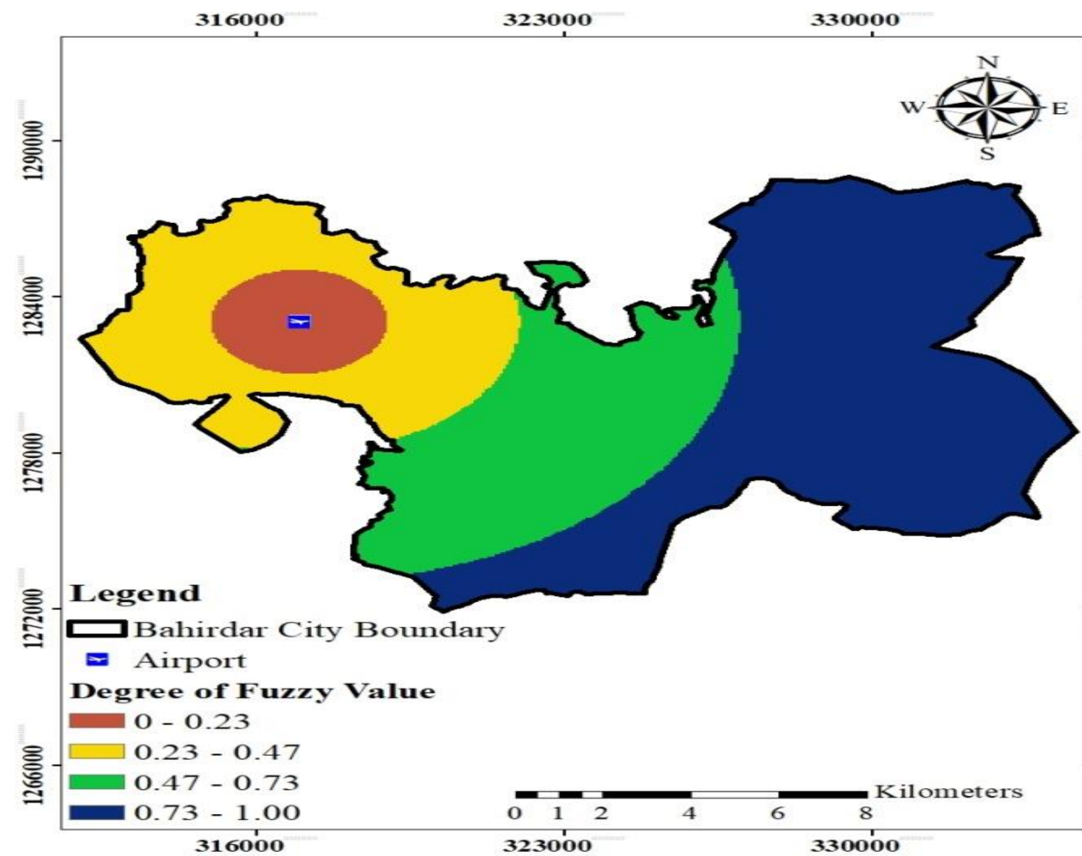

Figure 3:12 Airport Fuzzy value and suitability map

3.5.4.5 Road

Proximity to roads is one of the criteria that should be considered from different points of view during hazardous waste landfill site selection processes. Because waste disposal very close to roads may cause public health issues due to the hazardous effects on health,Esthetic considerations are recommended for good planning, and landfill sites should be accessible under any circumstances (Nas, B et al., 2010).Deposits closer to the road, on the other hand, provide an unappealing view.Moreover, waste disposal sites very far from the road network are also not recommended due to high transportation costs. Therefore, to minimize such problems, it must not be positioned very close to or far from roads. Minimum and maximum distances from the road network of the study area were set after summarizing different literatures. (Geneletti (2010); Sener et al. (2010); Sharifi et al. (2009); Wang et al. (2009)) used (0.5 km, >10 km) as unsuitable, (0.5 km–2 km) as low suitability, (2 km–5 km) as moderate suitability, and (5 km–10 km) as high suitability. The Euclidean distance was used to assess distances from or outside the road network. Based on the above and other considerations, the value is set below the table.

Table 3:8 Distance from roads Fuzzy value and FAHP weight

Distance from the roads(km)	Fuzzy Value	Suitability	Weight
<1, >10	0.00-0.228	Unsuitable	
1-2	0.228-0.470	Low suitable	0.06
2-5	0.470-0.727	Moderate suitable	
5-10	0.727-1.000	High suitable	

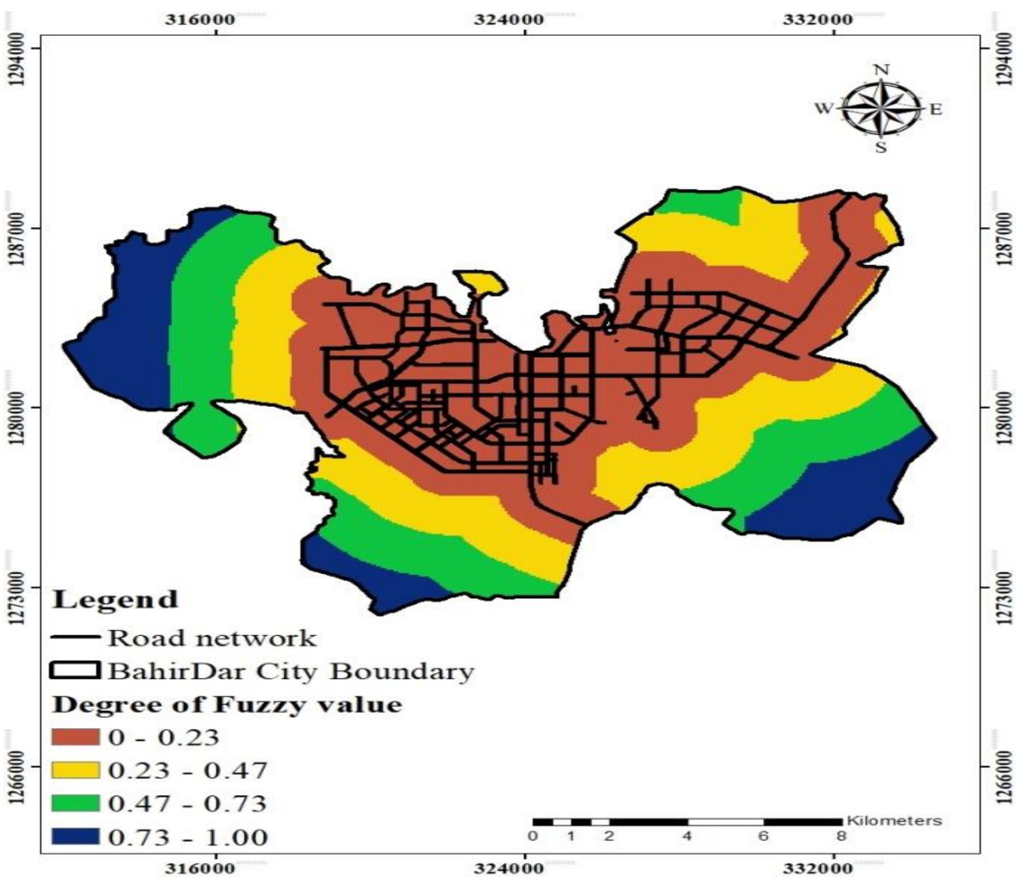

Figure 3:13 Road Fuzzy value and suitability map

3.5.4.6 Protected area

The protected area in this study includes the park, churches, mosques, schools, and health centers. The landfill should not be located in close proximity to sensitive areas. When the distance increases from these areas, suitability also increases. In this study, the X and Y coordinates for the above-listed protected areas were gathered using GPS during the field survey. According to Ghazaleh et al. (2019) More than 2.5km equal to high suitable; 1km–2.5km between suitable ; 0–1km equal to unsuitable The Euclidean distance was used to assess distances from or outside the protected area. Based on the above and other considerations the value set below the table.

Table 3:9 Distance from Protected area Fuzzy value and FAHP weight

Distance from the Protected(km) area	Fuzzy Value	Suitability	Weight
<1	0.00	Unsuitable	
1-2.5	0.00-0.598	Moderate suitable	0.037
>2.5	0.598-1.000	High suitable	

