Landfill Site Selection by Integrating Fuzzy Logic, Analytical Hierarchy Process and Weighted Linear Combination Method Based on Multi Criteria Decision Analysis

By

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Dedication

To

My Mother

Thanks for her love, care and motivation all the way since the start of my studies, and also to all those who encouraged me and prayed for me for the completion of this thesis.

Academic Thesis: Declaration of Authorship

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All praises to Allah, the Almighty, who is perfect in all of His creations, who has given us the gift of wisdom and enabled us to complete our tasks successfully, and on whom we ultimately depend for sustenance and guidance; blessings upon Prophet Muhammad (peace be upon him) for leading us in the right direction. I owe my sincere gratitude and pleasure to my esteemed research supervisor, Dr. Muhammad Azmat, for his devoted guidance and motivating attitude during the time of research. I'm also thankful to all of the members of my instruction and review committees for their collaboration and constructive criticism, which helped me gain a deeper understanding of research and successful accomplishment of its objectives. Without the sincere cooperation and constant encouragement of IGIS NUST, which assisted me in all of my activities, this research would not have been possible. It gives me great pleasure to thank all of my sincere friends, colleagues, and family members, particularly my parents, for their sincere attitude, encouragement, patience, and prayers, which motivated me to complete my tasks successfully at every turn.

RIAZ ZARIN

ABSTRACT

Rapid population growth integrated with poor governance and urban planning is of highly challenging resulting key for the siting of unsuitable landfill sites, particularly in developing counties. Therefore, the aim of this study was to identify the appropriate solid waste landfill sites in the capital of the country as a case study, by the integration of Geographical Information System (GIS) with weighted linear combination (WLC) method, analytical hierarchy process (AHP) and fuzzy logic based on multi criteria decision making (MCDM). We chose thirteen (13) criteria (9 factors and 4 constraints) and grouped them in two main categories (socio-economic and environmental) to obtain the objectives. The AHP was employed to evaluate the relative importance of the factors followed by standardization of criteria factors based on fuzzy set theory. Subsequently, all criteria factors were combined based on AHP and fuzzy logic-WLC method in order to obtain land suitability map. Finally, the sites were identified by the intersection of two combined suitability index layers. The obtained results depicted that the integration fuzzy logic, AHP and WLC technique with GIS can produce satisfactory results for the suitable locations of solid waste landfill sites over complex topographic regions. Overall, the land suitability obtained based on fuzzy-WLC is more refined and smooth because of its better segregation and its potential to consider full tradeoff between factors and average risk. The AHP identified (47 km^2) as high suitable while fuzzy-WLC generated 36 km^2 as suitable area. Finally, the intersection of both suitability index map shows numerous suitable landfill sites available in Islamabad city, however, the surface areas of the sites is small at individual level (less than 15 hectare).

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Chapter 1
Introduction

1.1 Landfill Site Selection Problems

Developing countries are facing crucial challenge towards the selection and management of solid waste disposal sites due to involvement of multiple factors including urban development, spatial land use alterations, environmental impacts, economic and future strategic planning and management, resulting mismanagement of waste (Alkaradaghi et al. 2019). According to Waste Atlas (2018) an estimated to 2 billion tonns of solid waste is produced worldwide which is expected to increase to 3.4 billion tonns by 2050. Currently, an average of 0.74 kg of waste is produced per capita per day, out of which 33 percent of waste remain uncollected by municipalities (Nanda & Berruti, 2020).

In South Asia, Pakistan as a developing country is lacking proper waste management strategy, thereby, generates 20 million tons of solid waste per year with increasing rate of approximately 2%, annually, which is expected to increase in future by 2.4% annually, ranging between 0.283-0.612 kg/capita/day (Ghauri 2018). Pakistan ranked sixteen in the list of countries with the maximum production of solid waste, as shown in Table.1. Pakistan has current production rate of 0.84 kg/capita/day (50,438, tonns/day) which is projected to increase 1.05 kg/capita/tonns (109,244 tonns/day) (Nanda & Berruti, 2020). Additionally, currently the waste landfill site in developing countries including Pakistan are being not selected based on proper factors (limited factors) and robust methodologies resulting low quality design and ignorant of the rules imposed by environmental agencies and proper landfill management (Mondelli et al. 2007). In order to address the aforementioned challenges it is necessary to evaluate the possible landfill site throughout Islamabad by considering the local condition, factors and environment of Islamabad.

Table 1. Current and estimated production of global solid waste.

Country	Current generation (kg/capita/day)	Current generation (tonnes/day)[a]	Projected (2025) (kg/capita/day)	Projected (2025) generation (tonnes/ day)
USA	2.58	624,700	2.30	701,709
China	1.02	520,548	1.70	1,397,755
Brazil	1.03	149,096	1.60	330,960
Japan	1.71	144,466	1.70	146,982
Germany	2.11	127,816	2.05	126,633
India	0.34	109,589	0.70	376,639
Russia	0.93	100,027	1.25	120,076
Mexico	1.24	99,014	1.75	–
UK	1.79	97,342	1.85	110,515
France	1.92	90,493	2.00	107,318
Italy	2.23	89,096	2.05	86,520
Turkey	1.77	86,301	2.00	135,962
Spain	2.13	72,137	2.10	78,926
Indonesia	0.52	61,644	0.85	151,921
South Africa	2.00	53,425	2.00	72,146
Pakistan	0.84	50,438	1.05	109,244
Canada	2.33	49,616	2.20	69,179
South Korea	1.24	48,397	1.40	58,496
Argentina	1.22	41,096	1.85	80,420
Nigeria	0.56	40,959	0.80	101,307
Egypt	1.37	40,822	1.80	83,583
Thailand	1.76	39,452	1.95	56,673
Australia	2.23	36,164	2.10	46,759
Vietnam	1.46	35,068	1.80	72,909
Philippines	0.50	29,315	0.90	77,776
Netherlands	2.12	27,945	2.10	31,206
Columbia	0.95	27,918	1.50	66,269
Venezuela	1.14	25,507	1.50	51,089
Algeria	1.21	23,288	1.45	46,078
Morocco	1.46	23,014	1.85	44,389
Malaysia	1.52	21,918	1.90	51,655
Poland	0.88	20,630	1.20	27,883
Saudi Arabia	1.30	20,000	1.70	50,424

(Source: Nanda & Berruti, 2020)

1.2 Solid Waste Managements

The term Solid waste management is umbrella terminology associated with the control and management of production, storage, collection, transfer and transport, processing and disposal of solid wastes. Integrated solid waste management includes the selection and application of suitable techniques, technologies and management programs to achieve specific waste management objectives and goals (Tchobanoglous and Kreith, 2002).

One of the most fundamental strategy in environmental management fall under the category of solid waste management because solid wastes are primary factors of soil, water and air pollution(Das et al., 2019). Without proper management of solid waste environmental management would be a distant dream. Source reduction, reuse and recycling are the primary strategies to manage the solid waste. Therefore, the three “Rs” of solid waste management chain are essential to attain environmental sustainability (Das et al., 2019). However some residual still remain after applying the three “Rs” for disposal. As solid waste management is decentralized process and depend on the economic status of a concern country therefore continuous monitoring of waste generation is the fundamental strategy in the management of solid wastes. Although, disposal of solid waste is the least preferred steps of solid waste management strategy in developed country but it is the most opted strategy in developing countries. Land filling is the widely opted strategy of waste management in developing countries because of its easy way of implementation. Das et al. (2020) mentioned following problems associated with waste management strategy of developing countries:

- Increasing waste generation.

- Lack of trained personnel and efficient system for the collection of solid waste.
- Inefficient waste transport system.
- Operational inefficiency in the treatment and disposal of solid waste.

Integrated solid waste management is a strategy with a primary aim of developing of sustainable solid waste management system that is environmental friendly, economically affordable and legally acceptable(Geng et al., 2007). Generally solid waste management strategies can summarized in to four category:

- Source Reduction
- Reuse
- Recycle/ waste transformation
- Landfilling

1.2.1 Reduction

Reduction is the processes of diminishing waste generation as it involves reduction of amount, volume and toxicity of solid waste (Abdel-Shafy & Mansour, 2018). It is one of the most basic strategy which diminish the amount of pollutant, the price associated with its handling and its environmental effect. There are many possible way of diminishing waste which include encouraging people and industries to buy product that involve less packaging, make use of reusable product and lessen by product from industries.

1.2.2 Recycling

The second step in the waste management hierarchy is recycling and reuse of waste (Abdel-Shafy & Mansour, 2018). Recycling involve the collection of waste material for reuse, reformation and remanufacturing of already used product. Recycling is an important strategy of waste management chain as it reduces the demand for new resources and the amount waste generation. Although reprocessing has negative impact on environment and people health but this effect is lesser than the generation of whole new waste. Approximately, 19 percent of solid waste is recycled globally (Nanda & Berruti, 2020).

1.2.3 Waste Transformation

Waste-to-energy conversion is one of the most common technique of solid waste managements. Various waste transformations including thermochemical and biological transformation methods are available to convert waste into solid, liquid and gaseous fuel to supports the growing energy demands (Nanda & Berruti, 2020). One of the most common technique of waste to energy conversion is the incineration of waste. In incineration process a sufficient amount of energy and steam is generated by the combustion of solid waste. Incineration not only generate energy but it also reduces the mass and volume of solid waste by 80-85 w% and 95-96 v% respectively.

Few others, technique of waste transformation are: pyrolysis, anaerobic digestion and aerobic compositing and gasification. The aforementioned, technologies are commonly practiced worldwide however they are not satisfactory to organic waste. The disadvantages are: toxic gas generation and bad odor and high energy consumption. Another method of waste transformation is waste valorization-the process of converting waste in to more valuable product. However the major disadvantage is caused by high energy needed to degrade highly stable recalcitrant compound and biopolymer.

1.2.4 Landfilling

Landfilling is one the oldest technique of solid waste management and it is defined as the process of disposal, compression and embankment of waste at suitable location (Sadhasivam et al., 2020). Landfilling is fundamental part of solid waste management especially in developing countries because of its low cost and convenient execution. An estimated of 70 percent of global solid waste end up in landfill and dump sites (Nanda & Berruti, 2020). However the disposal of solid waste in landfill sites has significantly decreases in developed countries it is likely to remain important strategy of integrated solid waste managements (Vaverková, 2019).

Although landfilling is one of the effective method of solid waste management, but there are many concern associated with landfilling as solid waste management strategy. The main concerns associated with landfill are: environmental pollution, ground water contamination and emission of toxic gases and bad odor from landfill. Another major problems associated with landfill is that the waste can be landfilled at limited time but the reclamation process took up to hundreds of years (Vaverková, 2019). In order to avoid the aforementioned problems and issue sanitary landfill emerged as alternative of open dumb and semi-controlled landfill. Sanitary landfill take into account the control of leachate and harmful gases thus minimizing the environmental risk associated with landfill.

1.2.5 Landfill Site Selection

Landfill is an engineered structured site where solid waste are buried and its delineation is one of the most substantial and challenging step in disposal and management of solid waste (Chamchali and Ghazifard 2019; Kamdar et al. 2019; Mian et al. 2017; Rahimi et al. 2020). Since, landfill act as ecological reactor for waste transformation, therefore landfill sites selection demands an in-depth consideration of various factors and constraints like environmental, technical, topographic and economic (Nanda & Berruti, 2020). Hence, substantial evaluation processes is necessary to evaluate these factors. Besides this a complete methodological structure is needed to identify best suitable disposal site with minimum negative impact to the people and physical environment.

