# Landfill site selection in Islamabad using Fuzzy-AHP and its Environmental Impact Assessment

By

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**(NUST201463300MSCEE62514F)**

**A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Remote Sensing and GIS**

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**(December 2016)**

# DEDICATION

I dedicate this work to my husband, parents and my beloved family.

# ACKNOWLEDGEMENTS

Thanks to Almighty Allah for giving me strength to understand, learn and complete this thesis research work.

It is a great pleasure to acknowledge my deepest thanks and gratitude to **Mr. Muhammad Ahsan Mehboob,** *Lecturer of Geographical Information System and Remote Sensing, Faculty of IGIS NUST*, for suggesting the topic, for his encouragement and comprehensive advice until this work came to existence.

I would like to express my extreme gratitude to **Dr. A D Khan**, *groundwater expert*, for providing me with all the necessary data required for the work.

Lastly, I would like to thank my family for their constant motivation, support and help.

Sehrish Baig

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| | |
|---|---|
| AHP | Analytical Hierarchical Process |
| CDA | Capital Development Authority |
| EIA | Environment Impact Assessment |
| EVIAVE | Evaluación del Impacto Ambiental de Vertederos |
| GIS | Geographical Information System |
| IRRC | Integrated Resource Recovery Center |
| MCDA | Multi Criteria Decision Analysis |
| WLC | Weighted Linear Combination |
| UNEP | United Nations Environment Program |

# ABSTRACT

Landfill site selection is a multifaceted practice which needs to include various diverse criteria. The objectives of this study was to select a landfill site using multi criteria decision support system in GIS and evaluate environmental impact assessment (EIA) of the selected site. Islamabad, capital city of Pakistan was selected as a study site. Eleven criteria were selected which include roads, railway, airport, ground water table depth, geology, soil texture, precipitation, slope, surface water, waterways and faults. The Analytical Hierarchical Process (AHP) and Buckley's fuzzy-AHP methods were used in a GIS. Criteria weights were calculated using AHP in Weighted overlay tool, which resulted in identification of eight possible landfill sites. These eight sites were assessed in Fuzzy-AHP against other non-quantifiable parameters (transportation issues, public nuisance, economic factors, land use, environmental impact and available vehicles) involving expert opinion. On the final site, EIA was carried out as per the guidelines of United Nations Environmental Program (UNEP). The result of this research illustrates the importance of the weights in identification of criteria for selecting the optimum location of landfill site i.e. near G-16, Islamabad. The area of selected landfill site is about 234 hectares and is 12.3 km away from existing dumping site in I-12. This process is useful in identifying dumping sites for cities where best landfill areas are occupied by urban sprawl.

*Chapter 1*

# INTRODUCTION

Due to growing urgency of environmental and health problems, much attention has been placed on devising mechanisms to select suitable landfill sites for safeguarding environment from infectious and chronic diseases (Nas et al, 2010). Landfill remains to be one of the most widely used methods for waste disposal (Wang et al, 2009). The process primarily focuses on disposal of waste by burial. It's a well engineered depression made into or on top of the land. The trash is buried in a way to isolate it from surrounding environment. In majority of places, MSW landfill uses a plastic liner to avoid leachate infiltration to surrounding areas. Alternative to landfills are processes involving burning of waste to reduce volume which ultimately must also be landfilled (Emberton and Parker, 1987)

Developed countries use secured and controlled processes in land filling. On contrary under developed or developing countries lack proper landfill guidelines (Aljabre et al, 2002) which leads to unplanned random dumping of waste on or into the ground causing negative impacts on human health. Poor planning of landfills have led to several environmental pollution including flora and fauna, soil deterioration, water and air pollution, solutions to these problems need to be found (Batjes et al. 2014).

Previously, planning and design of a landfill site involved selection of a suitable vacant area through site survey, treatment of waste and transfer of waste remains from the generation areas to the waste dumping sites, and selection of proper routes (Yesilnacar and Cetin, 2005). Over the years increase in risk of contaminating underground resources, mainly potable water and air pollution has led to equal need to develop standards and devising more scientific and engineered solutions (Hoornweg et al. 2013).

Researchers have been using combination of techniques to improve site selection process. Spatial multi-criteria decision analysis involving merging of Geographical Information System (GIS) with different multi-criteria decision analysis (MCDA) techniques to find environmentally suitable landfill site remains the most widely used method since it produces promising results (Kontos et al. 2003). A study developed a system based on fuzzy interference in siting landfill and conducted an evaluation process of soild waste management (Al-Jarrah and Abu-Qdais 2006).

## 1.1. Techniques for Landfill Site selection

### 1.1.1. Computational Models

Over the past two decades different techniques have been used by researchers around the globe for locating suitable landfill sites (El Baba et al, 2015). Some used computational models to refine their results for example; a computer program based on the Chang's fuzzy method was developed in MATLAB environment for ranking and selecting the landfill sites (Nazari, 2012). EVIAVE-based method was developed to select a suitable solid waste landfill site in Granada, Spain (Zamorano, 2008). A Spatial Decision Support Tool as a computer-based technology was developed to solve the complex process of landfill site selection for municipal solid waste management in Kampala and the neighboring Wakiso districts (Nakakawa, 2007).

### 1.1.2. Multi-Criteria Decision Methods

Other studies used multi-criteria decision analysis such as the Analytical Hierarchy Process (AHP), Weighted Linear Combination (WLC), Analytical Network Process (ANP), Factor Importance Coefficient (FIC), fuzzy logic, Dempster Shafer Theory (DST) and a combination of these for landfill site location. For Al-Hashimyahqadaa, landfill site selection was done using MCDA and GIS (Alanbari, 2014). Site screening method and AHP were employed to develop a digital GIS database including detailed information of primarily selected zones. Finally, ten landfill sites were selected as suitable for treating hazardous solid waste from the thermal power plant in Iran (Abessi & Saeedi, 2010). Similarly, AHP was combined with GIS for landfill site selection in Konya, Turkey (Sener et al. 2010). Another study uses MCDA with the help of AHP for selection of new suitable landfill sites along Gaza Strip (El Baba et al, 2015). With the help of weighted linear combination (WLC) method alongside spatial cluster analysis (SCA), suitable sites for allocation of landfill for a 20-year period were identified. Maron's I was used for analysis of spatial auto-correlation for the land suitability map. The purpose of mentioned study was to evaluate the suitability of the studied site as landfill for MSW in Karaj (Moeinaddini, 2010). A study by Beskese, (2015) attributed landfill site selection as a hierarchical decision problem, where factors like land area, soil conditions, climatological conditions, and economic considerations were investigated in detail. Expert opinion embedded in fuzzy AHP and fuzzy TOPSIS were used to find three possible sites for Istanbul city. Landfill site selection by using combination of AHP, fuzzy AHP, SAW and GIS has been used quite extensively by different researchers around the globe (Torabi, et al.