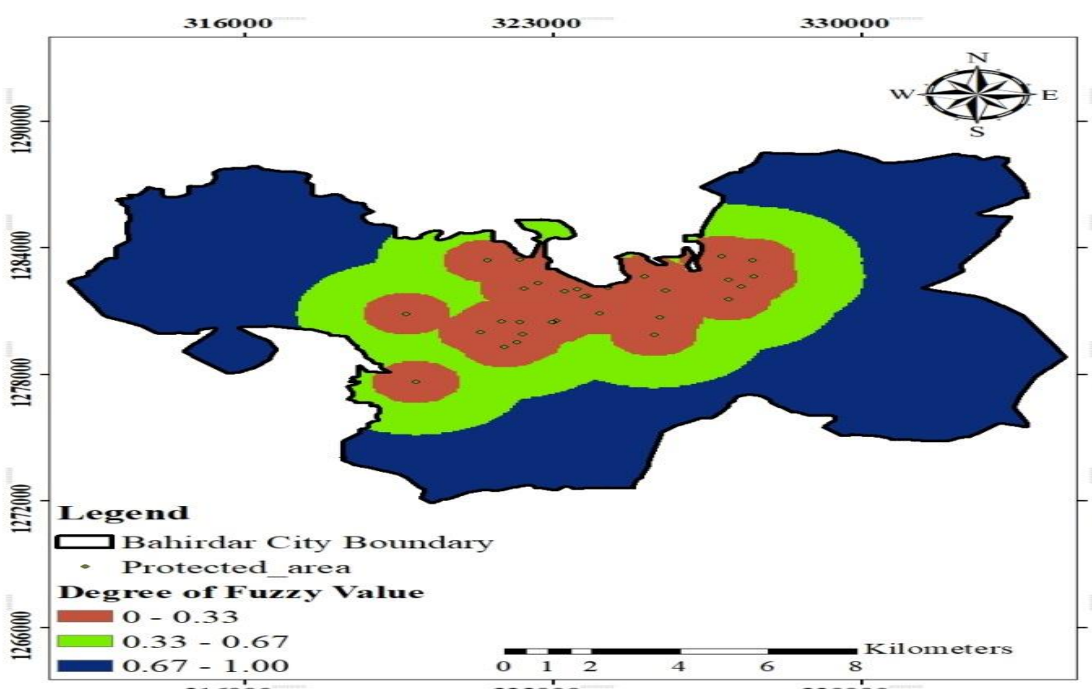

Figure 3:14 Protected area Fuzzy value and suitability map

3.5.4.7 Fault

Fractures, including joints and faults, are open paths for leachates from a landfill site to contaminate ground or surface water. Faults are key groundwater controls in any underground environment. Being poor areas, they typically act as conduits for subsurface movement or the accumulation of groundwater. It is therefore pragmatic that no landfill site be located around a high lineal density, as this may lead to significant contamination of groundwater supplies by leaching. High lineament density regions tend to support high groundwater availability (Mogaji, K. et al.). Therefore, landfills should be located in areas with low lineal densities.

Faults are geological structures that restrict the siting of a secure landfill site as these allow the leachate to flow quickly to realize groundwater. Chattopadhyay et al. (2009) showed that the area found within a 1000-m buffer distance from faults was considered unsuitable for a solid waste disposal site due to the high permeability of the soil near the fault and to keep ground water from contamination. Additionally, according to Hafezi et al. (2011) and Sharifi et al. (2009) applied less than 1km unsuitable, 1km-2km low suitable, 2km-4km moderate suitable and greater than 4km high suitable. Based on the above and other considerations, the value is set below the table.

Table 3:10 Fault Fuzzy value and FAHP weight

Distance from the Fault(km)	Fuzzy Value	Suitability	Weight
<1	0.00-0.228	Unsuitable	
1-2	0.228-0.470	Low suitable	0.025
2-4	0.470-0.727	Moderate suitable	
>4	0.727-1.000	High suitable	

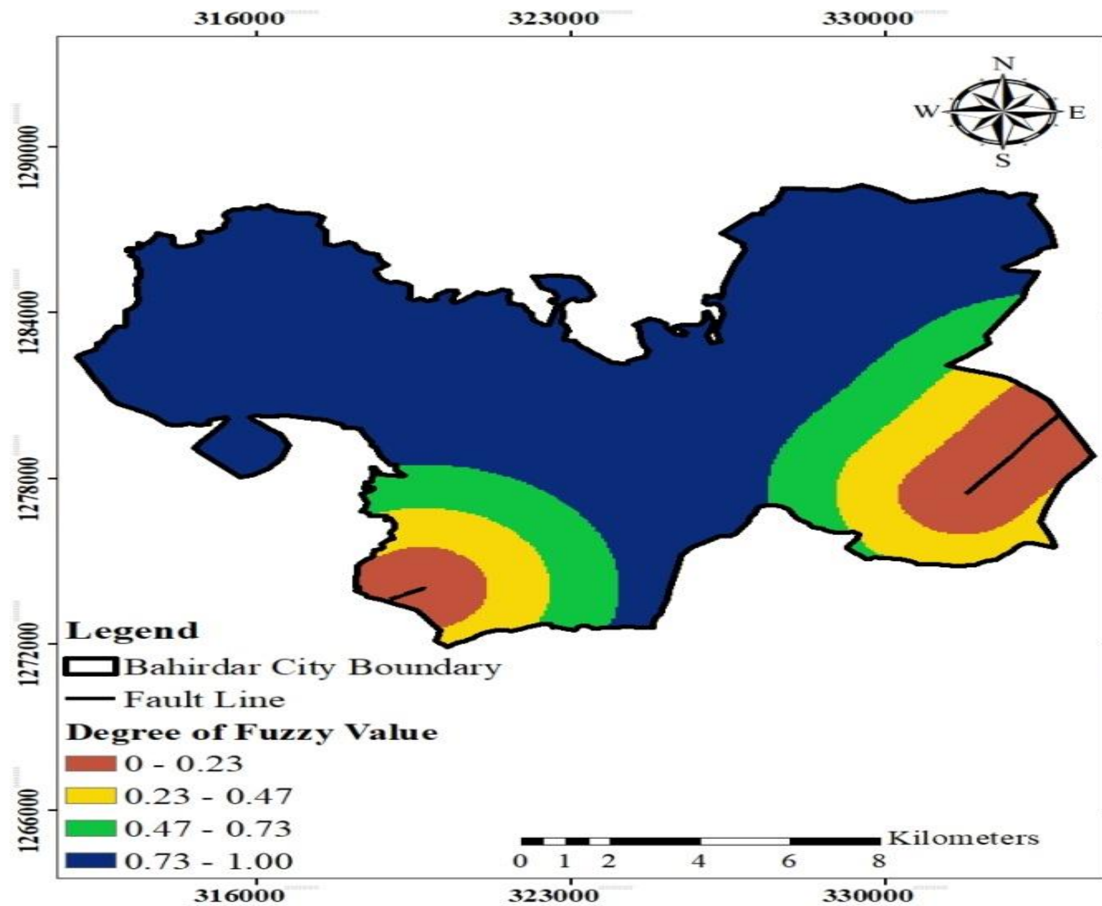

Figure 3:15 Fault area Fuzzy value and suitability map

3.5.4.8 Surface slope

The slope is an important determinant of many landscape processes including soil water quality, erosion risk, and surface runoff. The slope is very significant in the design of landfill sites, as its stability forms an important part of the material weight at the landfill site. Land slope has an impact on drainage, soil water content, the potential for erosion, and velocity of overland and subsurface flow (Donevska et al., 2012; Gorsevski et al., 2012). Steep area increases drainage from the landfill to the downstream, increasing downstream water pollution risks, intensifying engineering construction, and increasing landslide risks (Chabuk et al., 2016; Djokanovic et al., 2016).On the other hand, a flat location would affect the runoff drainage. The suggested slope for landfill construction is 8-12% Nevertheless, the limitations and values vary from location to location and depend on the topographical situation of each area (Chabuk et al., 2016; Donevska et al., 2012). Weight values with slope values of 30-68 were classified as the lowest and lowest slope

(0-10) areas deemed very suitable and assigned the highest weight values (Kamdar, I et al., 2019).According to Hasan et al. (2009), areas with a slope of 15% to 20% are best suitable for locating landfills; besides, Change et al. (2007) fixed a 12% slope as the best suitable slope, while areas with a slope >12% are unsuitable for siting landfills. In the present study, a 10 m DEM was analyzed by using the Spatial Analyst module of ArcGIS to estimate the surface slope of the region. Based on the above considerations, the value is set below the table.

Table 3:11 Slope Fuzzy value and FAHP weight

Slope (%)	Fuzzy Value	Suitability	Weight
>20	0.00-0.228	Unsuitable	
10-20	0.228-0.470	Low suitable	0.027
5-10	0.470-0.727	Moderate	
<5	0.727-1.000	High suitable	