1.3 Landfill Sites in Islamabad

Islamabad is capital metropolitan city of Pakistan located between 33°28′01″ N–33°48′36″ N latitude and 72°48′36″ E–73°24′ E longitude with total area of approximately 906 km^2. The geographical location of Islamabad, as shown in Figure 1. The Islamabad is at 6^{th} rank in Pakistan according to population with total of 1.01 million people. The city is divided into five administrative zones, which is further divided in to different sectors with area of each sector equal to 2 km^2. Identification of landfill site has been one of the major issue during the designing process of cities as it has huge impact on aesthetic, ecology, and environment of the area. Islamabad, the capital city of Pakistan was designed by famous Greek architect C.A Doxiadis around 1960s. Currently, Islamabad is the only planned city of Pakistan however with various ongoing development activities ICT has been struggling with rapid urbanization and gigantic levels of pollution from industrial, residential, and transportation sources. Unmanaged population growth couple with high pace of urbanization has negatively affected both the physical environment and public health of ICT.

Growing population, rapid urbanization and huge amount of waste generation are the primary concern of the ICT. According to the 2017 national population census, the total population of ICT is approximately two million, which makes it the ninth largest city of Pakistan thus generating a huge amount of waste. Currently, there are no particular landfill sites in Islamabad for the disposal of solid waste. AS, Islamabad Capital Territory Bye Laws, 1968, Section 132 Cantonment Act 1924 are some inadequate rules and regulations in Pakistan that deal with deposits and disposal of municipal solid waste (Pak-EPA 2016) however there is sufficient negligence when it come to the implementation process of these laws. The landfill site selection process for Islamabad is a huge challenge for the concerned governmental authorities because for the last five decades not a single permanent landfill has been designed for the city. As there is no permanent landfill exists in Islamabad therefore the waste still dumped in a residential areas of 1-12 sector. The Sangjani landfill sites proposed by the Metropolitan Corporation Islamabad (MCI), could not even start the construction work due to public resistance and deliberate official negligence. The kurri Road landfill site was also turned down public pressure and environmentalist. Despite the huge infrastructure available to the Capital Development Authority (CDA), a proposed landfill site project has not been initiated till date and past practices of dumping refuse of all kinds in area close to the residential sector continue. In order to address the aforementioned challenges it is necessary to evaluate the possible landfill site throughout Islamabad by considering the local condition of Islamabad.

1.4 Problem Statement

The landfill sites selection requires highly diverse factors and preferences, therefore, considering such diversification and preferences aim to resolve the issues regarding spatial decisions in context of requirements, objectives and selection of criteria thereby decline in level of complexity to provide rational decisions to cope with public resistance. Such issues are more complex and challenging in developing or low-income highly populated countries like Pakistan, which is ranked at six in the most populated country of the world. Its major metropolitan cities generate approximately 6000 tons of daily waste with 93% of this amount deposited in landfill (Azam et al. 2020).

However, as per author's information, there is hardly any study regarding the selection of a suitable landfill site that follow environmental and scientific principles of site selection for the capital city of Pakistan (i.e. Islamabad). Additionally, mostly previous and aforementioned studies provided analysis based on single approach without comparison and consideration of integrated approaches suitability based on local factors of the study regions.

1.5 Research Objective

The aim of this study is to identify the appropriate solid waste landfill sites in the capital of the country as a case study, by the integration of Geographical Information System (GIS) with weighted linear combination (WLC) method, analytical hierarchy process (AHP) and fuzzy logic based on multi criteria decision making (MCDM).

Chapter 2

Literature Review

Landfilling is an essential aspect of the waste management chain, which includes waste reduction, reuse, composting, and eventually landfilling. (Barzehkar et al. 2019; Kamdar et al. 2019). As a consequence, delineating landfill sites is one of the most important and complicated measures in solid waste disposal and management (Chamchali and Ghazifard 2019; Kamdar et al. 2019; Mian et al. 2017; Rahimi et al. 2020). Several studies have been reported for siting of landfill sites by adopting different Geographical Information Systems (GIS) based on integrated methodologies including analytical hierarchy process (AHP) and fuzzy logic (Alkaradaghi et al. 2019; Barzehkar et al. 2019; Demesouka et al. 2019; Donevska et al. 2012; Gorsevski et al. 2012; Ngoc and Schnitzer 2009; Şener et al. 2010). Several other similar methods have been reported in literature for the evaluation and selection of waste disposal sites, worldwide (Mohammed et al. 2018; Mohsen and Abbassi 2019; Mohsen and Abbassi 2020).

Mostly, the integrated techniques based on GIS including fuzzy logic and multi criteria decision-making (MCDM) are widely adopted for addressing difficult decision-making issues in the selection of a waste disposal site (Kharat, Kamble, Raut, Kamble, & Dhume, 2016). These approaches aim to optimize spatial locations of landfill sites to meet number of conditions or factors (Alkaradaghi et al. 2019). However, landfill sites selection based on MCDM and fuzzy logic is a tiresome task as it involves multiple factors such as land use planning (Nguyen et al. 2015; Romano et al. 2015; Van Niekerk et al. 2016), environmental (Cervelli et al. 2017; Iyalomhe et al. 2015; Rahman et al. 2014), operational and economic (Gorsevski et al. 2012). On the other hand, the criteria employed to determine the importance of these factors is often contradictory. The uncertainty and impreciseness of available information and biased human preferences make it difficult to get right numerical values for the evaluation criteria (Kharat et al. 2016). To address such challenges, recently GIS and AHP have identified as novel strategy for landfill identification (Kamdar et al. 2019; Osra and Kajjumba 2020; Torabi-Kaveh et al. 2016). One of the most commonly used MCDM techniques is the AHP, which decomposes a problem into a hierarchy with the target at the top (Saaty 2008). The AHP is a comprehensive approach to provide flexibility for taking comparatively appropriate decision on the basis of subjective judgments of the decision maker and empirical data (Saaty 1990). However, AHP become complicated with numerous criteria to be considered in the decision making process. Therefore, an integrated raster-based multi-criteria spatial decision support systems (MC-SDSS) approach was proposed by Demesouka et al. (2019), for the land suitability analysis in Northern Greece. While, Kamdar et al. (2019) selected landfill sites for Sonkhala, Thailand by the integration of GIS and AHP process using thirteen (13) different parameters by grouping them into three main categories (morphological, environmental and economic factors), subsequently, the AHP was employed to assign weight to main criteria and sub-criteria. Demesouka et al. (2019) employed GIS based multiple criteria decision aid (MCDA) method for the land suitability analysis for the landfill sites selection in Northern Greece. Further, Şener et al. (2010) applied a combined GIS and AHP approach for the solid waste landfill site selection in Konya, Turkey.

Furthermore, another integrated hybrid fuzzy delphi (FDM) AHP and decision making trial and evaluation laboratory (DEMATAL) based approach adopted by several researchers (Jamshidi-Zanjani and Rezaei 2017; Kharat et al. 2016; Mohsen and Abbassi 2019; Mohsen and Abbassi 2020; Saadat Foomani et al. 2017; Torabi-Kaveh et al. 2016) have adopted to identify, evaluate and prioritize landfill sites selection criteria by investigating the interrelationship between criteria factors. The aforementioned studies was based on three stages, first the identification of relevant criteria based on experts opinion, subsequently, FDM technique was employed to obtain the critical factors for site selection. In second step, the weights were assigned for decision criteria, which subsequently used to calculate their importance by using FAHP. Third, the DEMATAL technique was used to identify the causal relationship among different criteria to recognize influential criteria.

Jamshidi-Zanjani and Rezaei (2017) considered two main criteria (environmental and socioeconomic) and twelve (12) sub factors with the integration of fuzzy logic and multi attribute decision approach for the selection of potential landfill site in Markazi province, Iran. In aforementioned study, the weights of main and sub criteria were calculated by ANP model while the layer standardization was carried using fuzzy logic approach. Additionally, Rahimi et al. (2020) utilized hybrid decision-making method including fuzzy logic integrated with GIS tools for the selection of suitable solid waste disposal sites in Mahallat, Iran. Further, Hoque and Rahman (2020) adopted artificial neural network (ANN) surrogate model for the landfill sites selection and area calculations based on prediction of waste collection in Dhaka, Bangladesh. The aforementioned combination of GIS based integration with decision analysis approaches improve the abilities of research by providing a methodology framework to resolve complex conflicting goals and structured or semi-structured local issues related to public expressions such as stakeholders and technical experts. Since, the landfill sites selection requires highly diverse factors and preferences, therefore, considering such diversification and preferences aim to resolve the issues regarding spatial decisions in context of requirements, objectives and selection of criteria thereby decline in level of complexity to provide rational decisions to cope with public resistance. Such issues are more complex and challenging in developing or low-income highly populated countries like Pakistan, which is ranked at six in the most populated country of the world. Its major metropolitan cities generate approximately 6000 tons of daily waste with 93% of this amount deposited in landfill (Azam et al. 2020).

Landfill sitting problem has been addressed by many researcher globally using MCDM technique alone or in a combination with other method. Fatoyinbo et al (2020) considered geotechnical properties of the soil along with other environmental factors for the selection suitable landfill site within Akure metropolis. They assigned a suitability score to each factors (geotechnical and environmental) based on existing literature. After that they prepared the respective map of each factors using fuzzy membership. Finally all layer was combined based on fuzzy overlay. They concluded that GIS is efficient tool for environmental and urban planning. However, suitable score assign to each factors was based on literature review and proper method was not used for the comparison of different criteria and sub-criteria factors. Therefore the possibility that the favorable factors could overweight the least favorable factors was maximum.

Therefore, this paper proposed a comparison of different GIS based integrated approaches, AHP, fuzzy logic and weighted linear combination (WLC) approaches based on multi criteria decision method (MCDM) tested by different researchers in aforementioned literature. Approximately 600 Tons of solid waste is collected and transported from Islamabad on daily basis. However, as per author's information, there is hardly any study regarding the selection of a suitable landfill site that follow environmental and scientific principles of site selection for the capital city of Pakistan (i.e. Islamabad). Additionally, mostly previous and aforementioned studies provided analysis based on single approach without comparison and consideration of integrated approaches suitability based on local factors of the study regions. In this study a novel modelling technique has been adopted by integrating three different MCDM (AHP, Fuzzy logic and WLC) in order to remove the inherent disadvantages associated with each of the above method. The technique is novel because the biasedness arise due to expert judgment has been removed by AHP method, and the absence of measuring unit has been handle by 1-9 point scale of AHP. While, Fuzzy set theory has been used to remove uncertainty and inconsistency associated with data and factors. As a result, the study's main objective was to look at possible solid waste landfill sites. Finally all method were combine to get the final site that minimize and consider full tradeoff between factors and average risk. Islamabad by the integration of GIS with AHP, fuzzy logic and WLC approaches based on MCDM. TO achieve the aforementioned objective we chose thirteen (13) criteria (9 factors and 4 constraints) and grouped them in two main categories (environmental and socio-economic).The expected results will show various solid waste landfill sites in Islamabad by considering the surface areas.