2016; Bahrani et al. 2016; Ali, N., Saxena et al 2016; Torabi-Kaveh et al 2016 ;Foroughian & Eslami 2015; Rahmat et al 2016 and Eskandari,et al. 2016).

Within the context of Pakistan, Rathore, et al. (2016) used AHP along with simple additive weighted process (SAW) to generate a hierarchy of suitable sites for landfill to resolve the solid waste issue in Lahore District. A study by Ahmad, et al (2016) uses AHP and GIS based overlay technique to identify landfill sites in Sahiwal city of Pakistan, prioritizing each site on basis of distance from city center and area. Similar study by Ahmad, (2012) uses MCDA to identify a potential site for an appropriate landfill area for Faisalabad city using GIS.

#### 1.1.3. Analytical Hierarchical Process

AHP developed by Saaty uses expert's opinions to evaluate scores by dividing complicated problems into sum problems and forming a hierarchical system. It is a theory and methodology for modeling problems in the economics, social and management sciences. It breaks down an unstructured situation into its component parts. Arrange the parts or variables into a hierarchic order. Assign numerical values to personal judgments on the relative importance of each variable. Synthesize the judgments to determine which variables have the highest importance and should be acted upon to influence the outcome of the situation.

As basic AHP doesn't include vagueness for human judgments, it has been further improved by taking benefits from fuzzy logic.

#### 1.1.4. Fuzzy Analytical Hierarchical Process

In fuzzy AHP, comparison matrix of both criteria and alternatives is defined by predefined rating scale or linguistic variables represented by triangular membership functions. Van Laarhoven and Pedrycz initially perfomed fuzzy AHP later onwards Buckeley contributed towards the subject by finding out fuzzy priority of comparison ratios. Chang also introduced a new method related with the usage of triangular numbers in pair-wise comparisons.

Although there are some more techniques embedded in fuzzy AHP, within the study context, Buckley's method was implemented to determine the relative importance weights for both the criteria and the alternatives.

### 1.2. Environmental Impact Assessment

Environmental assessment (EA) is the term used for the assessment of a plan, policy, program, or project both positively and negatively in the light of environmental consequences prior to the decision to move forward with the proposed action.

An EIA auditing was performed by Omar, et al (2012) measuring significant aspects of the environment; air quality, water quality and noise level in Kuala Lampur on an already existing landfill site. Other than that, leachate toxicity monitoring was also carried using whole effluent toxicity (WET) method. Furthermore, the traffic impact assessment was undertaken to observe transport flow within the facility. Public survey was also performed on nearby neighborhood to obtain the general feedback of the community towards the facility.

### 1.3. Rationale

Islamabad the capital city of Pakistan has a population of 805,235 (Pakistan Bureau of Statistics) according to census of 1998. Capital Development Authority (CDA) is the main administrative body responsible for planning, construction, development and waste disposal within the capital. However, till date CDA has failed to come up with a proper landfill site and instead is engaged in open dumping with the absence of appropriate siting considerations.

CDA proposed dumping sites are usually located within a government-owned property located in any vacant area which maybe near a residential or developed site. Due to emerging health and environmental issues, Supreme Court of Pakistan took suo motu action in 2003 (PEPA) against CDA for disregarding environmental laws causing harm to protected nature which was ignored by CDA resulting in another complaint of Pak-EPA to Environmental Tribunal against CDA.

This research was aimed to identify suitable landfill sites based on environmental ecological parameters in Islamabad and also critical analysis of the sites for selection of most appropriate site using expert knowledge.

### 1.4. Objectives

This research has emphasis on the following two objectives:

1. Determine landfill site in the study area using combination of spatial technologies and Analytical Hierarchical Process (AHP).
2. Fuzzy AHP using expert knowledge and Environmental impact assessment of the selected landfill site.

*Chapter 2*

# MATERIAL AND METHODS

Development of landfill requires assessment of numerous different criteria over study area which is both complex and time consuming process. However, availability of GIS techniques accelerates this process by filtering out unsuitable areas. This research also used GIS for identification of suitable areas based on given criteria. Suitability of a criterion was defined with respect to its impact on surrounding environment and geographical factors. Thus in the first stage of analysis, several criteria were analyzed using AHP and GIS techniques prior to further detailed analysis and field inspection. Criteria taken reflected environmental and ecological factors, other criteria related to public nuisance and economic factors were assessed using expert knowledge using fuzzy AHP and further EIA was performed on final site.

## 2.1. Study area

Islamabad is the capital city of Pakistan as shown in figure 1. It is located at latitudes and longitudes of 33° 41′ 0″ N and 73° 5′ 0″ E. According to the census of 1998, Islamabad's population is 805,235 (Pakistan Bureau of Statistics) and total land area coverage is 1,165.5 sq km. Islamabad Capital Territory (ICT) falls under the jurisdiction of Capital Development Authority (CDA), which is the sole governing authority for ICT region. CDA has divided the region into five different zones. Based on CDA report 2005, Zones I and II can be considered as the urban and metropolitan regions of ICT. Margalla hills national park in Islamabad constitutes Zone III and the subsidiary forested area near Pakistan monument is