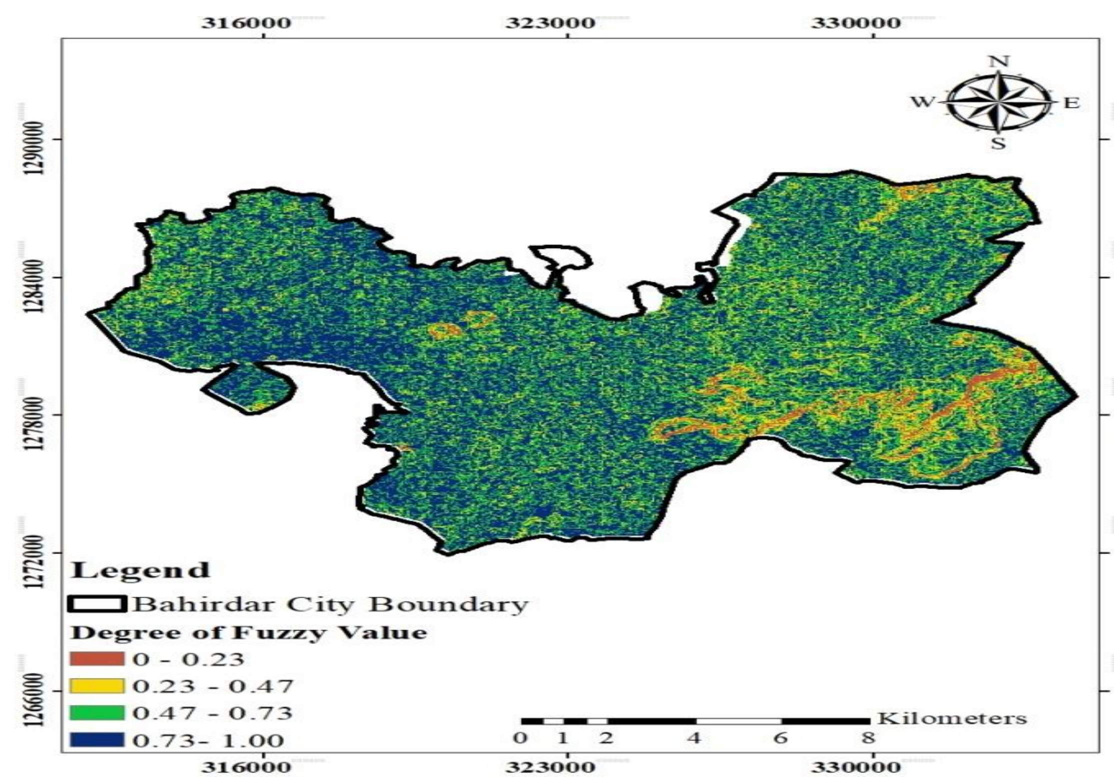

Figure 3:16 Slope Fuzzy value and suitability map

3.5.4.9 Soil Texture

For the purpose of reducing the potential effect the landfill produces on groundwater, using the permeability of soil as one selection criteria plays a crucial role so as to protect the health of human beings as well as other living things. The main reason behind this is the fact that the permeability of soil in an area has an indirect relation to the movement of leachate from the landfill to the inner part of the surface (high permeability of soil refers to high hydraulic conductivity, and vice versa) (Kabite et al., 2012). Solid wastes applied to soils that have less permeability reduce surface erosion and runoff and improve the degradation rate. The present study area has different soil types, namely, clay loam, coarse sandy loam, loamy sand, and sandy clay loam. The soil groups of coarse granule loam, coarse sandy loam, and loamy sand have higher permeability rates than others. The soil group of loamy sand has a moderate infiltration rate, whereas sandy clay loam, silt clay loam, and clay loam have a poor infiltration rate. It reveals that soil types with a lower infiltration (permeability) rate are more suitable for solid waste disposal.

Table 3:12 Soil texture Fuzzy value and FAHP weight

Soil texture	Fuzzy Value	Suitability	Weight
Sandy loam	0.00-0.228	Unsuitable	
loam	0.228-0.470	Low suitable	0.201
Clay loam	0.470-0.727	Moderate suitable	
clay	0.727-1.000	High suitable	

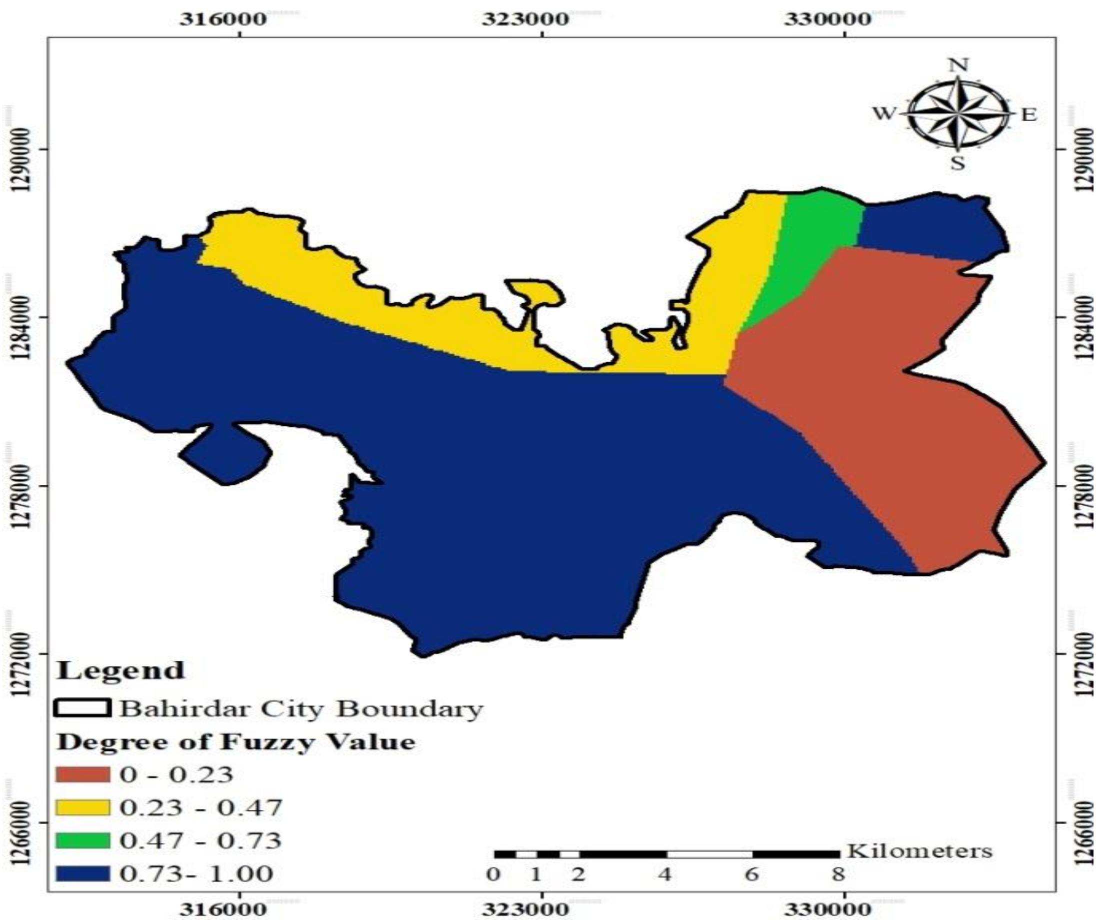

Figure 3:17 Soil Texture Fuzzy value and suitability map

3.5.4.10 Wells/Springs

Due to the seriousness of the effects leachates running out of the landfill have on the environment and health of the residents, using the ground water found in the boreholes is highly recommended to keep the landfill sites as far away as possible. Therefore, well-being is one of the most important criteria for this study. Thus, 28 water well points collected from Bahir Dar City Administration Water Supply and Sewage Office and Amhara Water Works Construction Enterprise were used. According to Hasan R et al. (2009) considers a minimum distance between 500m and 1000m required to separate landfill sites from water well points. According to A. Al-Hanbali et al. (2011), 300 m was the optimum distance to separate the water well points from landfill sites. Additionally, Danesh G et al. (2019) applied more than 1000 m used as suitable, 500–1000 m between used as moderate suitable, 0–500 m used as unsuitable. For the current study a minimum distance of 1000m was used and The Euclidean distance was used to assess distances from or outside the wells/springs. Based on the above and other considerations, the value is set below the table.

Table 3:13 Wells/Springs Fuzzy value and FAHP weight

Distance from the Wells/Springs(km)	Fuzzy Value	Suitability	Weight
0-0.5	0-0.333	Unsuitable	
0.5-1	0.333-0.667	Moderate suitable	0.025
>1	0.667-1.000	High suitable	

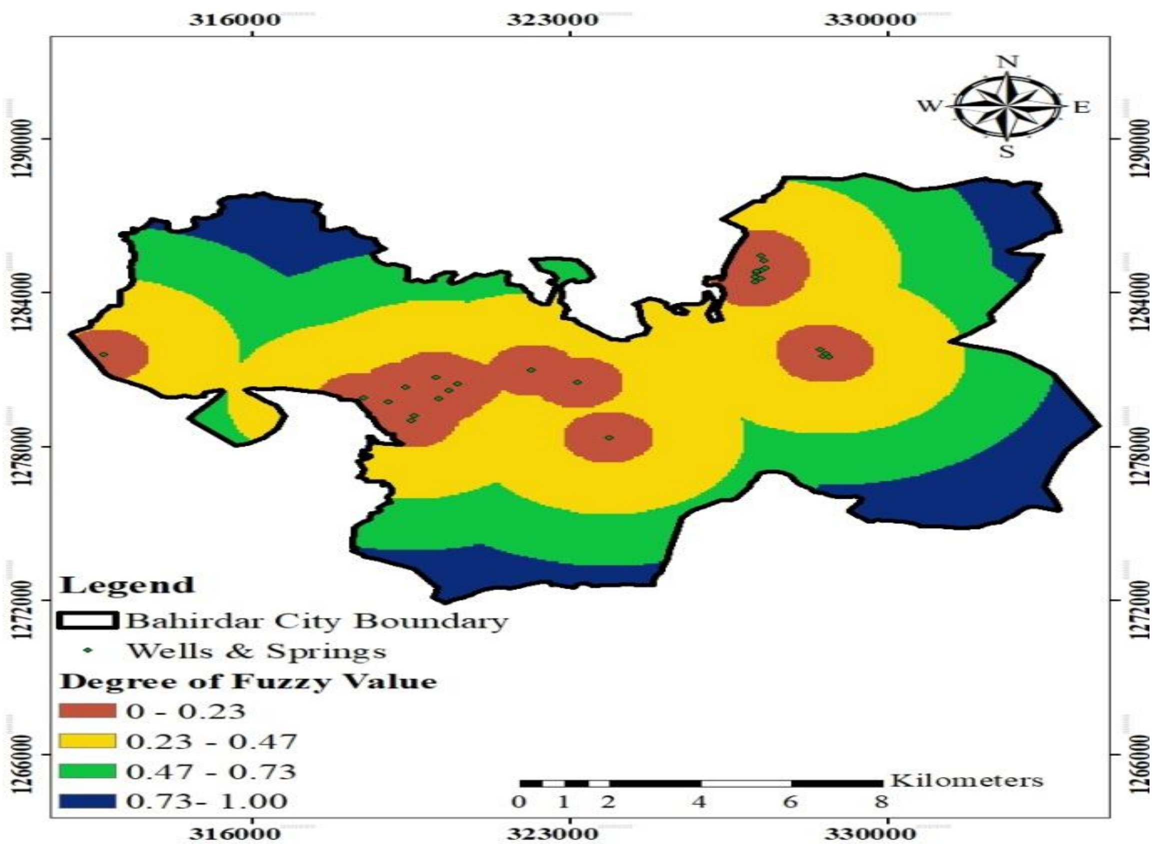

Figure 3:18 Wells/Springs Fuzzy value and suitability map

3.6.5 Fuzzy-AHP

The fuzzy-AHP method was used to assign a weight to each theme and class. Literature surveys, expert opinion, and field awareness were used to assign importance to each theme in the matrix.