Chapter 3

Materials and Methods

3.1 Study Area

Islamabad is capital metropolitan city of Pakistan located between 33°28′01″ N–33°48′36″ N latitude and 72°48′36″ E–73°24′ E longitude with total area of approximately 906 km^2. The geographical location of Islamabad, as shown in Figure 1. The Islamabad is at 6^{th} rank in Pakistan according to population with total of 1.01 million people. The city is divided into five administrative zones, which is further divided in to different sectors with area of each sector equal to 2 km^2. These sectors are further divided into four sub-sectors having a central shopping malls, parks etc. Since, the Islamabad is located at the northern edge of the Pothohar Plateau and at the foot of the Margalla Hills, the elevation of Islamabad Capital Territory (ICT) range from 400-700 m. Therefore, the climate of Islamabad is humid subtropical with four seasons: spring, autumn, summer and winter. The city has an overall extreme weather of hot summer with monsoon rain in July and August, and fairly cold winter with occasional snowfall over the hills. The city is mainly influenced by winter precipitation (western distribution pattern) and slightly with summer precipitation (summer patter), therefore, precipitation occurrence events are spread throughout the year. The temperature varies widely throughout the year with range between -2 – 46 °C. The terrain of the Islamabad and Rawalpindi vary from plain in southern part of the city to mountainous in North. Due to vast change in topography and elevation range (428–1440 m) from mean sea level, several local hill torrents and streams passing thorough the city mainly with drained by the Kurang River which originates from Margalla Hills, provides water to Rawal Dam and flows through Islamabad city and merges into the network of Nullah Lai.

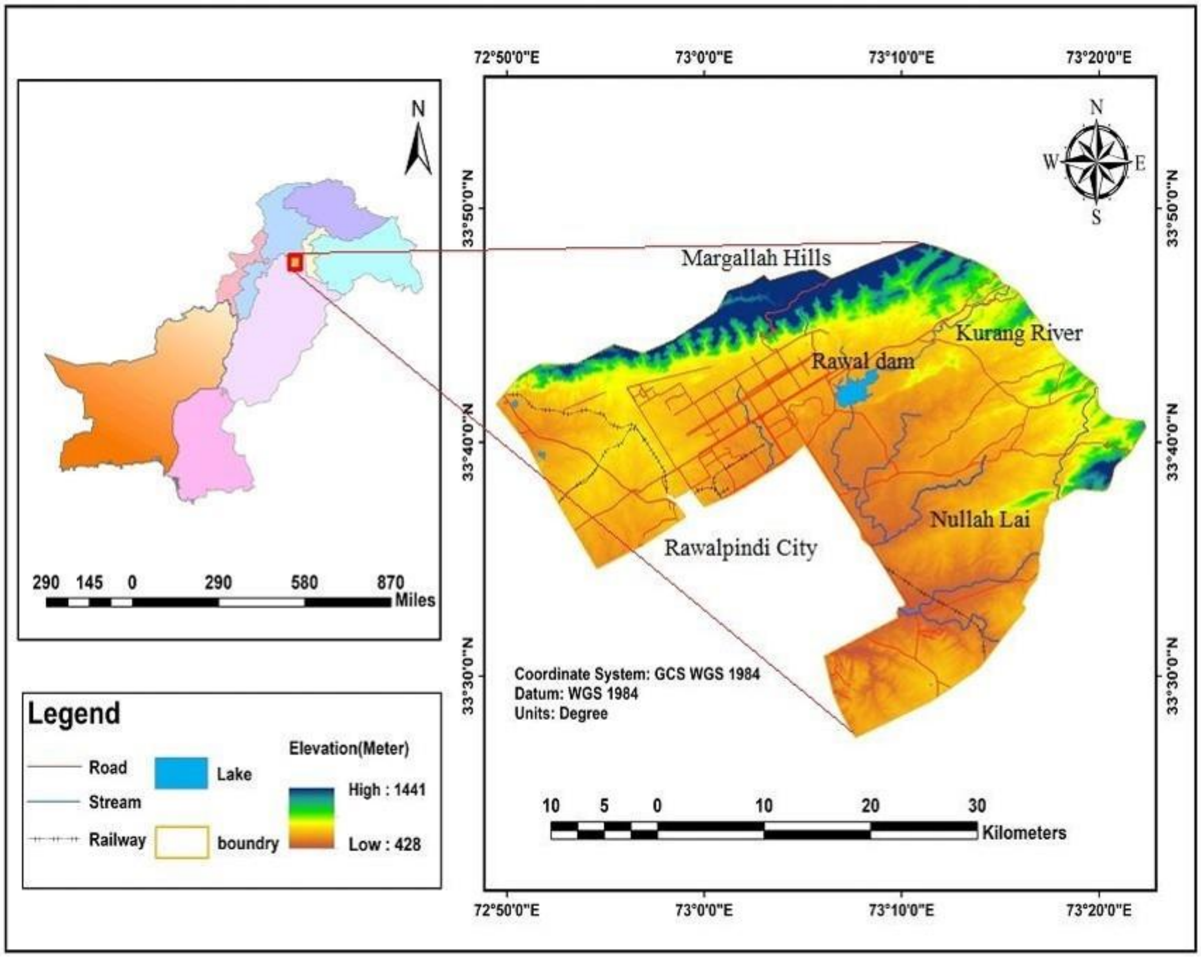

Figure 1. Location of the study area (Islamabad) showing elevation range, streams, Rawal dam.

3.2 General Methodological Design

The general methodological design/ methodology of the paper is as follow: Sec.1 of the study deals with the land sitting problems Sec.2 critical literature review of previous paper.. In Sec. 3 a comprehensive description of the modelling theories has been presented. The finding of the paper has been discussed in Sec. 4. While the final conclusion has been discussed in Sec. 5. In this study, nine factors (Table 2) and four constraints (including distance from the roads, railway lines, distance from the water bodies and river/streams, land use, land cover (barren land, built up, forest and water), settlements, soil type, land slope and population were extracted using GIS and evaluated for the selection of optimal landfill site in Islamabad city. These nine factors are grouped in to two main categories covering environmental and topographic and scio-economic factors. The first group is concerned about environmental and topographic characteristic of the study area, while the second group deals with the scio-economic factors. These factors are selected in order to address two important societal issues including environmental and economic concerning with the landfill site selection (Demesouka et al. 2019). Furthermore, expert judgment has be solicited for determining the level of significance of factors and constraints. The data/images used for the extraction of factors, is given in Table 2 while constraints map are presented in Figure. 2. The flow chart of methodology adopted in this study is presented in Figure. 3.

Further, after preparation of aforementioned criteria/factors, two different methods, fuzzy set theory and ranking (assigning rating value between 0-10) was employed to evaluate standardization of each layer (see Figure. 4 for basic concept of fuzzy logic approach). However, to exclude certain areas mask operation was performed using the constraints layer (Figure. 2) before standardization of each criteria factor. Expert judgments was solicited to define the control points of fuzzy membership of 9 criterion. The AHP method was employed to derive weightage for each criteria/category as adopted by several researchers for the selection of possible solid waste landfill, worldwide (Chabuk et al. 2017; Nguyen et al. 2015; Romano et al. 2015; Şener et al. 2010). Finally, all layers were integrated based on AHP and fuzzy-WLC method. In fuzzy-WLC method, first each factor was masked by the constraints then multiplied with their respective weights subsequently that all layers were integrated using MCE menus of IDRISI software (Figure. 4).

3.3 Fuzzy Logic

Fuzzy logic is one the most popular MCDM technique, in which standardization of spatial criteria through a continuous process (Alkaradaghi et al. 2019; Barzehkar et al. 2019). Fuzzy logic is used to resolve the uncertainty and imprecision contributed by decision-making (Kharat et al. 2016). Classical Boolean logic is dichotomous in nature which exhibits that certain elements are true or false an object belong to a set or it does not. The Boolean logic is defined as follow in Eq. 1 (Saadat Foomani et al. 2017).

$$\mu A(x) = \{1 if x \in A \; 0 if x \notin A\} \qquad (1)$$

Fuzzy logic is based on the assumption that binary logic is unable to recognize some of the transitional state or ambiguities that may exist between exactly true or false values. In comparison with classical set fuzzy set does not have crisp boundaries (Saadat Foomani et al. 2017). Fuzzy logic evaluate the possibility of degree of membership using membership function. For example, the membership function for a set ‘A’ on the universe of discourse ‘X’ is defined as follow in Eq. 2:

$$\mathrm{A} = X.\, \mu \mathrm{A}(x) \;|_{x \epsilon X} \qquad (2)$$

In this study, four types of membership functions, the sigmoidal, J-shaped, linear and user defined functions are using IDRISI software (see Table 3 and Figure. 4).

1. Sigmoidal membership requires the position four controls points (a, b, c and d) in order to define the shape of the curve. Points a, b, c and d represents the controls points where the membership function rises above zero approach 1, fall below 1 again and finally approach zero.

2. J-Shape function is also commonly used function. In J-shape function points and d indicate the points at which membership value approach to 0.5 rather than zero. The different possibilities of J-Shape are shown in Figure.4.

3. Liner function is simplest function because it transform the input values linearly on the 0 to 1 scale.

4. The user defined function acts in case if the membership function is not applicable for any of the above function, then the function defined by the user is utmost appropriate. The fuzzy membership function is then linearly interpolated between any two control points.

In this study fuzzy logic has been employed to standardize the factors. Fuzzy set theory has been used because of its power of resolving the uncertainties associated with data and decision maker. The uncertainty arise due to ambiguity and imprecision of decision of decision making and this is inherent nature of geographic data which hamper the evaluation processes for decision maker. As the traditional method are inadequate for dealing with the uncertainty in the decision making. While Fuzzy logic handle the imprecision in information and human cognition by introducing the concept of partial membership instead of full membership which allow a wide range of decision. Furthermore the complex topography of Islamabad city and varied spatial data need a flexible approach like fuzzy set theory for data standardization. Hence fuzzy logic has been used.

3.4 Criteria Description and Evaluation

The selection of suitable site depend on various factors like environmental, technical, topographic and economic factors. These factors are selected based on extensive literature review and guidelines of environmental protection agency of Pakistan (Alkaradaghi et al. 2019; Chamchali and Ghazifard 2019; Demesouka et al. 2019; Gorsevski et al. 2012; Kamdar et al. 2019; Kharat et al. 2016; Mian et al. 2017; Rahimi et al. 2020). The Advance Thermal Emission Reflection Radiometer (ASTER) Global Digital Elevation (GDEM) 30 meter was utilized to generate static parameters like slope using ArcGIS platform. Additionally, the Landsat-8 satellite data with spatial resolution of 30 meter was adopted for the extraction of land use and land cover and validated with the capital development authority (CDA), Islamabad. While, soil layer was developed by using soil data provided by soil survey of Pakistan. The vector layers were further used to extract proximity to road, rail and water bodies. The extracted images for the aforementioned factors were utilized for the preparation of datasets required to analyze suitability of landfill sites using multiple factors such as soil type, land cover, land slope, settlements, land use, distance from the roads and railway lines, distance from water bodies. Table 1 shows list of criteria/categories/factors along with data source. After screening out the most relevant criteria, the standardization of the factors based on fuzzy logic and ranking method, are presented in Table 3 and Table 4. In this study, four types of membership functions, the sigmoidal, J-shape, linear and user defined functions were used in IDRISI software (Table 4 and Figure. 4). These four kind of membership has been defined based on recommendations of expert opinion and by following the basic rules of Pakistan environmental protection agency. Previous literature also consulted to define the control point of fuzzy membership but expert's judgment and local factors of the region has been preferred over the previously used literature.