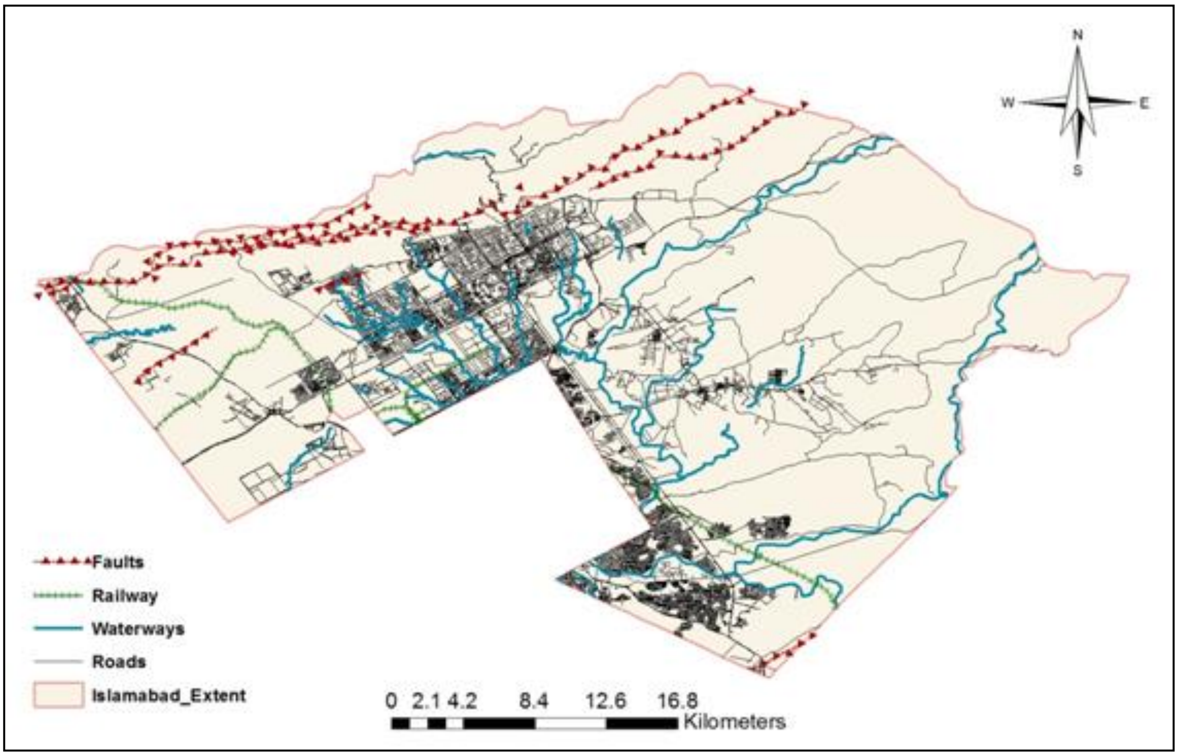


Figure 1. Location map of Islamabad, Pakistan, showing fault lines, railway network, waterways and road network within the study area.

also included in this zone. Zone III has been planned to protect the forested area of ICT. The remaining two zones IV and V constitute the suburbs of Islamabad's main metropolitan area. The population in these two zones is less as compared to Zones I and II, and much of land is barren and not vegetated. However, construction prohibition in zone 3 and 4 was lifted after constitutional amendment in 2010 which resulted in development of various housing schemes among which CDA was first to launch Rs 4 billion scheme. Such actions of CDA are causing serious environmental implications. Removal of green belts and forested areas caused an increase in capital's temperature and rapid growth of urban area is generating more waste which needs to be taken care of effectively. Repeated court pressures and public protest have forced CDA to plan a permanent landfill site.

From1980s till 2006, the CDA dumped its municipal waste in Sector H-12, before shifting to Sector H-11. Islamabad High Court took notice of the new site in 2010, it was moved to sector I-12, then to sector D-12 in 2013. After court's intervention, it was again shifted back to Sector I-12. Since the establishment in 1960, CDA has failed to find a location for a permanent dumping site.

To create a landfill within the study area would mean significant environmental impacts on air, ground water, atmosphere and landscape besides other affects on wildlife and ecology. Considering all these issues, a thorough analysis was required in selecting a suitable place for creating a landfill.

Despite being a developing country, Pakistan still lags in deploying proper waste management techniques. There are numerous techniques observed for treatment of solid waste, open dumping still stands to be the cheapest mean for the disposal of garbage in Pakistan, selection of criteria for landfill was quite detailed process depending upon several rules, parameters and factors

### 2.2. Dataset used

Geological map of Islamabad was acquired from Geological Survey of Pakistan. DEM having resolution of 30m was downloaded freely from SRTM website. A shapefile was used to extract DEM of study area Islamabad. Pakistan Meteorological Department Islamabad office provided precipitation of four meterological stations located at zero point, Islamabad international airport, Shamsa baad and Saidpur village. Ground water table depths were acquired from PCRWR (Pakistan Council for Research in Water Resources). Data was stored in manual files, it was converted to excel sheet format using MS Office Excel. Wind speed and direction was acquired from Pakistan Meteorological Department Islamabad Office and from NUST U.S Pakistan Center for Advanced Studies in Energy (USPCAS-E). Data was provided in excel sheet format, from which map was prepared in ArcMap. Softwares used were ERDAS IMAGINE 9.2. ArcGIS 10.2 and Microsoft Word/Excel/PowerPoint.

### 2.3. Landfill site selection methodology

The flowchart of the methodology using AHP and Fuzzy-AHP is shown in figure 2. It comprises of two stages, in the first stage eleven criteria were identified (road network, faults, precipitation, geology, soil texture, slope, ground water table depths, surface water bodies, water ways, railways and airport) and buffered

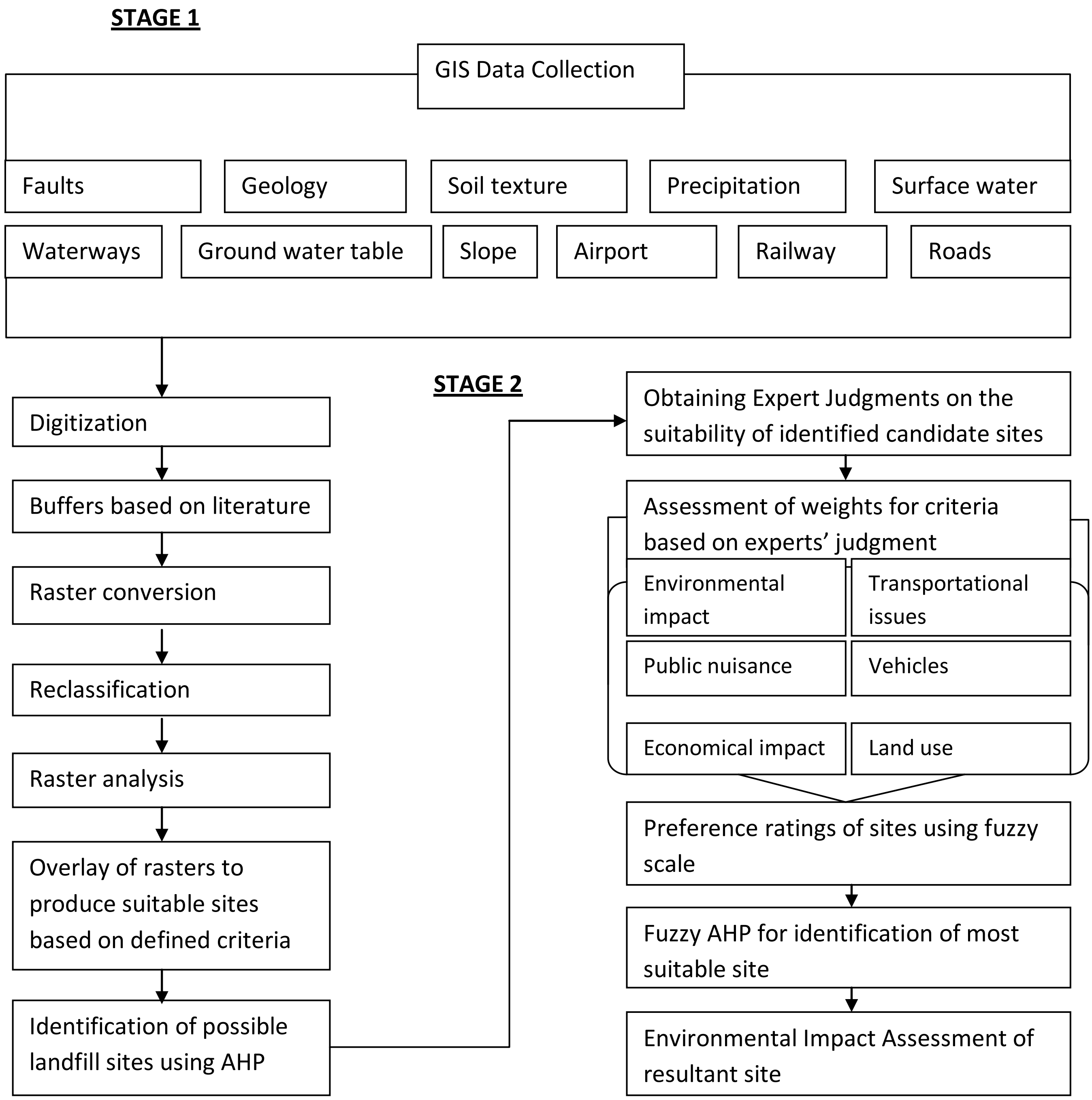


Figure 2. Landfill site selection research methodology.