Table 3:14 pairwise comparison matrix

	LULC	soil texture	Lithology	Airport	Road
LULC	1,1,1	1,3,5	2,4,6	3,5,7	4,6,8
Soil texture	1/5,1/3,1	1,1,1	1,3,5	2,4,6	3,5,7
Lithology	1/3.1/2,1	1/5,1/3,1	1,1,1,	1,2,3	1,2,3
Airport	1/7.1/5,1/3	1/6,1/4,1/2	1/3,1/2,1	1,1,1,	1,2,3
Road	1/8,1/6,1/4	1/7,1/5,1/3	1/3,1/2,1	1/3,1/2,1	1,1,1,
Surface water	1/9,1/7,1/5	1/8,1/6,1/4	1/5,1/3,1	1/3,1/2,1	1/3,1/2,1
Pro-area	1/9,1/8,1/6	1/9,1/7,1/5	1/9,1/8,1/6	1/5,1/3,1	1/3,1/2,1
Wells/Springs	1/9,1/8,1/6	1/9,1/8,1/6	1/9,1/8,1/6	1/9,1/8,1/6	1/9,1/7,1/5
Faults	1/9,1/9,1/7	1/9,1/8,1/6	1/9,1/8,1/6	1/9,1/9,1/7	1/9,1/7,1/5
slope	1/9,1/9,1/7	1/9,1/9,1/7	1/9,1/9,1/7	1/9,1/9,1/7	1/9,1/8,1/6

Table 3:15 pairwise comparison matrix

	Surface water	Pro-area	Wells/Springs	Faults	slope
LULC	5,7,9	6,8,9	6,8,9	7,9,9	7,9,9
Soil texture	4,6,8	5,7,9	6,8,9	6,8,9	7,9,9
Lithology	1,3,5	6,8,9	6,8,9	6,8,9	7,9,9
Airport	1,2,3	1,3,5	6,8,9	7,9,9	7,9,9
Road	1,2,3	1,2,3	5,7,9	5,7,9	6,8,9
Surface water	1,1,1,	1,2,3	4,6,8	5,7,9	6,8,9
Pro-area	1/3,1/2,1	1,1,1,	2,4,6	3,5,7	4,6,8
Wells/Springs	1/8,1/6,1/4	1/6,1/4,1/2	1,1,1,	1,3,5	1,2,3

Faults	1/9,1/7,1/5	1/7,1/5,1/3	1/5,1/3,1	1,1,1,	1,2,3
slope	1/9,1/8,1/6	1/8,1/6,1/4	1/3,1/2,1	1/3,1/2,1	1,1,1,

Table 3:16 Factors Weights using Fuzzy-AHP techniques

	LULC	**Soil texture**	**Lithology**
LULC	0.356 0.378 0.341	0.357 0.378 0.340	0.357 0.378 0.340
Soil texture	0.190 0.192 0.222	0.190 0.192 0.221	0.190 0.192 0.221
Lithology	0.131 0.136 0.156	0.131 0.137 0.156	0.131 0.137 0.156
Airport	0.075 0.074 0.077	0.075 0.074 0.077	0.075 0.074 0.077
Road	0.062 0.058 0.060	0.062 0.059 0.060	0.062 0.059 0.060
Surface water	0.051 0.047 0.050	0.051 0.048 0.050	0.051 0.048 0.050
Pro-area	0.040 0.036 0.035	0.040 0.036 0.035	0.040 0.036 0.035
Wells/Springs	0.031 0.027 0.023	0.03 0.027 0.023	0.031 0.027 0.023
Faults	0.030 0.024 0.020	0.030 0.024 0.020	0.030 0.024 0.020
slope	0.030 0.023 0.018	0.030 0.023 0.018	0.030 0.023 0.018

Table 3:17 Factors Weights using Fuzzy-AHP techniques

	Airport	**Road**	**Surface water**
LULC	0.357 0.378 0.340	0.357 0.378 0.340	0.357 0.378 0.356

Soil texture	0.190 0.192 0.221	0.190 0.192 0.221	0.190 0.192 0.190
Lithology	0.131 0.137 0.156	0.131 0.137 0.156	0.131 0.137 0.131
Airport	0.075 0.074 0.077	0.075 0.074 0.077	0.075 0.074 0.075
Road	0.062 0.059 0.060	0.062 0.059 0.060	0.062 0.059 0.062
Surface water	0.051 0.048 0.050	0.051 0.048 0.050	0.051 0.048 0.051
Pro-area	0.040 0.036 0.035	0.040 0.036 0.035	0.040 0.036 0.040
Wells/Springs	0.031 0.027 0.023	0.031 0.027 0.023	0.031 0.027 0.031
Fault	0.030 0.024 0.020	0.030 0.024 0.020	0.030 0.024 0.030
slope	0.030 0.023 0.018	0.030 0.023 0.018	0.030 0.023 0.030

Table 3:18 Factors Weights using Fuzzy-AHP techniques

	Pro-area	**Well/Spring**	**Fault**	**slope**
LULC	0.357 0.378 0.340	0.357 0.378 0.340	0.357 0.378 0.340	0.357 0.378 0.340
Soil texture	0.190 0.192 0.221	0.190 0.192 0.221	0.190 0.192 0.221	0.190 0.192 0.221
Lithology	0.131 0.137 0.156	0.131 0.137 0.156	0.131 0.137 0.156	0.131 0.137 0.156
Airport	0.075 0.074 0.077	0.075 0.074 0.077	0.075 0.074 0.077	0.075 0.074 0.077
Road	0.062 0.059 0.060	0.062 0.059 0.060	0.062 0.059 0.060	0.062 0.059 0.060
Surface water	0.051 0.048 0.050	0.051 0.048 0.050	0.051 0.048 0.050	0.051 0.048 0.050

Pro-area	0.040 0.036 0.035	0.040 0.036 0.035	0.040 0.036 0.035	0.040 0.036 0.035
Wells/Springs	0.031 0.027 0.023	0.031 0.027 0.023	0.031 0.027 0.023	0.031 0.027 0.023
Fault	0.030 0.024 0.020	0.030 0.024 0.020	0.030 0.024 0.020	0.030 0.024 0.020
slope	0.030 0.023 0.018	0.030 0.023 0.018	0.030 0.023 0.018	0.030 0.023 0.018

4.1 Dumping Suitability Analysis Results

The constraint maps were produced by merging each individual theme within the study area. This procedure created a constraint map for each theme containing only two classes represented by 1‟s (for suitable land) and 0‟s (for unsuitable land). The six constraint maps such surface water, road, fault, protected area, wells and airport were combined using overlay function (using direct multiplication of binary integer values) to create the final constraint map.

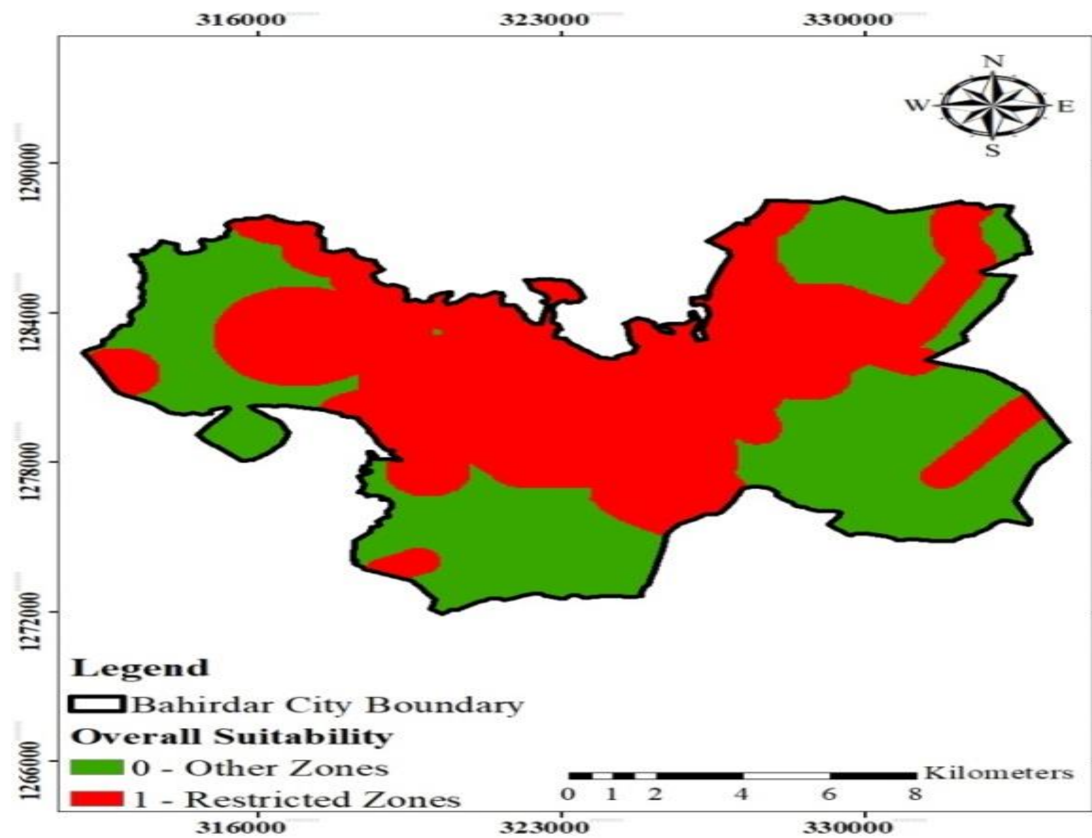

Figure 4:1 Restricted Sites of Bahirdar City

The weight module develops the pair wise comparison technique to help derive the weights and its consistency ratio for solid waste dumping site selection of the study area. According to Lawal et al., (2011), If CR< 0.10, the ratio indicates a reasonable level of consistency in the pair wise comparison, however, if CR = 0.10, the values of the ratio indicates inconsistent judgments. The aim of consistency ratios is to determine if the comparisons are consistent or not. In the present study Statistical analysis i.e., consistency ratios less than 0.09 (9%) so it is Accepted. Their characteristics show that the assigned weights are compatible with the expected outcomes.