Table 2. List of criteria/ categories used in this study for the evaluation and their data source.

Sr. No	Criteria/ Categories	Data Source
1	Land Slope (degree)	ASTER GDEM (USGS)
2	Land use (classes)	Capital development Authority, Islamabad
3	Settlements (m)	Capital development Authority, Islamabad
4	Land cover (classes)	Landsat-8 images (USGS)
5	Soil type (classes)	Soil Survey of Pakistan
6	Distance from roads (m)	Topographic Sheet, Survey of Pakistan
7	Distance from water bodies (m)	Topographic Sheet, Survey of Pakistan
8	Distance railway lines (m)	Topographic Sheet, Survey of Pakistan
9	Population density (person/pixel)	Landsat-8 images (USGS)

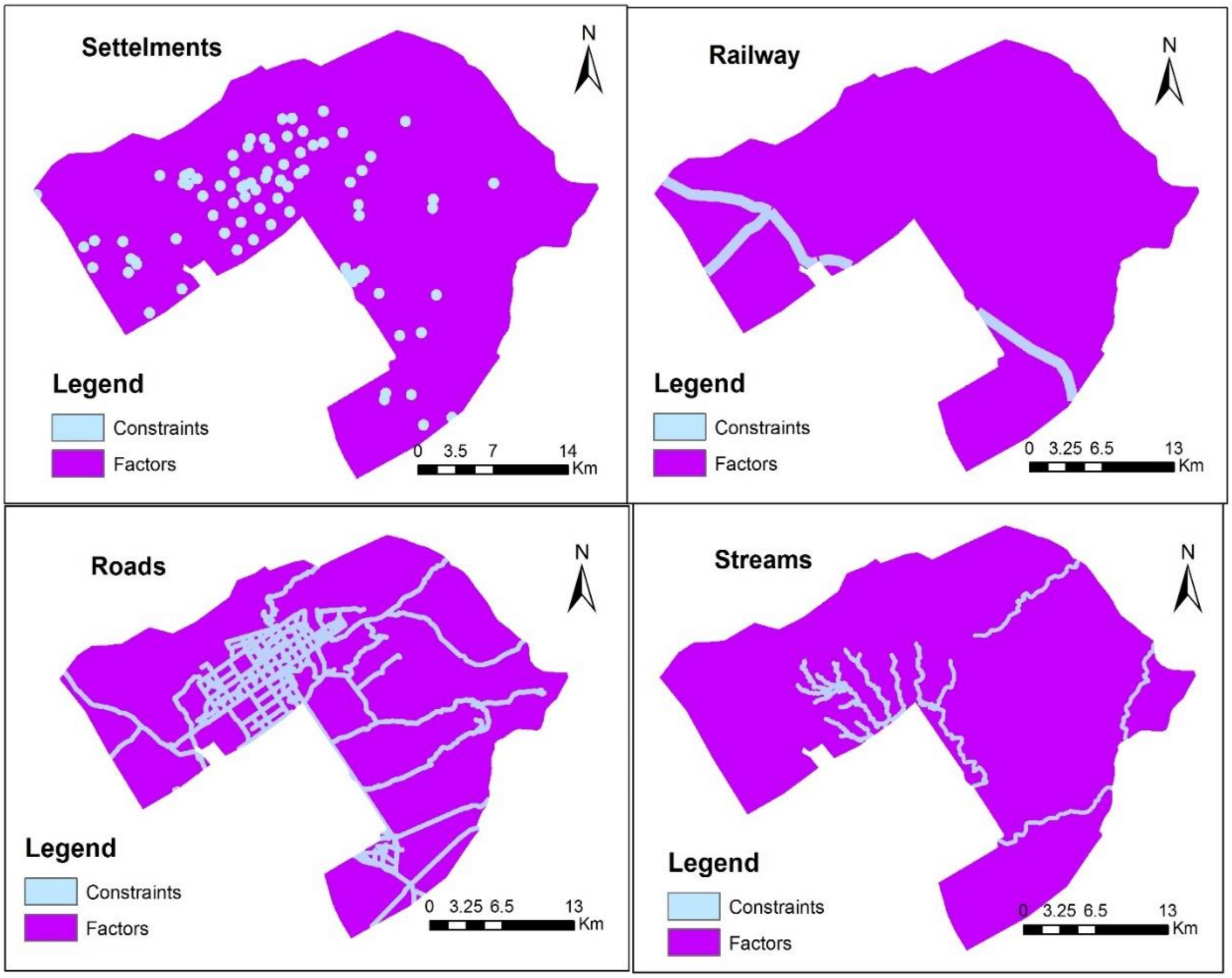

Figure 2. Constraints factors (a) 1000 m buffer around rail (meter), (b) 500 m buffer on both side of road line, (c) 500 m buffer around settlements, (d) 500m buffer around streams.

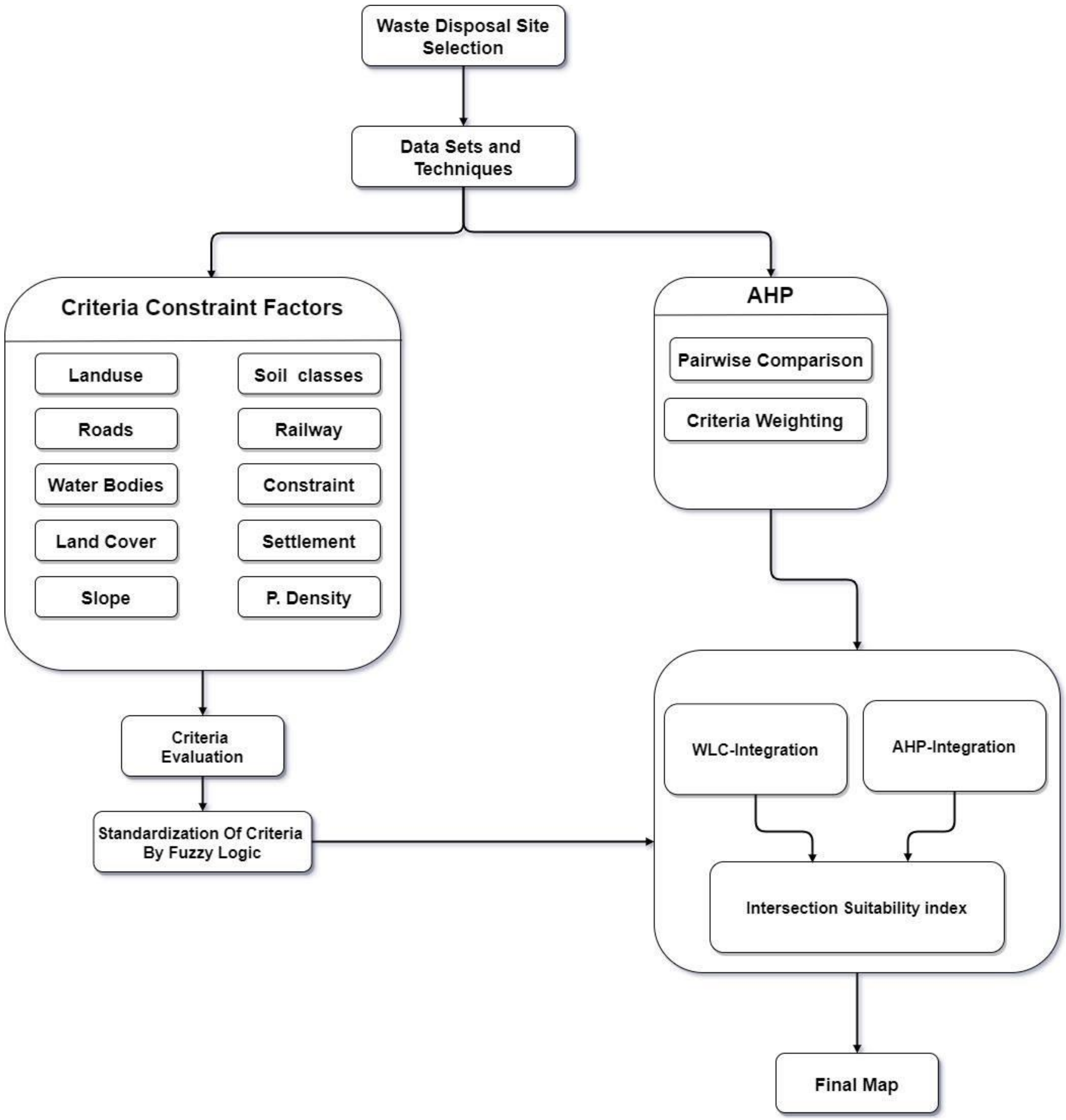

Figure 3. Methodology flow chart adopted in this study for the selection of suitable solid landfill sites.

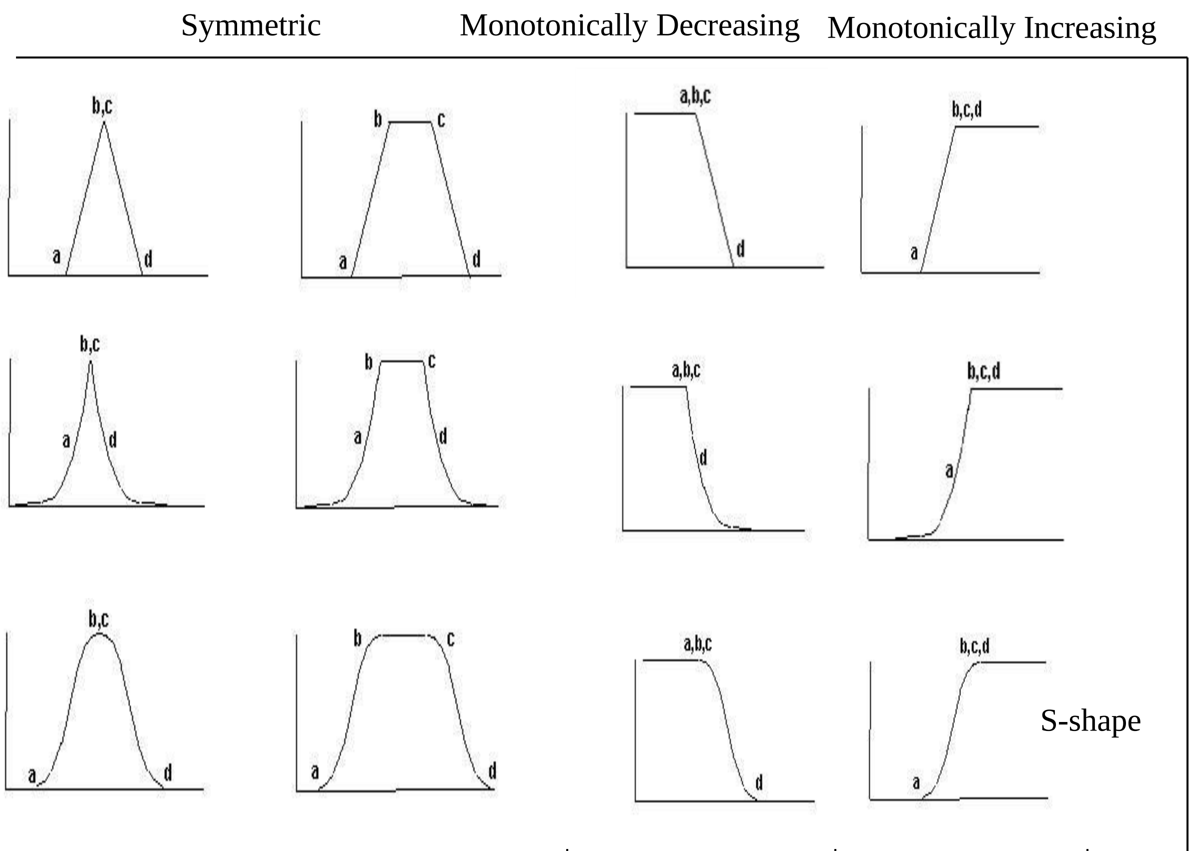

Figure 4. Shape and types of membership function used for the standardization of factors.