using literature information to identify suitable and unsuitable areas for landfill. The unsuitable areas for landfill were those areas which had bad environmental impact and may have higher building cost Lunkapis et al, (2004). The unsuitable areas were screened out using GIS raster calculator. The collected data was added in ArcGIS 10.2.2 and appropriate buffers were applied using literature knowledge and reclassified in ArcMap.

### 2.3.1. Preparation of Raster Maps

Vector data of road network, surface water bodies, water ways, faults, railways and airport was downloaded from Mapzen. Precipitation data acquired from PMD and TRMM point data was put into excel sheet and interpolated in ArcMap to generate monthly average rainfall map from 2010-2015. Wind map was prepared in a similar fashion.

Soil texture was found using Soil Info app developed by ISRIC. For preparing soil texture map, fish net was generated in ArcMap. Each point within fish net was assigned silt, clay and sand percentages using soil info app. Using texture triangle, soil texture map was prepared.

All maps were assigned buffer ranges based on literature knowledge and converted to raster format.

### 2.3.2. Analytical Hierarchical Calculation

AHP is a structured technique for arranging and analyzing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. In this method, a matrix has been produced to compare different landfill factors. Saaty developed this method in 1980. For each criterion weights were determined using pairwise comparsion. In AHP, Saaty's prescribed Scale ranging from 1 – 9 (table 1) was used in the preparation of pairwise comparison matrix for criteria involved in site selection, preferences among the criteria were determined using literature review and expert knowledge.

For the estimation of consistency ratio, weighted sum was calculated by multiplication of the criterion weights with the values of the original pairwise comparison matrix and then taking their summation. Consistency vector was calculated by division of weighted sum and criterion weights.

$$CR = CI/RI \quad \text{...............................................................} (1)$$

Where

$CI = \lambda Max - n / n - 1$

$\lambda Max$= Average of consistency vector

$n$= Number of factors used in the study

RI is the random index provided by Saaty and it depends on the number of criterion (n). In this study, eleven factors used to prepare the landfill map therefore RI against eleven was used in the formula for estimation of CR.

### 2.3.3. Weighted Linear Combination

Weighted linear combination is based on weighted average in which a common numeric range has been set among the factors to standardize them. After the standardization, factors layers were combined for composite map layer. Weights were assigned to each factor class according to relative dominant value. Any GIS system can be used having overlay capabilities to perform this analysis. Weighted Overlay tool was run in ArcMap which resulted in 8 possible landfill sites. Flowchart of stage 1 is shown in figure 3.

Table 1. Saaty's comparison table.

| Intensity of importance | Definition | Explanation |
|---|---|---|
| **1** | Equal importance | Two factors contribute equally to the objective. |
| **3** | Somewhat more important | Experience and judgment slightly favor one over the other. |
| **5** | Much more important | Experience and judgment strongly favor one over the other. |
| **7** | Very much more important | Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice. |
| **9** | Absolutely more important | The evidence favoring one over the other is of the highest possible validity. |
| **2, 4, 6, 8** | Intermediate values | When compromise is needed |

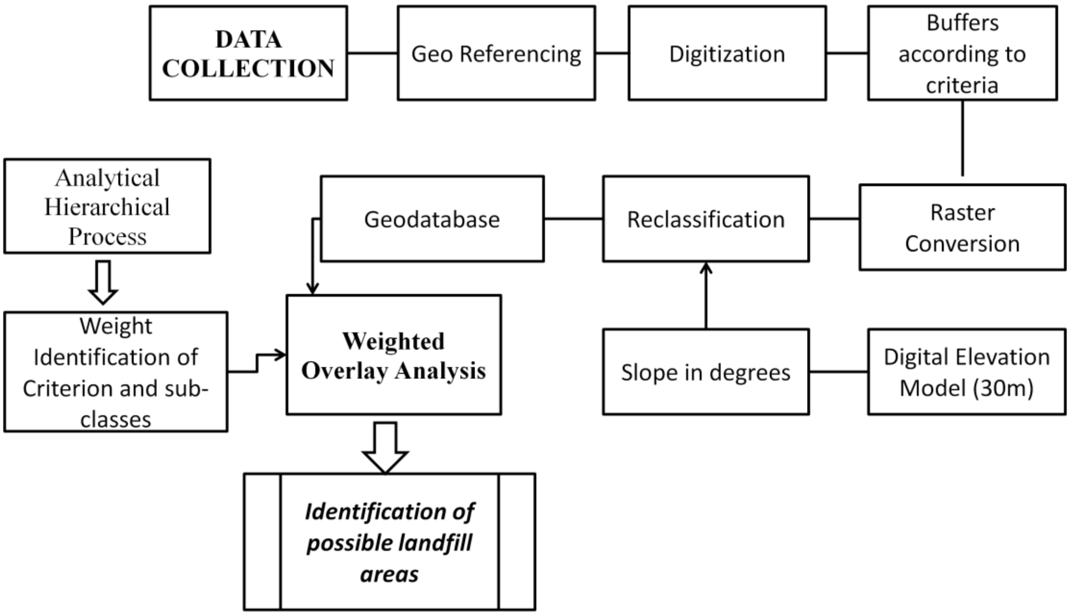


Figure 3. Preparation of raster maps and weighted overlay analysis for identification of suitable landfill sites.

### 2.3.4. Fuzzy Analytical Hierarchical Process

For 2nd stage analysis, Fuzzy AHP was used which embeds fuzzy theory to basic AHP. Since AHP only includes crisp data, the evaluation of different unquantifiable alternatives against different criteria required expert judgment. Fuzzy AHP method was therefore chosen for ranking different landfill sites for Islamabad city based on decisions given by experts. Two experts were selected based on their expertise in waste management. Experts participated in a questionnaire survey, using linguistic variables to give the preference ratings for each individual candidate site.

Van Laarhoven and Pedrycz (1983) were the first to develop fuzzy AHP applications. They defined triangular membership functions to extend AHP to fuzzy AHP (Shapiro, A. F. 2013).