Table 4:1 Factors Weights using Fuzzy-AHP techniques

	lower	**mean**	**upper**	**Defuzzy**	**Weight**
LULC	0.3567	0.3783	0.3403	0.358	35.92
Soil texture	0.1899	0.192	0.2214	0.201	20.15
Lithology	0.1310	0.1367	0.1557	0.141	14.14
Airport	0.0752	0.0738	0.0772	0.075	7.55
Road	0.0619	0.0586	0.0599	0.06	6.03
Surface water	0.0508	0.0475	0.0503	0.05	4.96
Pro-area	0.0396	0.0356	0.0348	0.037	3.68
Well/Spring	0.0310	0.0272	0.0234	0.027	2.72
Fault	0.0303	0.0240	0.0200	0.026	2.48
slope	0.0299	0.0227	0.0185	0.024	2.37
Column Total				1.00	100.00

(**Note:** Pro-area = protected area)

In order to select appropriate solid waste dumping site selection for the study area comparison of the different potion based on environmental, social and economic impact was done. From the weight calculation, the relative importance of each parameter has been determined for all parameters slope map, geological map, soil texture map, protected area map, road map, surface water map, airport map, wells map, fault map and land use/land cover maps. Hence, based on impact on surrounding environment, different weights were assigned to all parameters. The larger weight, the more important is the criterion in the overall utility. The weights were developed by providing a series of pair wise comparisons of the relative importance of the factors to the suitability of pixel for the activity being evaluated.

In the present study, information layers were first introduced to GIS, and the maps were weighed using the FAHP method. Then, the obtained results for each criterion layer are shown in Tables 3.4 to 3.8. In this table, in order to locate a hazardous waste disposal site in the study area using threshold values defined for each criterion and fuzzy membership functions, a degree of acceptability was determined. For constraint maps, Boolean logic was used to identify sites that are by no means suitable for waste disposal. Fuzzified maps of decision criteria are shown in Fig. 3.10 to Fig. 3.19. In general, the fuzzy logic scale ranges between 0 and 1, indicating that each area has a membership value that reflects its quality depending on the level at which each criterion is considered.Thus, each area or pixel that has a higher membership value and is closer to 1 in the fuzzy scale would be more desirable. After standardizing the maps and integrating and overlapping the considered layers, a single map of the located disposal sites was obtained to locate a proper site for waste disposal using the WLC combination method. Based on the obtained weight, the effect of each map on disposal location was determined. The weight determined by this method shows that geo-environmental criteria, with 43.25% of the total weight, play a greater role in the process of locating a disposal site for hazardous waste in this province; hydrogeological criteria, with 36.77% of the total weight; socioeconomic criteria, with 17.26% of the total weight; and morphologic criteria, with 2.72% of the total weight, are less effective in this process. Among the parameters used, land use and slope had the highest (0.358) and lowest (0.024) weights, respectively.

The results of this study showed that among all factors, land use criteria (0.358), lithology (0.141), and soil texture (0.201) were more influential than the other factors, as they are very important to protect water pollution from dumping leachate. Airport, road network, surface water, slope, protected area, fault, and wells or springs were also most important factors in locating a disposal site for hazardous waste in the research area.

After the overlay analysis and Weighted Linear Combination method of aggregation result Figure 4.1 shows the zoning of areas with potential for locating a disposal site for hazardous waste disposal in the studied area, classified into five levels: highly suitable, moderately suitable, suitable, lowly suitable, and unsuitable. Zoning results in Table 4.1 indicate that 421 ha (2%) of the study area are identified as extremely suitability and 1280 ha (6%) are identified as high suitability. However, a total of 4991 hectares (23.4%) of the study area was considered unsuitable (restricted) as the area is environmentally unfriendly and socially unacceptable for landfill siting. The area identified as unsuitable for siting is composed of built-up and water body areas, protected areas inappreciably close to airports, roads, groundwater wells, and surface water bodies. The reason behind this is to protect human health, the economy, and the environment from the potential effects of landfill sites. The remaining 12,698 hectares (68.6%) are considered suitable, with different degrees of suitability. Out of the 68.6% suitable areas, 38.6% and 30% were classified as low- and moderate-suitable, respectively. From the overall study area, 421 ha (3%) of the entire study area was selected as optimal for hazardous waste landfill. Most of the optimal locations were in the southwestern and southeastern parts of the study.

Table 4:2 Landfill Suitability of the study area

Suitability Classes	**Area (hectare)**	**Area (%)**
Unsuitable	4991	23.4
Low suitable	8251	38.6
Moderate suitable	6402	30
High suitable	1280	6
Extremely suitable	421	2
Total	21,345	100.00

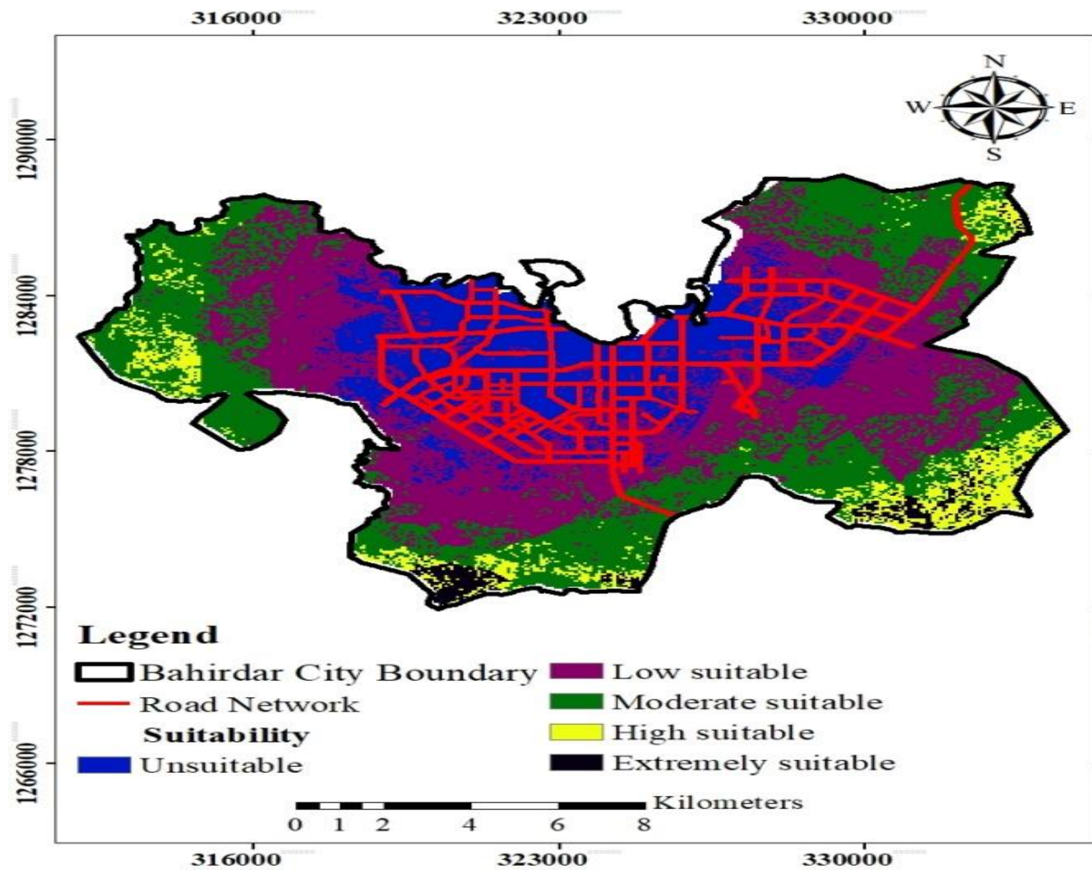

Figure 4:2 Suitable Sites Map using FAHP method with Fuzzy Logic

According to the FAHP weighting method with fuzzy logic, the south-east block of Bahirdar city is an excellent candidate for hazardous waste disposal.The south west block of Bahirdar city is selected as the second-preferable suitability site for dumping hazardous waste because it is smaller in size when compared to the area depicted in the south east block. Therefore, the south-east block of Bahirdar is extremely suitable for dumping hazardous waste in Bahirdar city.

4.1.1 Evaluating of Suitability dumping site and Proposed Structural Plan

A thorough investigation and assessment of ground conditions and stability is essential to determine whether a site is suitable for dumping site on, where the best place may be to locate a site and the type and size of foundations that will be required.