3.4.1 Environmental and Topographic Factors

Since, the Islamabad is located in the foot hill of Margalla, therefore, considering the slope is necessary to avoid steep slope areas. The excavation cost for steep slope is higher because of higher excavation cost and potential of landslide, therefore, land slope greater than 15% is consider inappropriate for landfill site (Demesouka et al. 2019). The slope was classified into four classes (0-5^0, 6-10^0, 11-20^0 and >20^0) (Figure. 5a). The score value of 10 was assigned to slope 0-5^0 because of most efficient for landfill site selection (Table 3). While, in case of fuzzy set S-Shape decreasing function was defined for the standardization of the slope (Table 4 and Figure. 5a). Thereby, slope of 15% and 30% were chosen as first and second control points (Table 4).

Land Cover (Classes): Land cover is primary determining factor in site selection process. The land cover map derived by supervised classification of Landsat 8 images (barren land, water bodies, urban areas, forest and vegetation) (Figure. 5b). The waste sites should be preferred in barren land and away from built up areas (Chamchali and Ghazifard 2019). Vegetation agricultural and water bodies are the least suitable sites in selection process of disposal sites. Table 3 & 4 shows that the rating and user defined membership function of land cover classes.

Soil types: As soil control the ground water recharge and therefore consideration of soil permeability is essential in order to protect ground water from contamination (Demesouka et al. 2019; Kamdar et al. 2019). The permeability is decrease by silt and hence minimizing the movement of pollutant. There are three major soil types in Islamabad such as sandy clay loam and mountainous rock, silt loam and silty clay loam and silt to fine sandy loam. These score was assigned equal to 9, 10 and 7, respectively, by following the permeability of the soil to reduce the

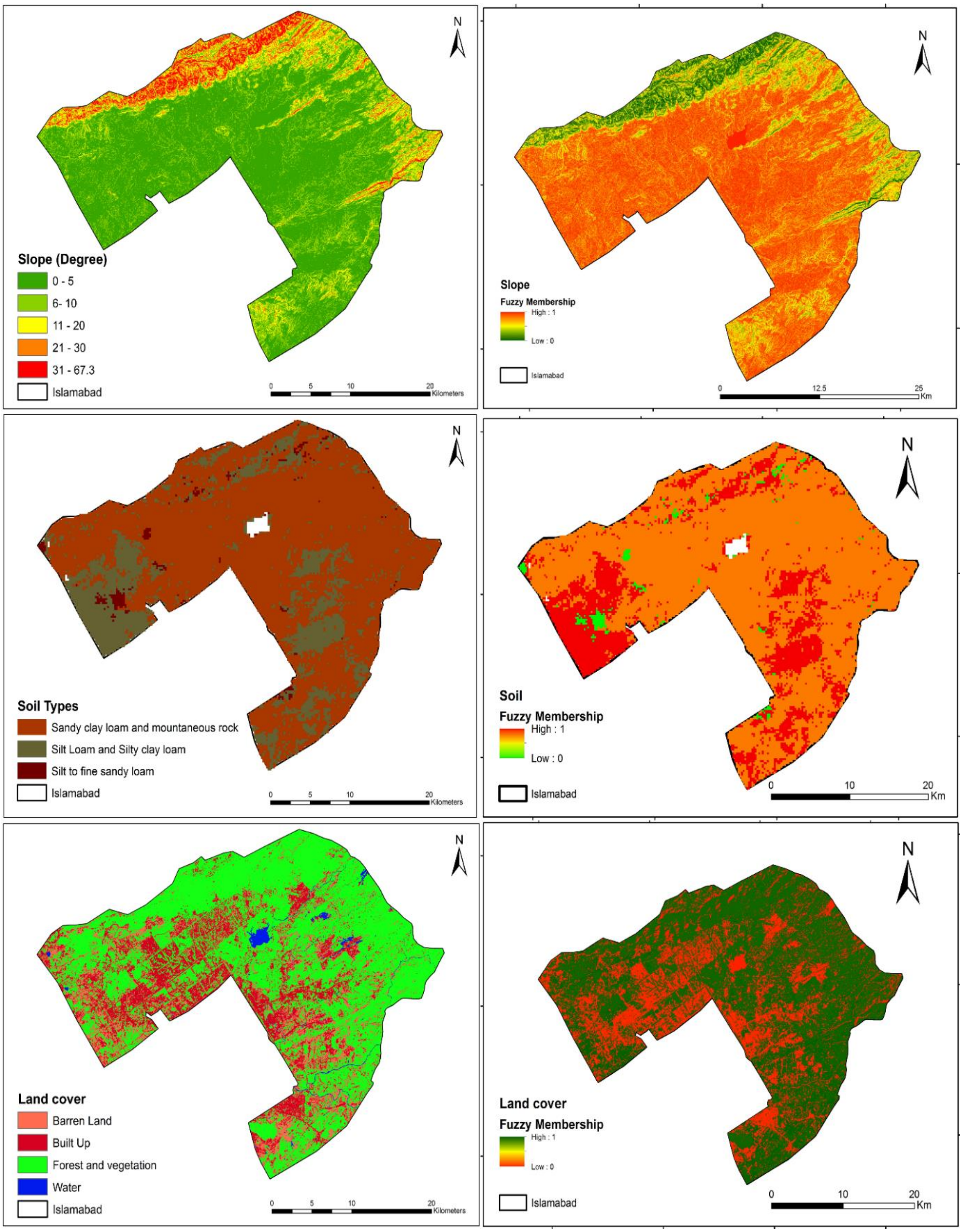

Figure 5. Criteria factors map for fuzzy logic (right) and AHP (left) including (a) slope, (b) soil type and (c) land cover.

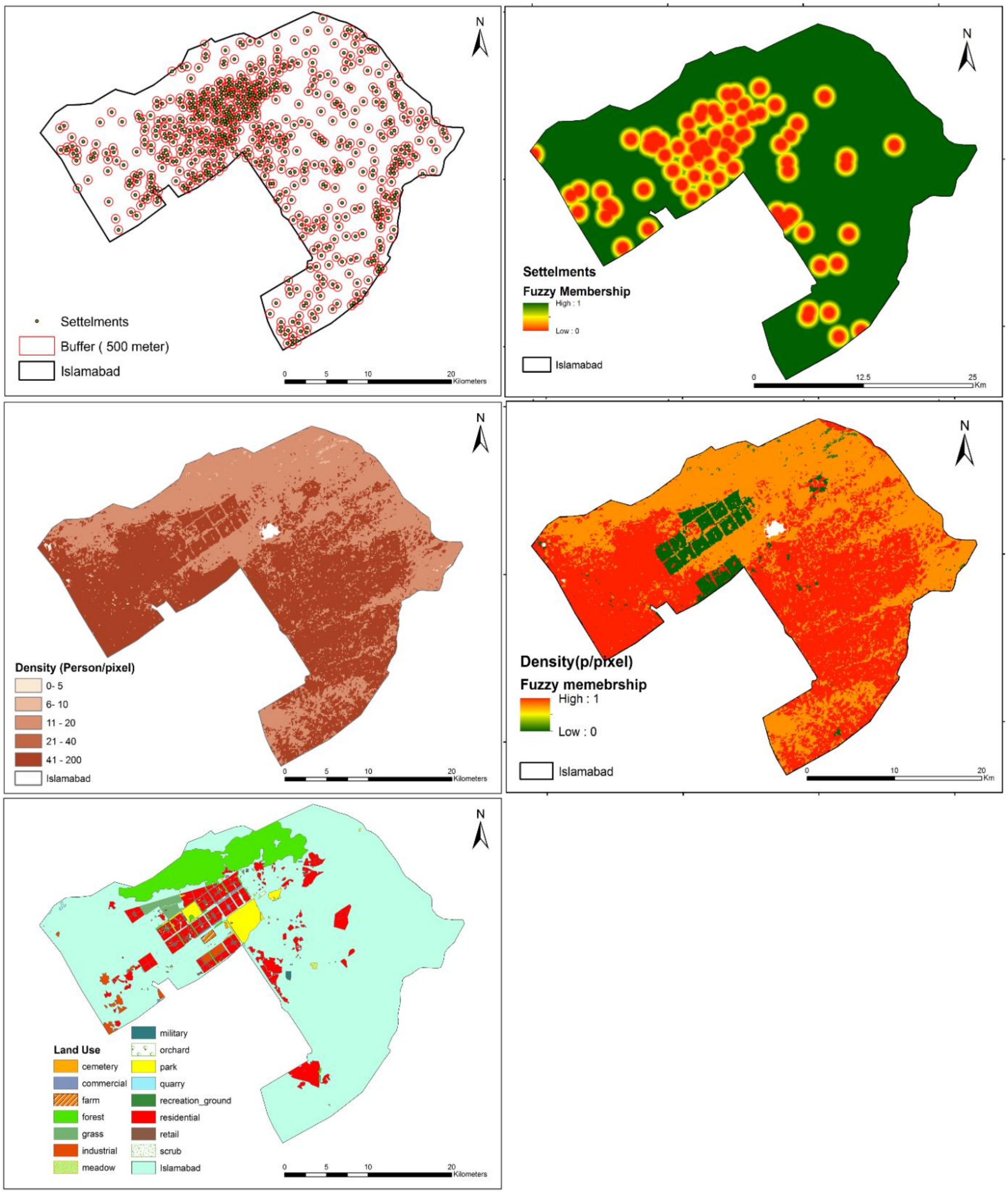

Figure 6. Same as Figure 5 but criteria including (a) settlements, (b) population density and (c) land use.

chance of contamination contribution from landfill solid waste during rainfall (Table 3). For fuzzy logic, the higher membership values were assigned to low permeable soil using user defined function (Table 4).