Later, Buckley contributed to the subject by determining the trapezoidal fuzzy numbers and used geometric mean to find fuzzy weights. Chang used triangular numbers in pair-wise comparisons and arithmetic mean to derive priority vector. Buckley's Fuzzy AHP steps are defined below

**Step 1:** In pair wise comparison, decision maker's preference of 1st criterion over 2nd criterion is indicated using fuzzy numbers. For example, $d_{12}^{k}$ shows expert's preference of criterion 1 over criterion 2. In our study there were 2 experts involved so we took average of their preferences.

$$A: \begin{bmatrix} d_{11}^{k} & d_{12}^{k} & d_{1n}^{k} \\ d_{21}^{k} & \dots & d_{2n}^{k} \\ d_{n1}^{k} & \dots & d_{nn}^{k} \end{bmatrix} \quad \text{.......} \quad (2)$$

**Step 2:** Geometric mean of comparison values was performed to find fuzzy weights for each fuzzy matrix using the equation:

$$r_i = \left(\prod_{j=1}^{n} d_{ij}\right)^{1/n} \quad \text{......(3)}$$

**Step 3:** Fuzzy weights were calculated by summing each $r_i$ , taking inverse of summation and arranging them in increasing order. Multiply each $r_i$ with reverse vector to get fuzzy weights.

$$\boldsymbol{w_i} = r_i * (r_i + r_i + r_i + r_i)^{-1} \quad \text{......(4)}$$

**Step 4:** Centre of area method proposed by Chou and Chang was used to de-fuzzy triangular weights by taking average of the weights and then normalized using the equation.

$$N_i = \frac{M_i}{\Sigma M_i} \quad \text{......(5)}$$

This research incorporates expert judgments and opinions which were taken from the main authoritative body CDA responsible for waste management within the study area. It also highlights all the relevant criteria, factors, issues and constraints in determining a potential landfill area, such information can be critically used for effective waste management. Environment Impact Assessment of the final identified site was conducted using UNEP checklist.

### 2.3.5. Environment Impact Assessment Methodology

Environmental Assessment of the site was specifically focused on determining key issues which may influence the surrounding nature and to identify potential impact on settlers. EPA-PAK has defined general guidelines for environment reports in 1997; however, research uses check list published by

UNEP in 2005 as it highlights detailed description of environmental setting which assisted in thorough analysis of proposed site.

#### 2.3.5.1. Data Collection

Data on the site location, capacity, climatology and other information related to the area were collected by physical survey to the site, and pictorial recording of certain site features and operations.

#### 2.3.5.2. Scope of EIA

Questionnaires were filled by experts from CDA and IRRC (a pilot project undertaken by UN-Habitat purpose of which is to construct sewerage treatment plant in each sector and to collect, segregate, and process and resale resource generated). Expert's judgment was incorporated to derive final landfill site keeping in view significance of impacts which were likely to be caused by landfill at the proposed area.

*Chapter 3*

# RESULTS AND DISCUSSION

## 3.1 Landfill site selection

The AHP technique has been used to evaluate each criterion, the process starts by creating hierarchy of the goal. Two main factors; environmental and economical, greatly influence landfill siting which is why each factor was decomposed into respective parameters such as geology, roads, rainfall, surface water, ground water, waterways, soil texture, faults, railway, airport and slope

In AHP, comparison of factors can be made using, a scale from 1 to 9 if the factors have a direct relationship and a scale from 1/2 to 1/9 if the factors have an inverse relationship. Each parameter was assigned weights on a scale of 1-9 based on available literature as shown in table 2. The weights assigned to factors and parameters reflect importance to landfill site suitability. Weights assigned to 11 factors were based on their comparison with each other and with respect to their importance with site selection for landfill.

Factor weights are given in table 3 after standardizing all factors. The sum of all factors was 1. Corresponding maps with all factors were reclassified as shown in figure 4, by spatial information technologies. Then, the final suitability map was produced by aggregation procedure based on weight as shown in figure 5.

Weighted Overlay is a technique which standardizes the values of dissimilar inputs to create an integrated analysis. It only accepts raster as input; within each raster layer values were prioritized. After assigning scale factor and weights to

Table 2: Criterion weights used in weighted overlay analysis.

| Factor | Class Range | Class Rating Value | Factor Rating |
|---|---|---|---|
| **Slope** | 0-5° (Very gentle slopes) | 9 | 9 |
| | 5°-10° (Gentle slopes) | 4 | |
| | 10°-20° (Moderately steep slopes) | 1 | |
| **Ground water** | 148-61m | 9 | 8 |
| | 61-45m | 7 | |
| | 45-35m | 9 | |
| | 35-24m | 6 | |
| | 24-3m | 1 | |
| **Precipitation** | 948-1022mm | 8 | 8 |
| | 1022-1095mm | 5 | |
| | 1095-1165mm | 3 | |
| | 1165-1243mm | 2 | |
| | 1243-1317.6mm | 1 | |
| **Soil Texture** | Sandy Loam | 1 | 9 |
| | Loam | 4 | |
| | Sandy Clay Loam | 6 | |
| | Clay Loam | 9 | |
| **Soil** | Potohar clay, | 9 | 8 |
| | Murree formation, | 7 | |
| | Chorghali, | 4 | |
| | Chinji, | 3 | |
| | Margalla limestone, | 2 | |
| | Alluvium | 1 | |
| **Distance from Roads** | 0-125m | 7 | 8 |
| | 125-250m | 7 | |
| | 250-370m | 4 | |
| | 370-500m | 2 | |
| | >500m | 1 | |
| **Distance from Faults** | 0-500m | 1 | 9 |
| | 500-1000m | 3 | |
| | 1000-1500m | 6 | |

| Factor | Class Range | Class Rating Value | Factor Rating |
|---|---|---|---|
| | 1500-2000m | 7 | |
| | >2000m | 9 | |
| **Distance from Airport** | 0-2500m | 1 | 7 |
| | 2500-5000m | 2 | |
| | 5000-7500m | 4 | |
| | 7500-10000m | 7 | |
| | >10000m | 9 | |
| **Distance from waterways** | 0-250m | 2 | 4 |
| | 250-500m | 3 | |
| | 500-750m | 3 | |
| | 750-1000m | 6 | |
| | >1000m | 9 | |
| **Distance from Surface water** | 0-250m | 1 | 4 |
| | 250-500m | 4 | |
| | 500-750m | 6 | |
| | 750-1000m | 9 | |
| | >1000m | 8 | |
| **Distance from Railways** | 0-500m | 1 | 1 |
| | 500-1000m | 3 | |
| | 1000-1500m | 6 | |
| | 1500-2000m | 7 | |
| | >2000m | 8 | |