Based on the results the highly suitable areas are suitable for solid waste dump site due to the parameters or far from faults, airport, surface water, road and suitable according to soil, slope, soil texture, geology and land-use/ land-covers. Dump site in these areas is preferable over others because of the least effects that may cause on the environment and public. The southeastern part of Bahirdar city having high elevation was excluded from the selection of dump site as it comprises the recharge area for low-lying regions of the city. Similarly, the north part of Bahirdar city is a potential source of groundwater for the city and its surroundings and hence excluded from the dump site. Therefore, a high suitable dump site should be identified most preferably from the southern part of Bahirdar city. Proposed structural plan dump site and the final site selection results were compared. Proposed structural plan dump site is located in an inappropriate or not suitable area due to the site are around homes, near the road, agricultural area and near river bank but, the final results of site selection processes is properly suggested dump site location is based on scientific criteria. The final results of this study are considering on the factors used and the constraint area. Therefore, the current result is more preferable than the open dump site. It is placed surrounding the built-up area, roadsides and nearby river. Considering the effect of solid waste on health, economy and other aspects of human life, the properly selected site can be accessed by road. Generally Proposed structural plan for dumping site is clearly unsuitable beyond the scope of public health, hygiene, public reactions, noise, dust, and odor, its poor implementation.

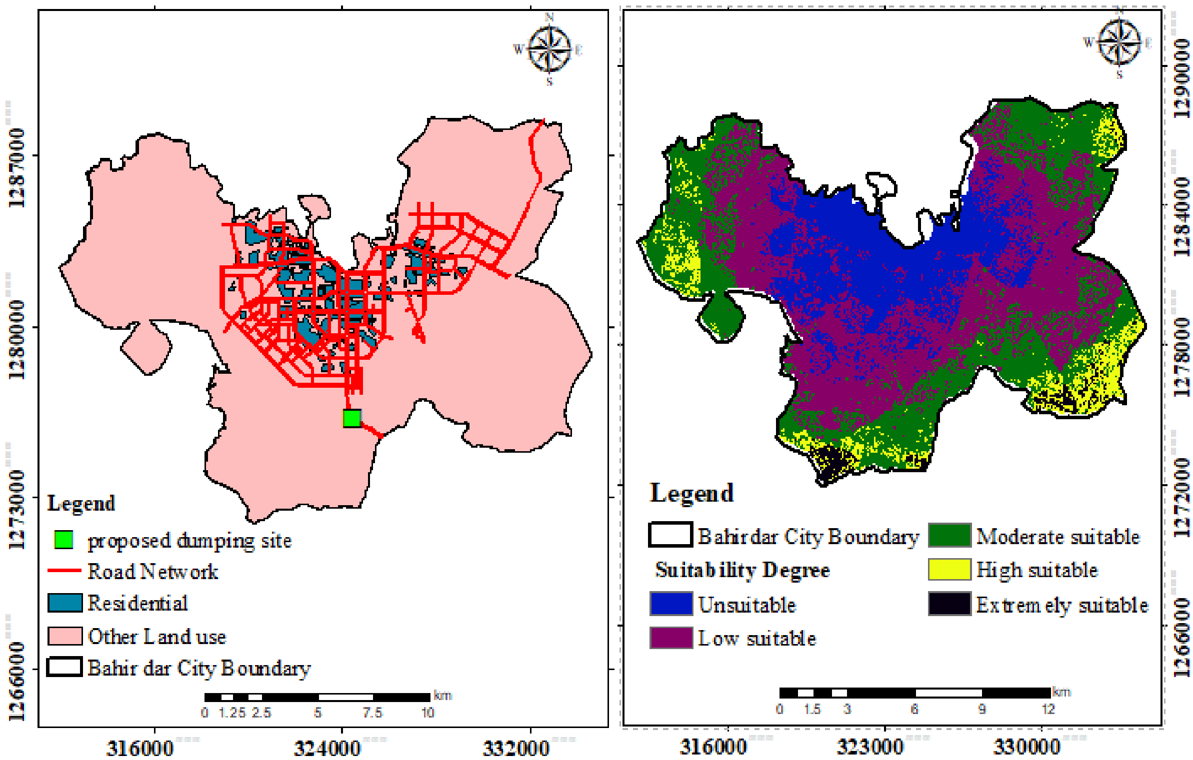

Figure 4:3 Suitability dumping site and proposed structure plan in Bahir Dar city

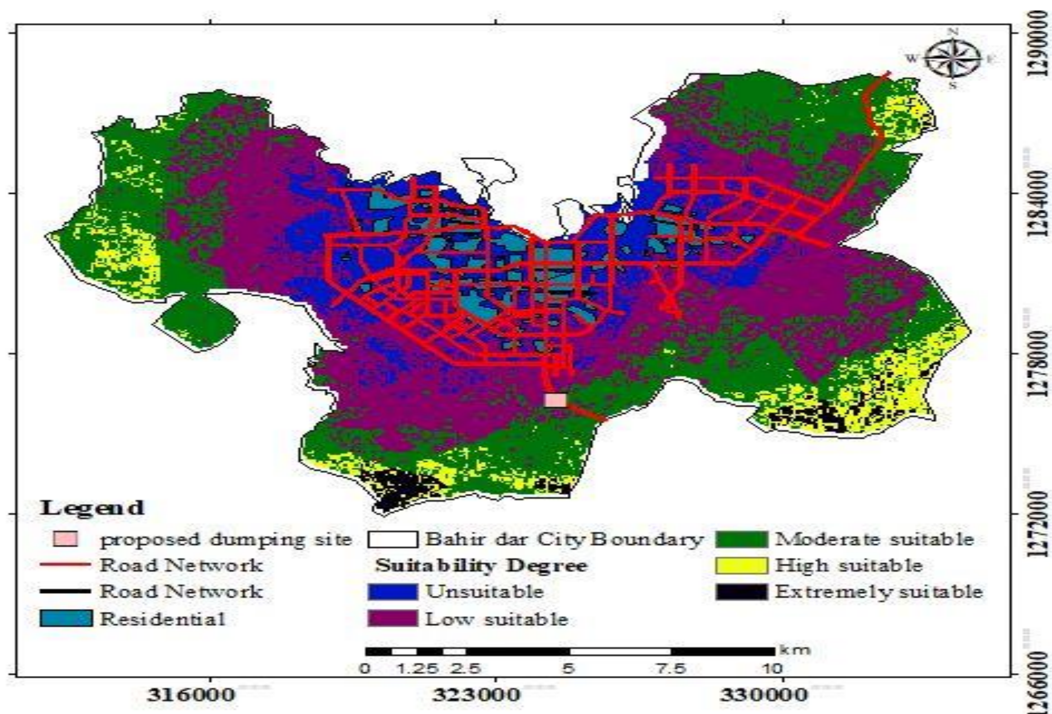

Figure 4:4 Evaluating between suitability dumping site and proposed structure plan in Bahir Dar city

4.2 DISCUSSION

In GIS and Remote sensed data and data analysis techniques to monitor and map solid waste disposal sites that are currently incomplete. The present study would represent an important first step in addressing a critical gap in the detection of illegal waste disposal sites and enhance the cost-effectiveness and efficiency of waste management efforts. Due to their ability to manage large volumes of spatial information from various resources, GIS is ideal for site selection studies (Kao et al., 1997).

Existing landfill site is clearly unsuitable beyond the scope of public health, hygiene, public reactions, noise, dust, and odor. The overall dump site suitability selection showed five dump site suitability classes: unsuitable (restricted), less suitable, moderately suitable, suitable and highly suitable. Bare-land, water body, built-up areas and vegetation lands used for the dump site selection processes due to their land-use/land-cover effect and values. Bare land in the study area was identified as the best option for the solid waste dump site. Areas with slope >20% were excluded as they are unsuitable whereas areas with slope $0-10\%$ were found to be the best for dump site (Akbari et al., 2008). Areas within 700 m radius and >4900 m were excluded to minimize public health effects (Sam and Steven, 2017).

Groundwater circulation and the downward flow of pollutants through rocks and soils depend on the hydrogeological condition of the materials, more specifically hydraulic properties such as porosity, permeability, and transitivity (Tsegaye Mekuria, 2006). The proximity of a solid waste dump site to a groundwater well point is an important environmental criterion in the dump site selection so that well points may be protected from the runoff and discharge. Therefore, solid waste disposal should be placed away from wells. Additionally, it can have irreversible human and environmental effects. Distance from surface water was considered as an important criterion for this research. In Bahirdar city, the area totally 28 functional wells. But this is assumed to be an appropriate buffer distance with respect to previous literature (Sumathi et al., 2008; Eskandari et al., 2012).

According to Tyowuah and Hundu (2017), contamination of ground/surface water resources by leachate is a principal concern in relation to disposal sites. Deep groundwater areas are preferable as chances of groundwater pollution will be minimized with increasing depth (Augustin 2008). Waste disposal should also be away from faults (Rafee et al., 2011). The fault is one of the criteria that was considered for solid waste disposal site selection. It is a better system for identifying fault area from Digital Elevation Model of Bahirdar city.

According to the experts' opinions and environmental standards, four criteria, including hydrogeological, geo-environmental, morphologic, and socioeconomic criteria, were suggested for this purpose. This criterion consists of 10 sub-criteria. The rapid growth in hazardous waste is directly related to increased urbanization and technological development. Even though hazardous waste management has a significant impact on the economy and the environment, most previous waste management research has focused on general non-hazardous solid waste management. A review of past studies has shown that no significant study of the optimized location of the municipal hazardous waste landfill in Bahirdar city has been performed.

The study attempts to integrate fuzzy logic models with a fuzzy analytical hierarchy approach and multi-criteria decision analysis (FAHP-MCDM) that could be an effective tool for incorporating various features that affect the selection of landfill sites. A previous study showed that the selected disposal sites were only for non-hazardous waste and were considered urban centers, and land use criteria had the highest weight based on the traditional AHP weighting method. Different researchers have selected only the traditional AHP weighting method for suitable landfill sites. When using the traditional AHP weighting method, the decision-maker’s preferences and personal judgment affect the AHP result enormously, generally leading to wrong decisions.