Distance from water bodies: In case of distance from water bodies (m), the landfill destinations should not be found close a body of surface water, therefore, a safe buffer zone around the surface water is necessary in order to protect water resources from pollution (Donevska et al. 2012). In ranking, three buffer zones were defined as 0-564, 565-1350 and >1351 m with assigned score values of 0, 3 and 10, respectively **(**Table 3). While, a buffer of 500 m representing full non-membership function was defined as first control point '(a)' of the S-shape decreasing membership function. While, control point '(b)' is set on 1500 m distance, meaning higher the distance higher the suitability (Table 4 and Figure. 7a). The score was assigned by considering protection measures to secure surface water (rivers and water bodies) from contamination risk

3.4.2 Socio- Economic factors

Distance from Roads and Railways: The roads determine the transportation cost of waste from source to destination. Therefore, waste disposal sites should not be too close or too far from the roads (Ahmad and Mahmood 2015). In this study, the roads were reclassify into five classes (0-564, 565-1350, 151-2443, 2444-3962 and >3963 m) based on Euclidean distance calculations in comparison to main roads and highways to the landfill sites, thereby, score was assigned as 0, 7, 10, 5 and 3, respectively. The score was assigned based on distance from the main roads, highways and cost effectiveness for the solid waste transportation, therefore, the score 10 was given to the buffer zone of 1351-2443 (Table 3 and Figure. 7b). In case of railway lines, the buffer zone on both sides of the line was classify into two (0-1000 and >1000 m) with maximum score of 10 assigned to later class (i.e. >1000 m) (Figure. 7c). In case of fuzzy membership function, for railway line and major highways, the J-shape increasing function was adopted (Table 4).

Population Density and settlements: proximity of landfill site to dense population and settlement is hazardous in nature because of its bad odor and aesthetic sense (Shahabi et al. 2014). In case of settlements, the buffer zone of (0-500 m) around the central point of village and settlements were created (with maximum score of 10 assigned to a class (i.e. >500 m) (Table 3 and Figure. 6a). While, the population density in form of person per pixel was classified into five classes with maximum score assigned equal to 5 to the lowest dense area (0-5) (Figure. 6b). While, in case of fuzzy logic, a “user defined” membership function was defined for population density, while, “linear increasing” membership function for distance of 1000 m as “a” control points and 2000 m as “b” control points (Table 4). The detailed description is provided in Table 3 and Table 4.

3.5 Analytical Hierarchy Process (AHP)

In this study, Analytical Hierarchy Process (AHP) multi-criteria approach was employed to establish the relative importance of the criteria for the determination of suitable solid waste landfill sites in Islamabad city, Pakistan. The AHP is one of the widely used approach in multi criteria decision making proposed by Saaty (1990). Following that, many researchers around the world have followed the AHP method for multi-criteria analysis using multiple factors for the determination of a possible solid waste landfill site. (Alvarado et al. 2016; Nguyen et al. 2015; Romano et al. 2015; Şener et al. 2010). It creates a decision hierarchy by breaking down the complex decision problems into its simplest forms. The AHP is a comprehensive approach to the

Table 3. Suitability ranking of sub-criteria and final weight of criteria

Sr. No.	Criterion/ Category	Buffer Zone	Rating	AHP Normalized Weight
1	Distance from the main roads and highways (m)	0-564	0	0.03
		565-1350	7	
		1351-2443	10	
		2444-3962	5	
		>3963	3	
2	Distance from railway lines (m)	0-1000	0	0.012
		>1000	10	
3	Distance from water bodies and rivers streams (m)	0-564	0	0.14
		565-1350	3	
		>1351	10	
4	Land use	Commercial	0	0.03
		Farms	0	
		Forest	5	
		Grass	3	
		Industrial	0	
		Residential	0	
		Park	0	
		Military	0	
5	Land cover	Barren land	10	0.10
		Built up	0	
		Forest and Vegetation	5	
		Water	0	
6	Settlements (m)	0-500	0	0.10
		>500	10	
7	Soil type	Sandy Clay loam and Mountainous Rock	9	0.062
		Silt Loam and Silty Clay Loam	10	
		Silt to fine sandy loam	7	
8	Slope (degree)	0-5	10	0.048
		6-10	5	
		11-20	0	
		>20	0	
9	Population density (person/pixel)	0-5	8	0.14
		6-10	5	
		11-20	0	
		21-40	0	
		>40	0	

Table 4. (a) Fuzzy set memberships function with controls points for landfills site selection, (b) categories pairwise comparison matrix and weighting.

(a) Objectives and Criteria	Control points (a)	Control points (b)	Fuzzy function/ membership
Environmental and topographic factors			
Slope (%)	15	30	S-shaped decreasing
Distance from water bodies (m)	500	1500	S-Shaped increasing
Land Cover (Classes)			
(a) Barren land			(a) 0.8
(b) Water	User defined		(b) 0
(c) Urban			(c) 0.1
(d) Forest and vegetation			(d) 0.2
Soil types (Classes)			
(a) Sandy clay loam and mountainous rock	User defined		(a)0.3
(b) Silt loam and silty clay loam			(b) 0.8
(c) Silt to fine sandy loam			(c)0.2
Land use (classes)			
(a) Commercial			
(b) Farms			
(c) Forest			
(d) Grass	User defined		User defined
(e) Industrial			
(f) Residential			
(g) Park			
(I) military			
Socio- Economic factors			
Proximity to Road (m)	500	1500	J-shaped Decreasing
Proximity to Settlements	1000	2000	Linear increasing
Proximity to Railway line	500	2000	J-shaped decreasing
Population Density (p/pixel)			
(a) 0-5	User defined		(a) 0.7
(b) 6-10			(b) 0.6
(c) 11-20			(c) 0.5
(d) 21-40			(d) 0.1
(e) >40			(e) 0

(b) Criteria/ Category	Built up	Soil type	Railways and Roads	Water bodies	Slope	Land cover and land use
Built up	1	2	9	4	7	5
Soil Type	0.50	1	7	3	6	4
Road and Railways	0.11	0.14	1	0.17	0.33	0.20
Water bodies	0.25	0.33	0.6	1	5	2
Slope	0.14	0.17	0.3	0.20	1	0.25
Land cover and land use	0.20	0.25	0.5	0.50	0.4	1

provide flexibility for taking comparatively appropriate decision based on subjective judgments of the decision maker and empirical data. It provides a combination of non-materialistic and materialistic features to produce weights for each criteria (Rezaei-Moghaddam and Karami 2008).

Primarily, the AHP approach considers the pairwise comparisons rather direct assessment of score and weights for the criteria resulting slight judgmental inconsistencies due to imperfection of human decisions (Saaty 1990). A nine point numerical scale is more commonly used in typical analytical hierarchy. AHP numerical scale range from 1-9 with 1 being equal importance to 9 extreme importance (Articte 1995). The AHP scale of relative importance for the pairwise comparison is defined as follows:

AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong, importance, 9- Extreme importance (2, 4, 6, 8 values in-between).

Finally, all layers were combined on the basis of weighted overlay method to get the suitability index map. The comparison rating of different factors was decided on the basis of literature review and expert's opinion. The pairwise comparison matrix were designed based on AHP scale, given in Table 5. Saaty's consistency index (Eq. 3) was used to evaluate the result of consistency matrix.

$$CI = (\lambda - n)/(n - 1) \quad (3)$$

In this case, CI is the consistency Index, λ is the average of consistency vectors and n is the total number of criteria. Consistency vectors were calculated by dividing weighted sum vectors by criteria weight. While, weighted sum vectors were calculated through multiplication of weights with column wise elements in comparison matrix and sum of these values over rows. The value of λ should be greater or equal than total criteria used in matric generation in order the CI to be relevant.

The following equation (Eq. 4) was used to calculate consistency ratio:

$$CR = (CI)/(RI) \qquad (4)$$

Where; *CI* is consistency index, *CR* is consistency ratio and *RI* is random index. If CR is greater than 0.10 then result is unacceptable

3.6 Selection of Suitable Sites by WLC Method and AHP Method

All the layer were combined based on AHP and weighted overlay method. WLC is spatial multi criteria evaluation method in which suitability is based on the relative importance of the criteria (Jamshidi-Zanjani and Rezaei 2017). WLC incorporate both criteria and constraint factors and characterized by full tradeoff between factors and average risk (Yousefi et al. 2018) and is based on (Eq. 5).

$$SI = \sum W_i S_i \qquad (5)$$

SI is the suitability index of the area, W_i is the weight of criterion *i* and S_i is the standardized suitability score of criterion *i* (Rahimi et al. 2020).

In this study, each standardized factors both from fuzzy logic and ranking method was multiplied by its respective weight from AHP, subsequently, each layer was added. Further, in AHP method, the integration was performed by adding an extension of AHP updated version of extAHP extension (AHP 1.1) in ArcGIS (10.5). All the nine factors were selected as input parameter and overlaid according to their weights. The categories pairwise comparison matrix

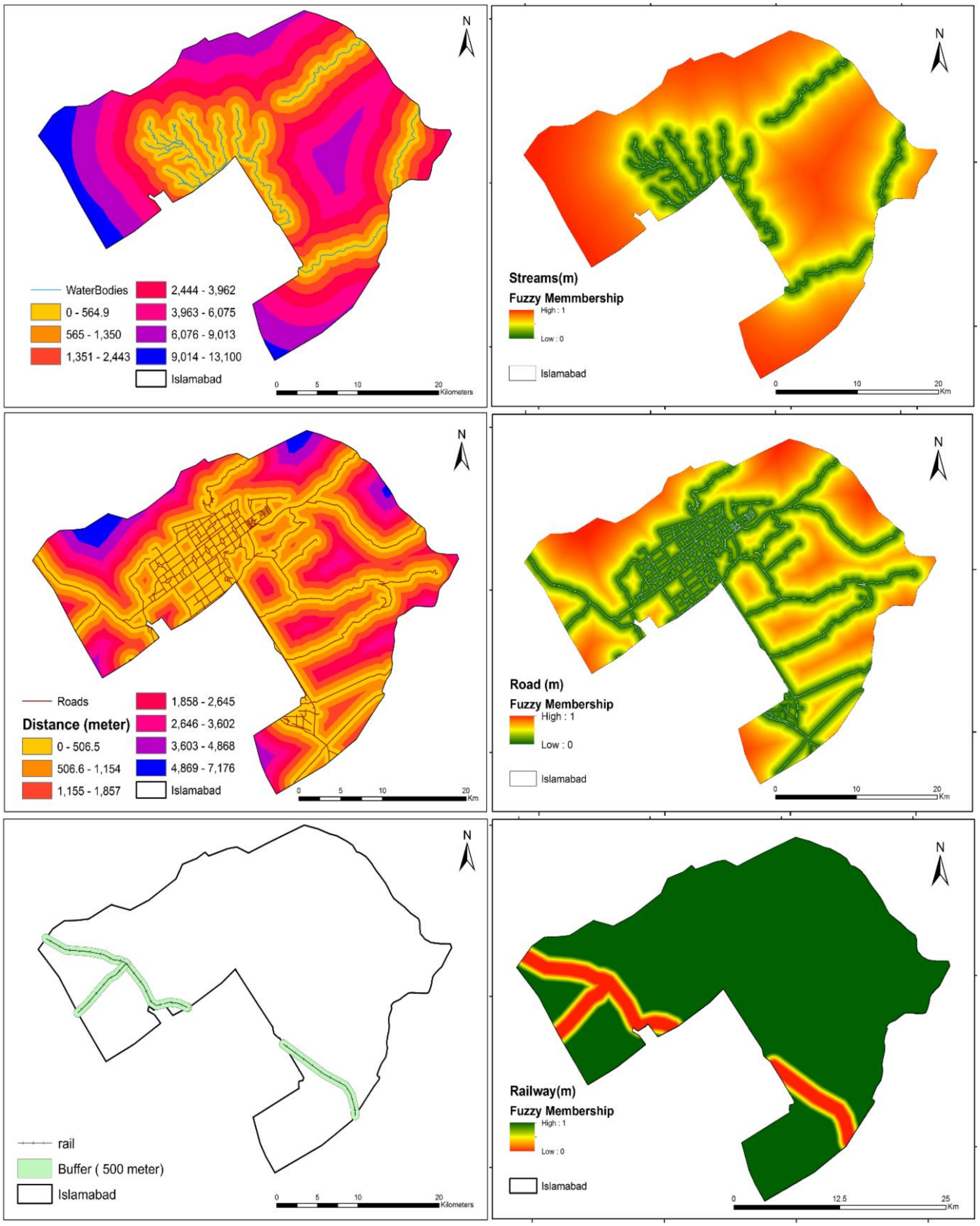

Figure 7. Figure 7. Same as Figure 5 but criteria including (a) distance from water bodies, (b) distance r from roads and (c) distance from railway lines.