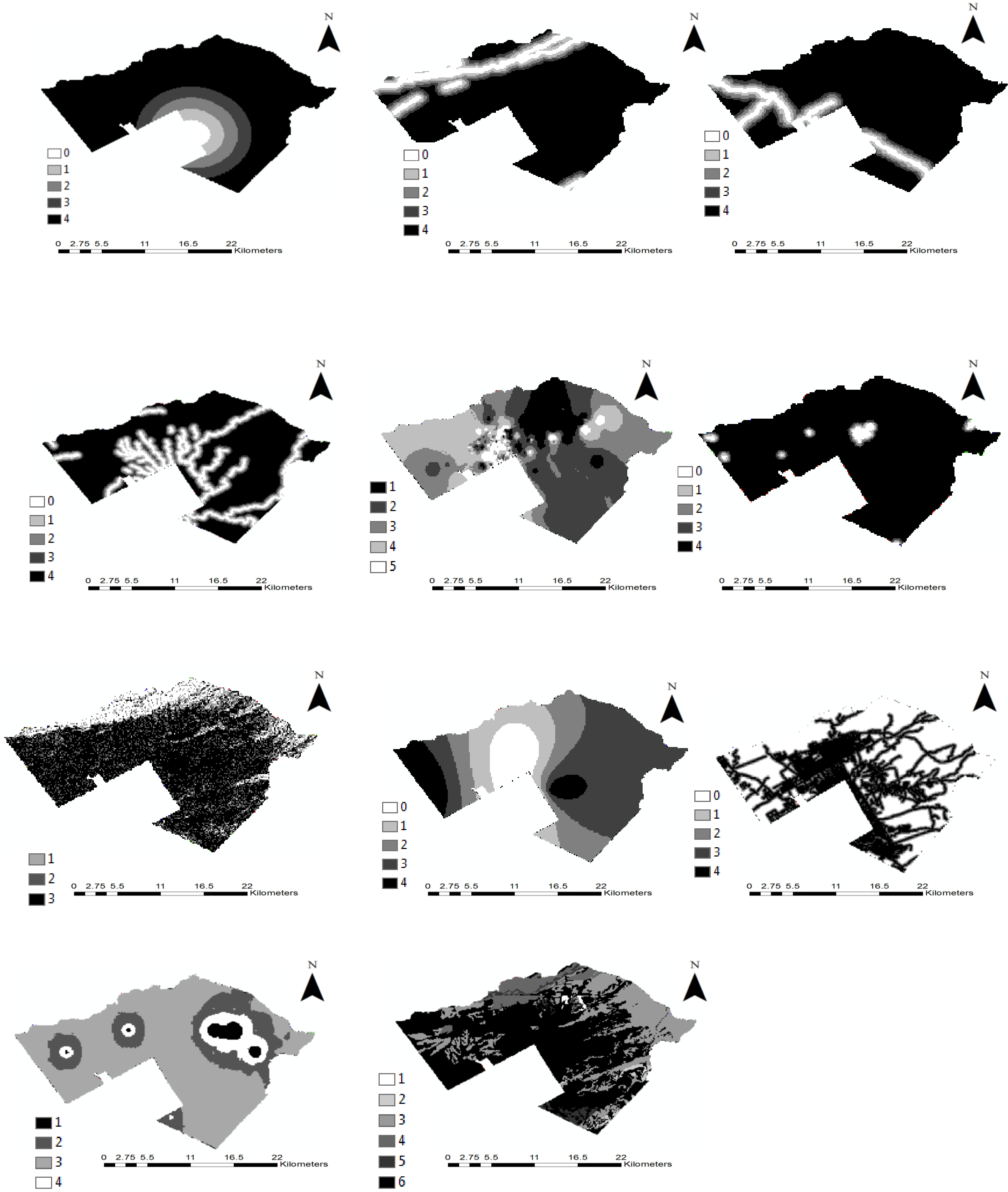


Figure 4 a. Airport area suitability b. fault line suitability c. Railway suitability d. waterways suitability e. groundwater table depth suitability f. surface water suitability g. slope suitability h. precipitation rate i. road access suitability j. soil texture and geology.

Table 3 AHP, buffer ranges and weights of respective criterion.

| Criteria | Weight | Sub criteria | Weight | CR |
|---|---|---|---|---|
| | | 0-125 | 0.50 | |
| Roads | 0.048656 | 125-250 | 0.29 | 0.04 |
| | | 250-370 | 0.11 | |
| | | 370-500 | 0.06 | |
| | | >500 | 0.04 | |
| | | 0-5 | 0.72 | |
| Slope | 0.128596 | 5-10 | 0.19 | 0.1 |
| | | 10-20 | 0.07 | |
| | | 0-250 | 0.03 | |
| Surface water | 0.022067 | 250-500 | 0.07 | 0.1 |
| | | 500-750 | 0.13 | |
| | | 750-1000 | 1.29 | |
| | | >1000 | 0.49 | |
| | | 948-1022mm | | |
| Precipitation | 0.187873 | 1022-1095 | 0.53 | 0.03 |
| | | 1095-1165 | 0.23 | |
| | | 1165-1243 | 0.10 | |
| | | 1243-1318 | 0.08 | |
| | | | 0.04 | |
| Groundwater | 0.203177 | 148-61 | 0.46 | 0.09 |
| | | 61-45 | 0.25 | |
| | | 45-35 | 0.17 | |
| | | 35-24 | 0.07 | |
| | | 24-3 | 0.03 | |
| | | 0-250 | 0.04 | |
| waterways | 0.024379 | 250-500 | 0.07 | 0.1 |
| | | 500-750 | 0.10 | |
| | | 750-1000 | 0.25 | |
| | | >1000 | 0.54 | |
| | | 0-500 | 0.03 | |
| Faults | 0.085138 | 500-1000 | 0.06 | 0.1 |
| | | 1000-1500 | 0.13 | |
| | | 1500-2000 | 0.27 | |
| | | >2000 | 0.49 | |
| | | Sandy Loam | 0.04 | |
| Soil Texture | 0.140683 | Loam | 0.10 | 0.1 |
| | | Sandy clay loam | 0.21 | |
| | | Clay Loam | 0.63 | |
| | | 0-2500 | 0.03 | |
| Airport | 0.187873 | 2500-5000 | 0.06 | 0.07 |
| | | 5000-7500 | 0.12 | |
| | | 7500-10000 | 0.27 | |
| | | >10000 | 0.50 | |
| | | Potohar clay, | 0.48 | |
| Geology | 0.108631 | Murree | 0.23 | 0.03 |
| | | formation, | 0.11 | |
| | | Chorghali, | 0.07 | |
| | | Chinji, | 0.04 | |
| | | Margalla | 0.03 | |
| | | limestone, | | |
| | | alluvium | | |
| | | 0-500 | 0.03 | |
| Railways | 0.011417 | 500-1000 | 0.07 | 0.05 |
| | | 1000-1500 | 0.16 | |
| | | 1500-2000 | 0.36 | |
| | | >2000 | 0.36 | |