The current study used fuzzy AHP in a GIS environment to locate suitable landfill sites. Whereas the GIS analysis allowed for the analysis of various spatial data for the purpose of targeting potential landfill locations, the MCDA allowed for the inclusion of expert judgment, specifically the determination of weights. In the present study, the FAHP method has been used to address wrong decisions. The fuzzy-AHP approach is promising as it fixes important limitations of traditional AHP. Initially, AHP has been utilized in a unilateral method to assign weights based on expert information to the parameters while permitting a specific level of subjectivity in the pairwise comparison matrix. Furthermore, a constrained scale of judgment, the rank reversal phenomenon, and the absence of transitivity, have recognized the inconsistency of the technique.

Additionally, unlike previous research where there was a focus on only geo-environmental and economic factors, this research begins to focus on hydrogeological and social factors as relevant inputs for the landfill site selection process. The inclusion of social factors in site selection projects remains important as the literature indicates that regardless of the environmental and economic viability of locations for landfills, there is a growing community resistance to their construction. Incorporating social factors into the modelling process could help address such community resistance. Furthermore, previous studies did not focus on hydrogeological factors, but they were included in the current study because they were used to protect water pollution from dumping leachate.

What is more important in this study was to select a site by using a weighted linear combination and overlay analysis to solve problems caused by hazardous waste related to transmission of diseases, fire hazards, unpleasant odors, atmospheric and water pollution problems, and urban aesthetic problems. For new and backup municipal waste dump sites in the future, the FAHP-based appropriate landfill prospective sites can be taken into consideration. Also in this study, the proposed GIS-based fuzzy-AHP model makes the application more realistic and reliable.

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This study aimed to determine a suitable site for a landfill in Bahirdar city. which is extremely important for the protection of water resources in the region. Landfill site selection is a complex process that requires consideration of many factors such as environmental, geological, economic, social, and morphological.

Bahir Dar's population is rapidly growing as a result of natural births and immigration, primarily from nearby rural areas. The waste is disposed of in an unscientific location, affecting the climate, the water supply, and the esthetics of the environment. Random and irrational landfill site selection could be detrimental to the environment, local population, and nearby aquatic resources, including groundwater. The study offered an integrated framework with a focus on organizing the landfill suitability site map decision-making process by using proper data collection, criterion weighting, and normalization. In this study, ten themes were chosen after a thorough literature review. A combination of FAHP and fuzzy logic models were used in this study; such variables as slope, distance from bodies of water, distance from roads, distance from protected area, distance from airport, land use and land cover, distance from fault, soil texture, lithology class, and distance from wells and springs areas were considered. The criteria weightings were derived from the FAHP method by constructing a matrix of pairwise comparisons between criteria. These themes have been developed through RS (remote sensing) and conventional data. Subsequently, potential landfill sites were identified and divided into five classes: unsuitable (fuzzy value 0.3–0.5), low-suitable (0.5-0.65), moderately suitably (0.65–0.8), high-suitable (0.8-0.9), and extremely suitably (0.9–1.0). As per the statistical analysis, 3%, 6.6%, and 18% of the total area were under the "extremely suitable," "highly suitable," and "moderately suitable" landfill site zones, while 41.5% and 30.9% accounted for the "low" and "restricted" zones, respectively.

According to the findings of this study, the most suitable areas were mostly in the south east and south west of the study area and met the requirements of environmental, economic, and residential factors. The common areas identified showed the most suitable lands for waste disposal landfills, with an appropriate distance from residential areas and open space. Therefore, the result showed that a combination of GIS, FAHP, and fuzzy models using multi-scientific and environmental criteria could be used to develop an effective and efficient methodology for selecting suitable landfill sites in Bahirdar City. It can be concluded that the methodology applied in the present study is capable of locating a suitable landfill site in Bahirdar city, and a future study should be carried out as well in other provinces in Ethiopia.

5.2 Recommendations

- ✓ This study takes major environmental, socio-economic factors in to consideration for dumping site selection. Nevertheless, other factors such as cost of construction, community preferences, landscape and aspect also influence landfill site selection and therefore, should be included as evaluating criteria. Therefore, the selected landfill site (site 1) should be evaluated with these factors especially with cost of construction.
- ✓ Further hydro-geological investigation for the selected landfill sites should be studied in order to additionally compare the dumping sites and predict the effects that will result from the landfill. Moreover, hydraulic conductivity of the site should be further studied in order to reduce the effect of leachate and gas to the maximum.
- ✓ To protect surface water pollution in the downstream areas, runoff must not flow into and out of the landfill. Hence, retaining and draining structures should be constructed around the landfill.

REFERENCES

Afzali, A., Sabri, S., Rashid, M., Samani, J. & Ludin, A. (2014). Inter-municipal landfill Site selection using analytic network process. Water Resources Management, 28(8), 2179–2194.

Agaji, I. & Wajiga, G. (2012). An Object Oriented System for the Location of Landfills For Nigerian Municipals. Science World Journal.

Alam, P. & Ahmade, K. (2013). Impact of solid waste on health and the environment. International Journal of Sustainable Development and Green Economics (IJSDGE), 2(1), 165–168.

Amato, F., Tonini, M., Murgante, B. & Kanevski, M. (2018). Fuzzy definition of rural Urban interface: an application based on land use change scenarios in Portugal. Environmental Modelling & Software 104: 171-187.

Aryafar, A., Yousefi, S. & Ardejani , F. (2013). The weight of interaction of mining activities: groundwater in environmental impact assessment using fuzzy analytical hierarchy process (FAHP). Environ Earth Sci 68(8):2313–2324

Ayaim, M., Fei-Baffoe, B., Sulemana, A., Miezah, K. & Adams, F. (2019). Potential sites for landfill development in a developing country: a case study of Ga South Municipality, Ghana. Heliyon, 5, 1–8.

Ayilara, M., Olanrewaju, O. & Odeyemi, O. Waste Management through Composting: Challenges and Potentials. Sustainability 2020, 12, 4456.

Ayo, B. & Ibrahim, B. (2011). Selection of Landfill Sites for Solid Waste Treatment in Damaturu Town-Using GIS Techniques, Journal Environmental Protection, Universiti Teknologi Malaysia, Johorstate, Malaysia,pp1-10.

Chabuk, A., Al-Ansari, N., Hussain, H.M., Knutsson, S. & Pusch, R., (2016). Landfill site selection using geographic information system and analytical hierarchy process: a case study Al-Hillah Qadhaa, Babylon, Iraq. Waste Manag. Res. 34, 427–437.

Chang, N., Parvathinathan, G. & Breeden, B. (2007). Combining GIS with fuzzy multi criteria decision-making for landfill sitting in a fast growing urban region, Journal of Environmental Management.

Chattopadhyay, S., Dutta, A. & Ray, S. (2009). Municipal solid waste management in

Kolkata, India – A review.
Chinasho, A. (2015). Review on community based municipal solid waste management and its implication for climate change mitigation. American Journal of Scientific and Industrial Research, 6(3), 41–46.
Costa, C. & Vansnick, JC. (2008).A critical analysis of the eigenvalue method used to derive priorities in AHP. European Journal of Operational Research 187: 1422–1428.
Cox, E. (1995). Fuzzy Logic for Business and Industry. Boston: Charles River Media.
Chang D. (1992). Extent analysis and synthetic decision, Optimization techniques and Applications, Vol. 1, Singapore: World Scientific, pp.3.
CPHEEO (2000), 'Manual on MSW Management', Ministry of Urban Development, Government of India.
Cummins, V. (2002). 'A new approach to Landfill Site Selection in Ireland Using GIS', 3 BGA Geo-Environmental Engineering Conference.
Danesh,G. & Monavari,S. (2019).Compilation of a model for hazardous waste disposal site selection using GIS-based multi-purpose decision-making models. Environ Monit Assess 191:122.
Debishree K. & Samadder,S.(2014).Application of GIS in Landfill Siting for Municipal Solid Waste, Dhanbad, India.
Djokanovic, S., Abolmasov, B. & Jevremovic, ´ D., (2016). GIS application for landfill site selection: a case study in Pancevo, ˇ Serbia. Bull. Eng. Geol. Environ. 75, 1273– 1299.
Donevska, K., Gorsevski, P., Jovanovski, M. & Peševski, I.(2012). Regional non-hazardous landfill site selection by integrating fuzzy logic, AHP and geographic information systems. Environ. Earth Sci. 67, 121–131.
Eastman, JR. (2001). Guide to GIS and Image Processing,. 2:p. 01610-1477.
Effat, H., & Hegazy, M. (2012). Mapping potential landfill sites for North Sinai cities using spatial multicriteria evaluation. EJRS, 15, 125–133.
Elaalem,M (2012) land suitability evaluation for sorghum based on Boolean and fuzzy-multi criteria decision analysis methods. International Journal of Environmental Science & Development vol, 3 No. 4.

EPA, (2018). Environmental management of landfill facilities (Solid waste disposal).

Eric, S. & Bernard K.(2019). Hazardous waste landfill site selection in Western Ghana: An integration of multicriteria decision analysis and geographic information system. waste Management & Research Vol. 37(7) 723–736.

Eskandari, M., Homaee, M. & Mahmodi, S. (2012): An integrated multi criteria approach for landfill siting in a conflicting environmental, economical and socio-cultural area. – Waste Management 32(8): 1528-1538.

FFE. (2010). “Forum for environment assessment of solid waste management system of Bahir Dar city, for the development of an ISWM Plan.