and weight for different factors, is given in Table 5. While, the priority/ weight of the subclasses of each main factor is given in Table 6. To exclude certain areas mask operation was performed using the constraints layer (Figure. 2) before standardization of each criteria factors. The areas with lowest and high suitability index was assigned to unsuitable and highly suitable class, respectively. Integration of fuzzy layers were performed based on WLC and MCE menus using IDRISI software. Constraints and criteria factors was integrated by applying AHP as criteria weight (Shahabi et al. 2014). Finally, both suitability index map combined based on intersection in order to get the matching suitability index, subsequently, a selection criteria of suitability index greater than 0.75 was applied to finalize the final potential sites as shown in selection criteria. In this case selection criteria is defined as suitability index of the suitable site should be greater than six (>0.75).

Chapter 4

Result and Discussion

4.1 Evaluation of Criteria Weight

The results for the criteria weight based on multi criteria decision-making AHP approach shows that the consistency index (CI) and random index was found 0.107 and 1.25, respectively. While, the consistency ratio (CR) was found 0.086, which is less than 0.10, which shows an acceptable range (Table 5a). Further, the weights for the criteria based pairwise comparison shows that the priority values for the built up/settlements and land values (0.40) are maximum in comparison to soil type (0.27), surface water (0.14), land cover (0.10), slope (0.048) and rain and road (0.02). In consistent to priority values, the highest and lowest ranking was found for built up and distance from the roads, respectively. The criteria of built up and land use values received highest weight value followed by soil type and water bodies. The criteria of road and rail received lowest weight because the accessibility and transportation to all region of Islamabad is affordable.

4.2 Suitability Result

The suitability index map for the optimal solid waste landfill site in Islamabad city using AHP approach, is presented in Figure. 8a. The suitability index is developed to categorize the area on the basis of potential (least costly, away from urban center and water bodies) based on the weight contributing factors. Broadly, the suitability map is ranged from low (0) to high (1) values with a unique colour scheme of green (with low suitability), yellow (medium suitability) to red (high suitability). It noticed that the AHP method provided substantial red spots over the Islamabad city in comparison to fuzzy-WLC. However, both methods show the suitable sites located out of city. Additionally, it observed that the suitability index is very low over North of the Islamabad

Table 5. Final main criteria weight based on multi-criteria decision-making AHP method,

(a) Sr. No.	**Criteria/ Category**	**Priority**	**Rank**
1	Built up and land use classes	0.40	1
2	Soil Types	0.27	2
3	Surface water	0.14	3
4	Land cover	0.10	4
5	Slope	0.048	5
6	Rail and road	0.02	6

Consistency Index: 0.107

Random Index: 1.25

CR = 0.086 < 0.10 which is acceptable.

Table 6. Area of suitability classes from both the method.

Suitability Classes	**Area (km^2)-AHP**	**Area (km^2)-Fuzzy-WLC**
Restricted	255	255
Unsuitable	244.9	201.4
Least suitable	158.3	272.3
Moderate Suitable	200.8	141.3
Highly Suitable	47	36

close to Margallah Hills and residential sectors. This fact may be associated with the slope over Margallah Hills and high weights assigned to settlements and land values in residential areas. While, multiple spots on the west, southeast part of city having highest suitability index (Figure. 8). The land suitability index map based on integration of fuzzy-WLC, is shown in Figure. 8b. The suitability index was made by integrating of fuzzy layers based on WLC and MCE menus using IDRISI software. The landfill suitability index shows that land suitability in the north and central part of the city was found very low. However, high suitability was found in west and south-east part of the city. Additionally, landfill suitability index map shows that the result obtained using fuzzy-WLC are more refined and smooth in comparison to AHP which may be associated with the better segregation power of fuzzy-WLC method.

Further, the land suitability value (ranging 0-1) using both methods were reclassified in to four classes (unsuitable, least suitable, moderate suitable and highly suitable) (Figure. 8b). An equal interval classification method was employed in order to classify land suitability values in respective classes (Figure. 8b). The four suitability classes were found as unsuitable (0–0.25), least suitable (0.25–0.5), and moderate suitable (0.5–0.75) and highly suitable (>0.75) over the Islamabad using AHP and fuzzy-WLC. Furthermore, area of each category using both methods was calculated and compared as shown in Table 5b and Figure. 9 & 10. Table 5b depicts that the similar value of restricted area (255 km2) simulated by using AHP and Fuzzy-WLC method. The unsuitable area was found higher 244.9 km2 using AHP technique in comparison to fuzzy-WLC 201.4 km2. However, least suitable area estimations were perceived far less using AHP technique (158.3 km2) in comparison to fuzzy-WLC (272.3 km2). Noticeably, the moderate suitable area using AHP (200.8 km2) higher than fuzzy-WLC (141.3 km2). These differences of

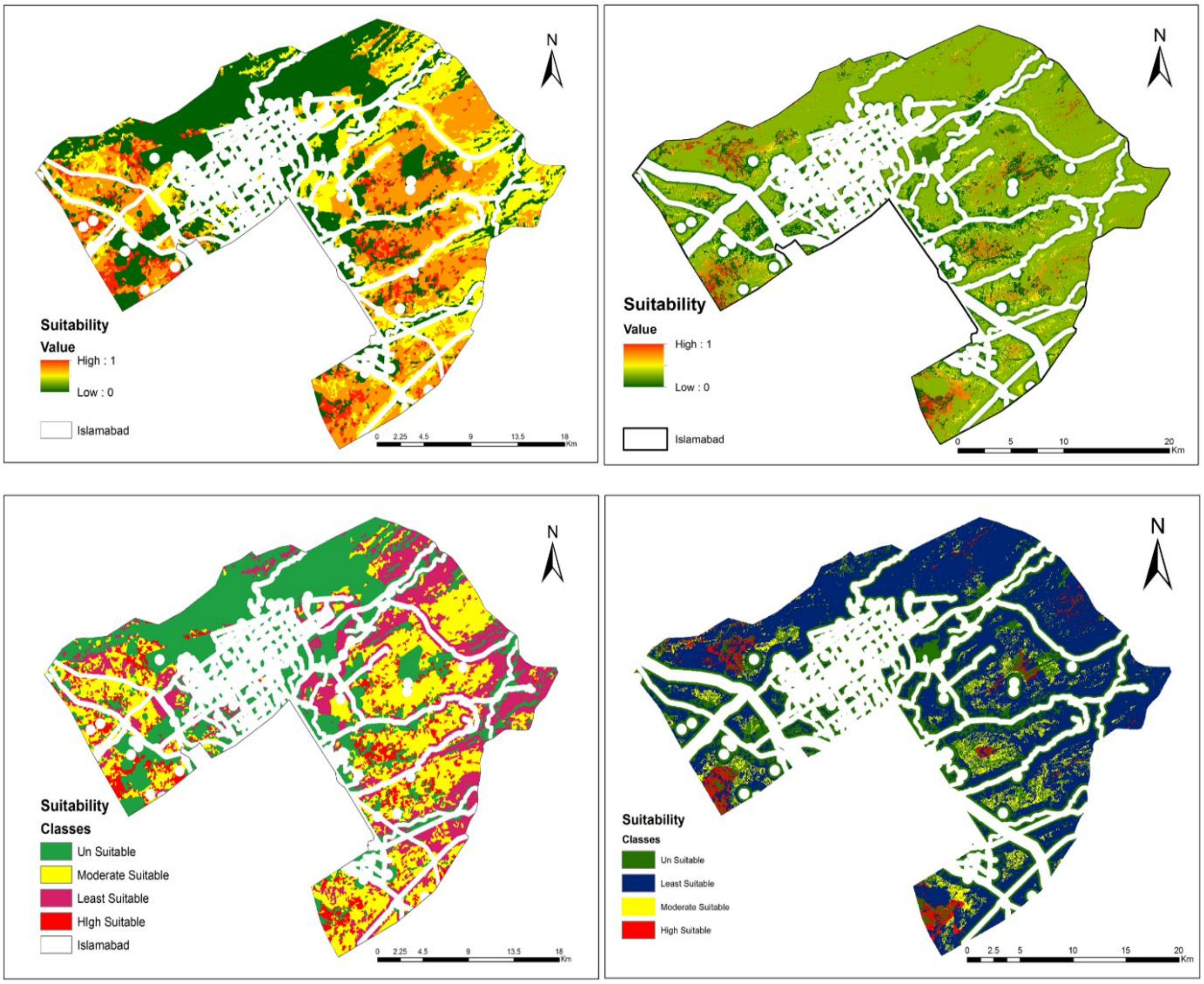

Figure 8: (a) Land suitability index map of Islamabad based on AHP method (left) and fuzzy logic (right), (b) Classified map from both AHP integration (left) fuzzy-WLC (right).

areas simulated by both methods are may be associated with the better segregation of fuzzy-WLC and its potential to consider full trade-off between factors and average risk. Overall, results showed that a very few highly suitable sites (47 km2 for AHP and 36 km2 for fuzzy-WLC) are available in Islamabad city, however, moderate suitable sites can be considered for landfill sites by taking pre-emptive measures.

4.3 Suitable Site Selection

Finally, the suitability index map were combined based on intersection in order to estimate the matching suitability index, subsequently, the selection criteria based on suitability index greater than 0.75 was applied to finalize the landfill sites as shown in Figure. 5. Further, Figure. 5 shows the spatial locations of most suitable sites in Islamabad city by adopting AHP and fuzzy-WLC approach. It noticed that the most of the suitable sites are located out of Islamabad city particularly in west and southeast side of the Islamabad. This area is stand out because of the availability of barren land, clay soil and low population density. Interestingly, most of the north side of the Islamabad is unsuitable for landfill site selection because of forest Cover Mountain and high elevation. Noticeably, not a single landfill site was identified in the sectors developed by Capital Development Authority (CDA). This may be associated with the high cost of land value and high population density in CDA sectors. Additionally, it noticed that most of the large area sites are located in the low slope regions of the Islamabad. Interestingly, AHP approach provided numerous small suitable sites with range between 4 to 6 hectares. Conversely, fuzzy-WLC approach provided very few number of landfill sites with large area between 4.11 to 13.08 hectares. Overall, it observed that the fuzzy-WLC provides robust results in comparison to AHP technique for the landfill sites location and area selection. The result from both method provides numerous suitable landfill sites having different areas at different locations in the city Islamabad.