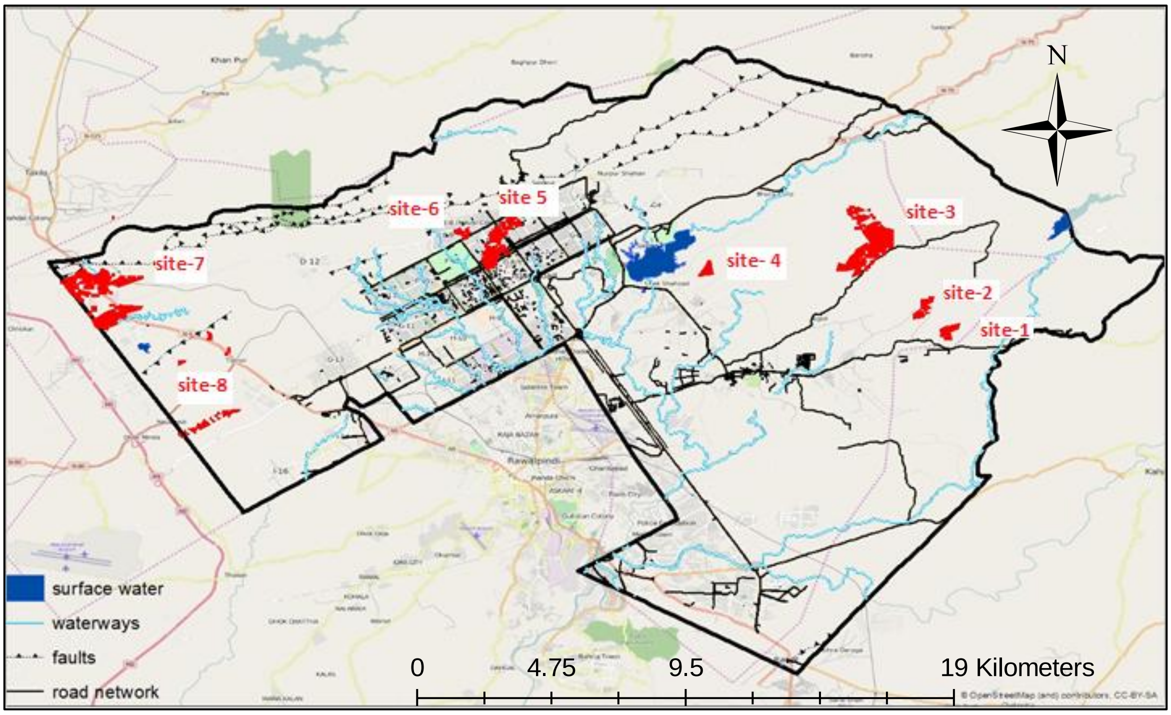

Figure 5. Weighted overlay resulted in eight possible landfill sites.

each layer, weighted overlay tool was run and resulted in different suitable sites out of which sites having higher values were extracted. Eight sites eventually resulted from overlay analysis and were further put forward for fuzzy expert based analysis.

Field manager of currently operational IRRC in Islamabad was one of the experts participated in survey. The second expert participated was from Capital Development Authority Sanitation Department; it is responsible for adequate sanitation and waste disposal services and is the main authoritative body in the city.

Experts were permitted to use their own ranking scale or select values from prescribed rating scale: (5=Very Good, 4=Good, 3=Fair, 2=Poor and 1=Very Poor) to evaluate alternatives against each criterion. From literature knowledge six criteria were selected which are: Transportation Issues (TI), Economic Impact (EC), Environmental Impact (EI), Public Nuisance (PN), Land Cover (LC), Vehicles (VC). Each criterion has its own significance in assessing alternatives with respect to development of landfill.

After running Buckley's Fuzzy AHP calculations, site 8 was identified as the most suitable site for construction of landfill. The site was further put to environmental analysis with respect to checklist provided by UNEP and was identified as both secure and environmentally suitable, subject to detailed prior planning about its construction and planning.

Eleven parameters were selected for the study, each was weighted by AHP based on literature knowledge and mapped using GIS technology for completion of stage1as discussed below in detail.

Islamabad has a well developed transportation network. Access to landfill is an important parameter in selection of good landfill area. Areas which are located close to road network are considered suitable for landfills (El Baba et al. 2015). World Bank suggests a distance of 0.2km to 10km from main roads whereas Taylor (2006) considers distance less than 3km as appropriate. Based on the literature suggestions, buffer values for roads are shown in figure 6.

Leachate from garbage can pollute nearby water bodies due to which Landfills should not be constructed near lake, ponds, streams, rivers. Therefore, buffer of 250m was drawn around all surface water bodies. Highest grade was assigned to buffer value >1000m and lowest grade was assigned to 250m buffer as shown in figure 7.

Toxic chemicals in the form of lechate can filter from the dump into the groundwater near surface; due to such reasons ground water depth has always remain an influential factor in determining a suitable landfill site (Almasri, 2008 & El Baba et al, 2015). Ground water data was acquired from PCRWR (Pakistan council for research in water resources) and was interpolated using IDW tool in ArcMap. Water depth ranged from 3 meters to 145 meters as shown in figure 8. Near surface water tables are considered worse as lechate is more likely to penetrate into water causing contamination whereas indepth water tables are best for landfills (kumar and Hassan, 2013 , El baba 2015), ground water depths were classified accordingly.

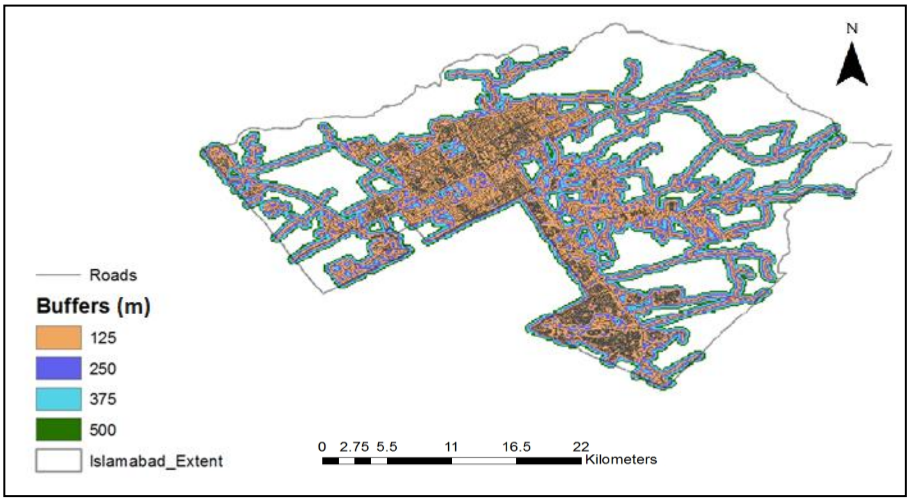


Figure 6. Road network, buffer distance in meters. Areas which lie at a distance >500m are filtered to considering them as inaccessible based on literature information.