Gbanie, S., Tengbe, P. & Momoh ,J. (2013). Modelling landfill location using Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA): Case study Bo, Southern Sierra Leone. Applied Geography 36: 3–12.

Geneletti, D. (2010). Combining stakeholder analysis and spatial multicriteria evaluation To select and rank inert landfill sites. Waste Management 30: 328–337.

Geologic Survey of Ethiopia (2012) Integrated Hydrogeological Mapping of Bahir Dar Map Sheet for the City of Bahir dar, Ethiopia.

Gizachew, K. (2012). GIS-Based Solid Waste Landfill Site Selection : A Case Study of Addis Abeba. 38 (2-3): 59-72.

Gorsevski, P., Donevska, K., Mitrovski, C. & Frizado, J. (2012). Integrating multi-criteria evaluation techniques with geographic information systems for landfill ite selection: a case study using ordered weighted average. Waste Manag. 32, 287–296.

Gorsevski, P., Jankowski, P. & Gessler, P. (2006). An heuristic approach for mapping landslide hazard by integrating fuzzy logic with analytic hierarchy process. Control Cybern. 35, 121–146.

Hanine, M., Boutkhoum, O., Tikniouine, A. & Agouti, T. (2016). Comparison of fuzzy AHP and fuzzy TODIM methods for landfill location selection. SpringerPlus, 5(501), 30pp), 501.

Harun, H. & Haris, H. (2014). A Multi-Criteria Approach to Selecting a Landfill Site with the Aim of Protecting the Environment. Pol J Environ Stud 23: 1499-

1505.

Hasan,R., Tetsuo, K. & Islam,A. (2009). Landfill demand and allocation for Municipal solid waste disposal in Dhaka city-an assessment in a GIS environment, Journal of Civil Engineering (IEB), 37 (2), 133-149.

Hereher, M., Al-Awadhi, T. & Mansour, S. Assessment of the optimized sanitary Landfill sites in Muscat, Oman. Egypt. J. Remote Sens. Space Sci. 2020, 23, 355– 362.

Idowu, I., Atherton, W., Hashim, K., Kot, P. & Alkhaddar. An analyses of the status of landfill classification systems in developing countries: Sub Saharan Africa landfill experiences. Waste Manag. 2019, 87, 761–771.

Kamdar, I., Ali, S., Bennui, A., Techato, K. & Jutidamrongphan, W.(2019). Municipal solid waste landfill siting using an integrated GIS-AHP approach: A case study from Songkhla, Thailand.149, 220–235.

Kao, J., Lin, H., and Chen, W. (1997). Network geographic information system for landfill siting. Waste Management and Research. 15 (3):239−253.

Keivan, G. & Javad , L. (2014). Waste Disposal Site Selection Using an Analytic Hierarchal Pairwise Comparison and ELECTRE Approaches Under Fuzzy Environment. Journal of Intelligent and Fuzzy Systems 26: 693-704.

Kontos, T., Komilis, D. & Halvadakis, C. (2005). Sitting MSW landfill with a Spatial Multiple criteria analysis methodology. Waste Management, 25(8):818-833.

Kontos, TD. Komilis, DP. & Halvadakis, CP. (2003). Sitting municipal solid waste landfills in Lesvos Island with a GIS based methodology waste management, Lesvos.

Lee, S., Mogi, G. & Hui, K. (2013). A fuzzy analytic hierarchy process (AHP)/data envelopment analysis (DEA) hybrid model for efficiently allocating energy R&D resources: in the case of energy technologies against high oil prices. Renew Sust Energ Rev 21:347–355.

Mahini, A. & Gholamalifard, M. (2006). Siting MSW landfills with a weighted linear combination methodology in a GIS environment. International Journal of Environmental Science & Technology.;3(4):435-445.

Mikhailov, L. & Tsvetinov, P. (2004). Evaluation of services using a fuzzy analytic hierarchy process. Applied Soft Computing 5: 23–33.

Moeinaddini M (2010). Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj). Waste Management.;30(5):912-920.

Moeinaddini, M., Darvishsefat, A., Khorasani, N., Danehkar, A., & Zienalyan, M. (2010). Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP).

Mogaji, K., Aboyeji, O. & Omosuyi, G.(2011). Mapping of Lineaments for Groundwater Targeting in the Basement Com-plex Region of Ondo State, Nigeria, Using Remote Sensing and Geographic Information System (GIS) Techniques. Int. J. Water Resour. Environ. Eng. 3, 150–160.

Mohammad, A., Alanbari, N., Hadeel, K. & Sven, K.(2014). Modeling Landfill Suitability Based on GIS and Multi-criteria Decision Analysis: Case Study in Al-Mahaweelqadaa, Scientific Research, Iraq, pp829.

Motlagh, Z. & Sayadi, M. (2015). Sitting MSW landfills using MCE methodology in GIS environment (case study: Birjand plain, Iran). Waste Management, 46, 1–16.

Naser, M. & Hadi, N. (2011). Hazardous waste landfill site selection in Khorasan Razavi Province, Northeastern Iran.

Nishanth, T., Prakash, M. & Vijith, H. (2010). Suitable site determination for urban solid waste disposal using GIS and remote sensing techniques in Kottayam municipality, India. International Journal of Geomatics and Geosciences, 1(2), 197–210.

Nishanth,T., Prakash, M. & Vijith, H. (2010). Suitable site determination for urban Solid waste disposal using GIS and Remote sensing techniques in Kottayam Municipality, India. International Journal of Geomatics and Geosciences.

Oštir, K., Veljanovski. T., Podobnikar.T. & Stančič, Z.(2003). Application of satellite remote sensing in natural hazard management: the Mount Mangart landslide case study, International Journal of Remote Sensing.

Qiu, F., Chastain, B., Zhou, Y., Zhang, C. & Sridharan, H. (2014). Modeling land suitability/capability using fuzzy evaluation. – GeoJournal 79(2): 167-182.

Sahnoun, H (2012) GIS and multi-criteria analysis to select potential sites of agro-industrial complex. Environmental Earth Sciences.;66(8):2477-2489.

Sam, Z., and Steven, J. (2017). Site Suitability Analysis for Solid Waste Landfill Site Location Using Geographic Information Systems and Remote Sensing: A Case Study of Banket Town Board, Zimbabwe. Review of Social Sciences, 2 (4):19−31.

Saaty, T. (1980). The Analytic Hierarchy Process. Pittsburgh, PA: RWS Publications.

Seiied, T., Seiied, S., Ebrahim, F.,Taghi, E. & Ali, M. (2015). Site Selection of Sarein's Municipal Solid Waste Landfill Using the GIS Technique and SAW Method, International Journal of Environmental Science and Development,Vol.6, Iran,pp-934.

Sener, s., sener, E., & Nas, B.(2010). Combining AHP with GIS for landfill site selection: A case study in the Lake Beyşehir catchment area (Konya, Turkey). Waste Management 30: 2037–2046.

Sharifi, M., Hadidi, M. & Vessali, E. (2009). Integrating multi-criteria decision analysis for a GIS-based hazardous waste landfill sitting in Kurdistan Province, western Iran. Waste Management 29: 2740–2758.

Smith, J. & Winterfeldt, D. (2004). Decision analysis in management science. Management Science 50: 561–574.

Subhrajyoti, C. & Sujit, D. (2012). GIS and Remote Sensing For Landfill Site Selection- A Case Study on Dharmanagar Nagar Panchayet Volume 1, PP 36-43.

Taibi, A. & Atmani, B. (2017). Combining fuzzy AHP with GIS and decision rules for industrial site selection. Int J Interact Multimed Artif Intelle 4(6)

Tinc, C. (2013) Data Construction Process and Qualiflex-Based Method for Multiple-Criteria Group Decision Making With Interval-Valued Intuitionistic Fuzzy Sets. International Journal of Information Technology & Decision Making 12: 425-467.

Tirusew, A. & Amare, S. (2013).Solid waste dumping site suitability analysis using Geographic Information System (GIS) and remote sensing for Bahir Dar Town, Ethiopia, African Journal of Environmental Science and Technology,

Volum 7/11/, pp 976-989, November 2013.
Torabi, M., Babazadeh, R., Mohammadi, S. & Zaresefat, M. (2016). Landfill site selection using combination of GIS and fuzzy AHP, a case study: Iranshahr, Iran. Waste Manag Res 34(5):438–448.
Tsegaye Mekuria, (2006). A multi-criteria analysis for solid waste disposal site selection using Remote Sensing and GIS, Addis Ababa University, Ethiopia. Unpublished Master's Thesis,11–25.
Unep. (2010a). Assessment of the Solid Waste Management System in Bahir Dar Town and the Gaps identified for the Development of an ISWM Plan.
Wang, G., Qin, L. & Li, G. (2009). Landfill site selection using spatial information technologies and AHP: A case study in Beijing, China. Journal of Environmental Management 90: 2414–2421.
Yakubah, B. & Rodney, T. (2011). Landfill Site Selection by Integrating Geographical Information Systems and Multi-Criteria Decision Analysis: A Case Study of Freetown, Sierra Leone. African Geographical Review 1: 67-99.
Yesilnacar, M., Suzen, ML., Kaya, BS. & Doyuran, V. (2012). Municipal solid waste landfill site selection for the city of Sanliurfa-Turkey: An example using MCDA integrated with GIS. International Journal of Digital Earth 5: 147-164.
Zeinhom.E., Rasha E. & Ahmed E. (2010).Integrating GIS and MCDM to Deal with Landfill Site Selection, international Journal of Engineering &Technology, Mansoura University, Egypt,pp33-34.