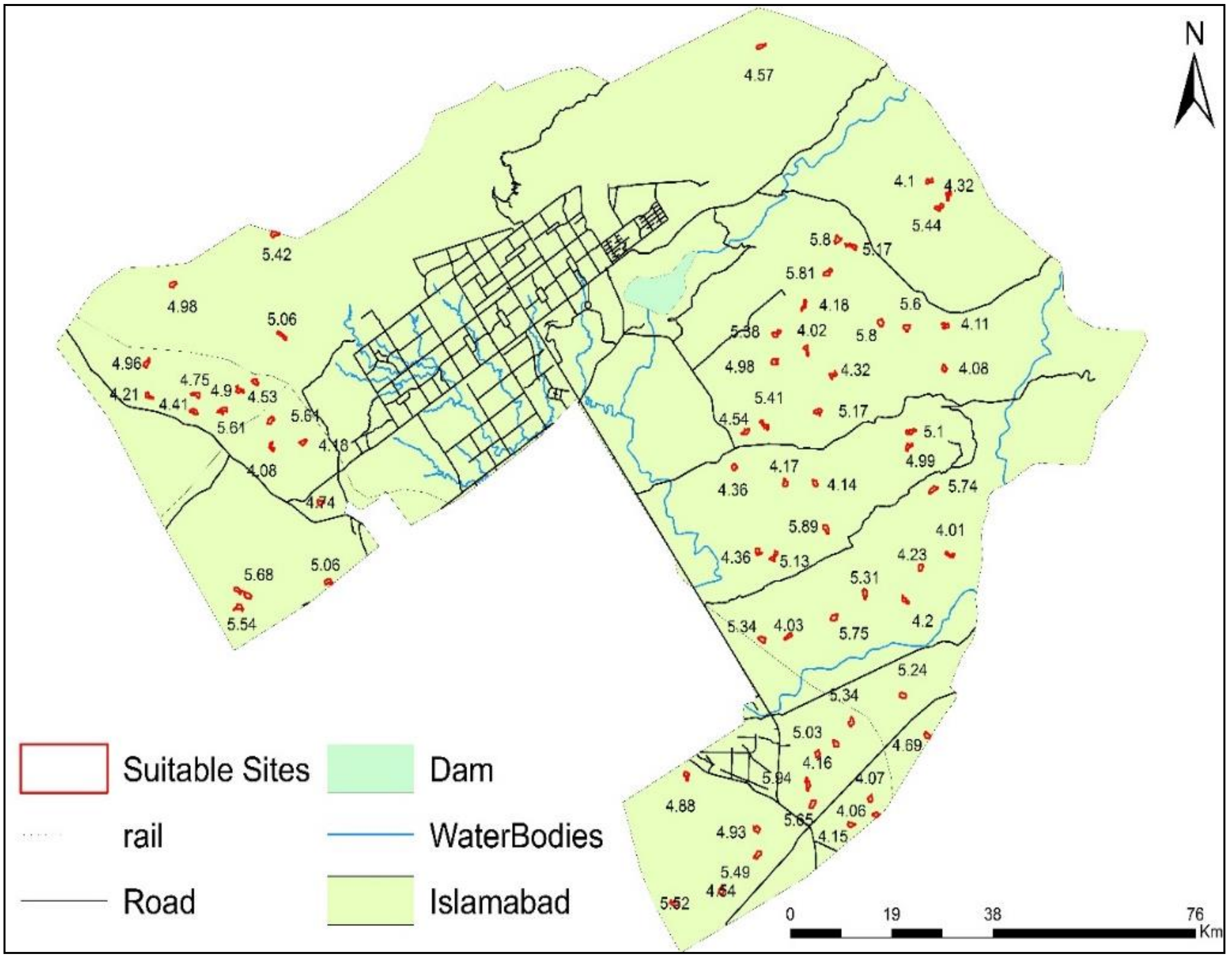

Figure 9. Final suitable sites after applying model criteria and selection criteria (a) AHP approach showing area of each designated site in hectare.

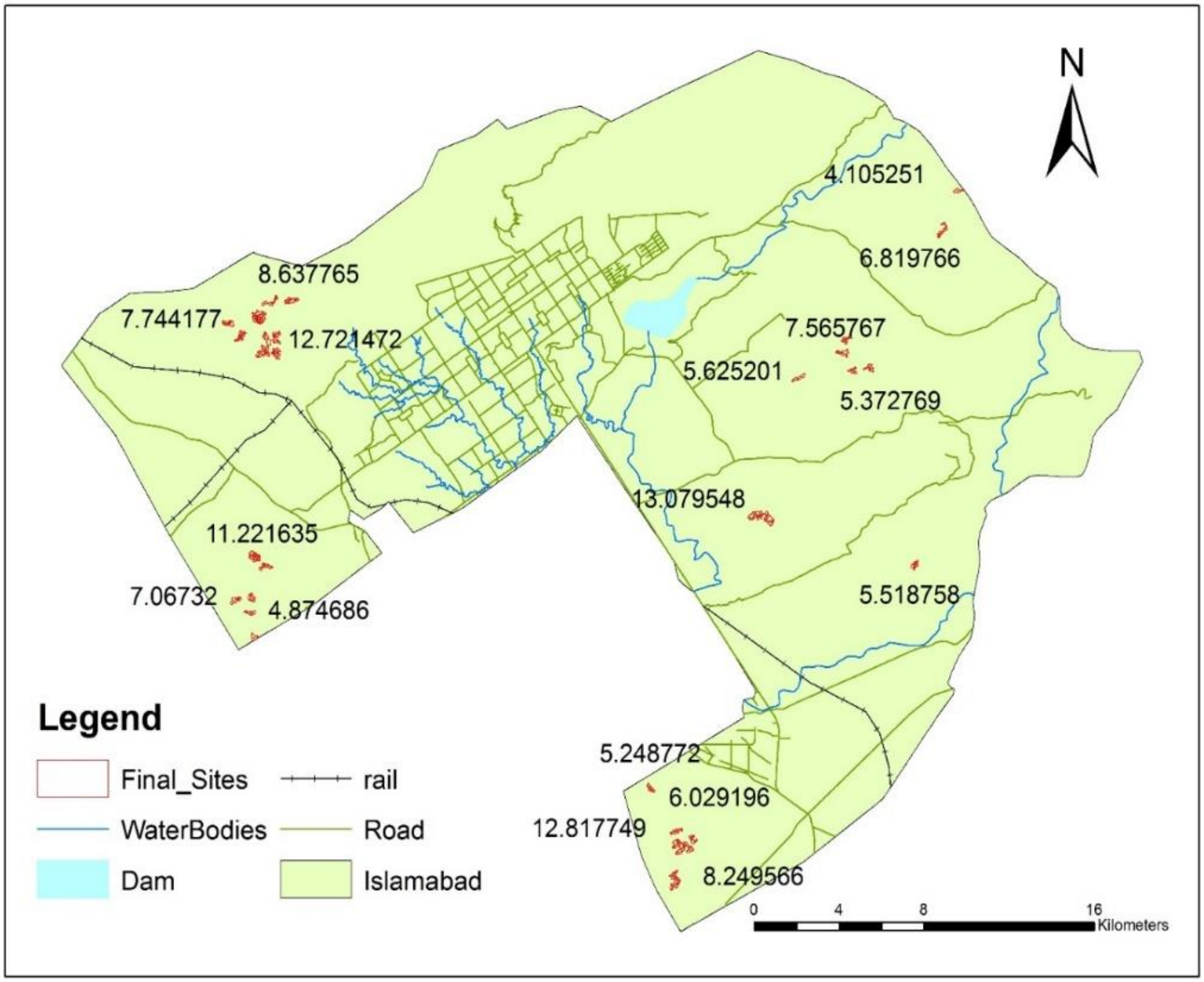

Figure 10. Final suitable sites after applying model criteria and selection criteria (b) fuzzy logic WLC approach, showing area of each designated site in hectare.

However, land suitability obtained based on fuzzy-WLC shows overwhelming advantage on AHP approach and provides more refined and smooth because of its better segregation and potential to consider full tradeoff between factors and average risk.

The results obtained in this are in consistent with the previous studies carried out in metropolitan cities of developing countries (Chabuk et al. 2017; Demesouka et al. 2019; Donevska et al. 2012; Hoque and Rahman 2020). Chabuk et al. (2017) applied GIS based AHP and simple additive weighting (SAW) approach for the landfill site selection in Al-Musayiab Qadhaa located in north side of Babylon Governorate and reported range of 5.95 to 7.96 km^2 area for the disposal site. While, Donevska et al. (2012) used AHP and fuzzy logic for the selection of disposal sites in Polog Region, Macedonia and reported that the similar results like in current study.

Chapter 5

Conclusions and Recommendations

Since, the landfill is a primary step of waste management strategy, therefore landfill sites selection demands an in-depth consideration of various factors and constraints. Islamabad, the capital city of Pakistan lack proper landfill sites designed based on environmental and scientific criteria. Therefore, this study is an attempt to demonstrate the effectiveness of integrated approach of AHP, fuzzy logic-WLC method based on multi criteria decision making (MCDM) to investigate the suitable solid waste landfill sites in a metropolitan city like Islamabad. To achieve the objective we used total of 13 criteria (9 factors and 4 constraints) and grouped them in two main categories (environmental and socio-economic) to achieve the objectives. These factors, according to their significance were distance from road (meter), railway line, distance from water bodies, land use map, land cover map, settlements, soil type, slope, population density (person/pixel). In this study AHP was employed to evaluate the relative importance of the aforementioned factors followed by standardization of criteria factors based on fuzzy set theory. Finally, all criteria were combined based AHP and Fuzzy logic-WLC method in order to obtain land suitability map.

The result from both method provides numerous suitable landfill site at different locations in Islamabad city. However, land suitability obtained based on fuzzy-WLC shows overwhelming advantage on AHP approach and provides more refined and smooth because of its better segregation and potential to consider full tradeoff between factors and average risk. Additionally, landfill suitability map from both methods show that land suitability in the north and central part of the city is very low. The result from AHP identified (47 km^2) as high suitable, while, fuzzy-

WLC generated 36 km^2 as suitable area in Islamabad city. The overlanding of environmental and socio-economic factors based suitability maps provided accurate results for the determination of possible landfill sites. By considering expert opinion and field visits, it seems the obtained suitable sites were very well defined and suitable in real conditions. However, the aggregate area of highly suitable site is very minimal in comparison to moderate and unsuitable sites. While, the area of each suitable site was also very small even not more than 14 hectares. However, the city administration can consider number of different suitable site for nearby regions. This adopted methodology and results obtained in this study can be useful for the better solid waste management in a metropolitan city like Islamabad. Furthermore, the novel technique adopted in this paper can be applied to optimum landfill site selection of solid waste. Finally, the method adopted in this study is scientific which help the decision maker to accomplish decision analysis function. The proposed methodology will be helpful for environmental scientist, disaster management's officials, resource managers, urban planner and city designer.

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