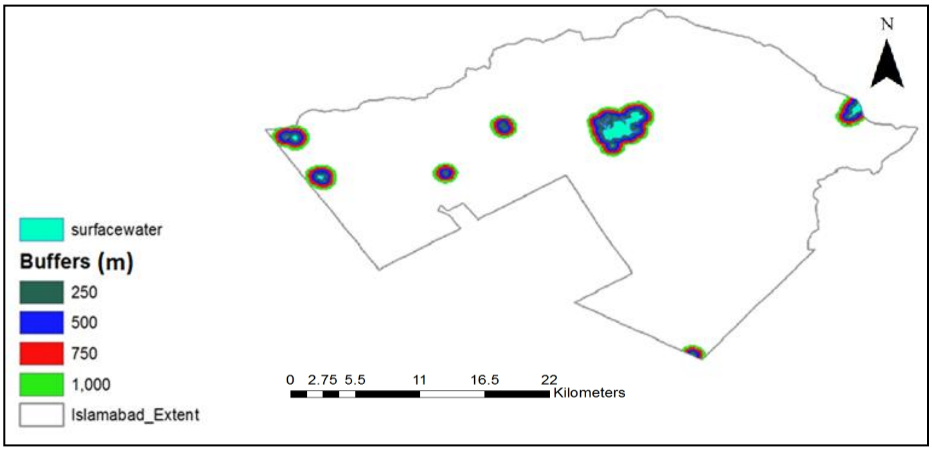


Figure 7. Surface water, buffer distance in meters. Areas within 1000m are filtered as sites near water are likely to get contaminated by leachate inflow.

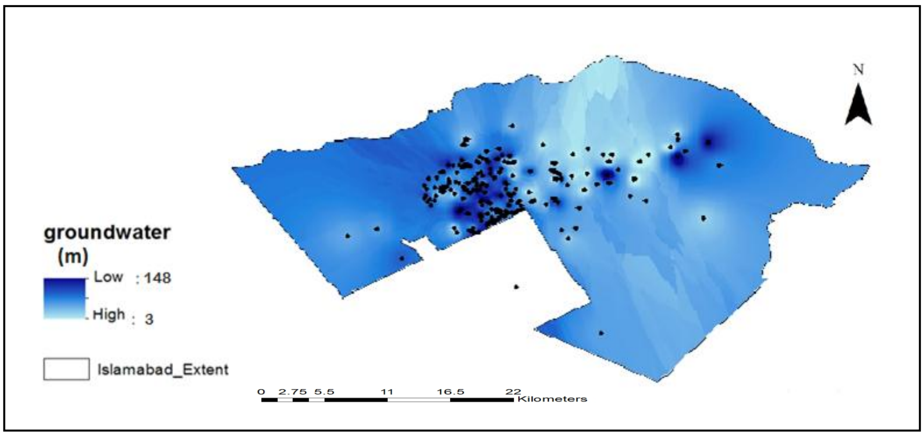


Figure 8. Ground water table depths.

Landfill should not be located near any fresh water source like rivers, lakes or streams. According to worldwide literature, any leachate flow into the water will contaminate it resulting in various diseases and can harm nature (Wang, 2009, Minghua et al. 2009). In the study buffer range of 250m was drawn around waterways, highest rank was assigned to the farthest buffer range as shown in figure 9.

Faults increase permeability of rocks and provide leachate access to ground water and can damage surrounding structure in case of earthquake (Elahi, et al. 2014). Study area is dominant with five major active fault lines. Buffer zones of 500m on either side of fault lines were applied to avoid locating the facility too close to the actives fault line as shown in figure 10.

Soil property such as soil texture plays a very vital role in determining the rate of transport of lechate to underground water. Soil texture in study area was identified as Sandy Loam, Loam, Sandy clay loam and Clay Loam. Clay Loam is termed as best soil texture for landfill (El baba, et al. 2015) and hence given highest score. Soil texture map was prepared from data provided by ISRIC as show in figure 11.

Daily precipitation for a period of six years (2010-2015) was acquired from PMD and TRMM, was used to prepare average daily precipitation map of the study area. Less rainfall is considered optimal in selecting a landfill site and hence, decreasing grades were assigned to increasing precipitation rate**.**

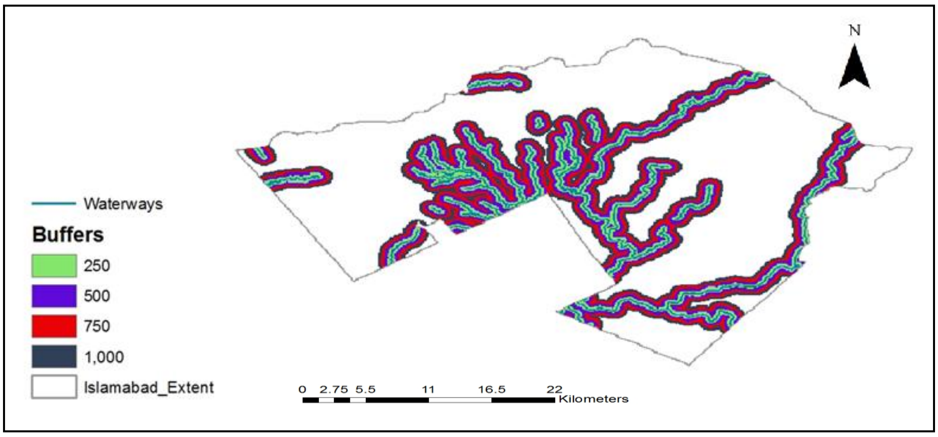


Figure 9. Water ways, buffer distance in meters. Areas at a distance >1000m are considered suitable.

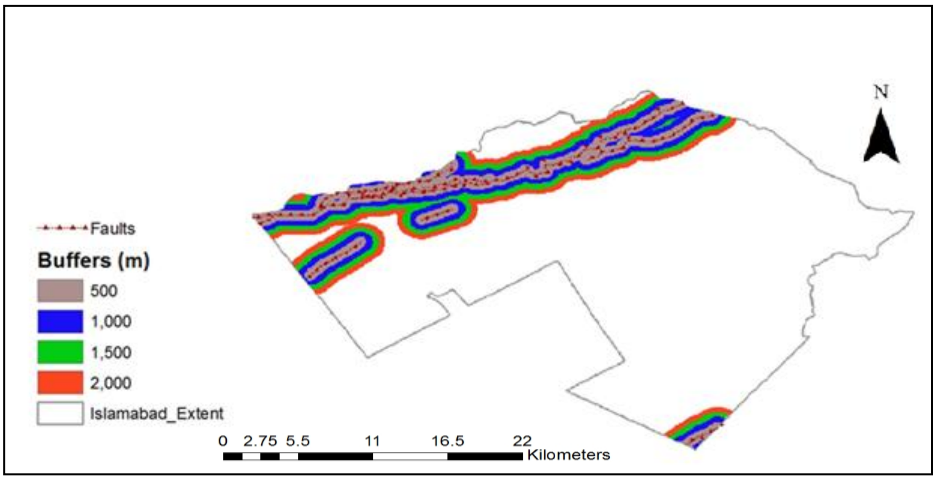


Figure 10. Faults, buffer distance in meters, Areas at a distance >2000m area considered suitable.

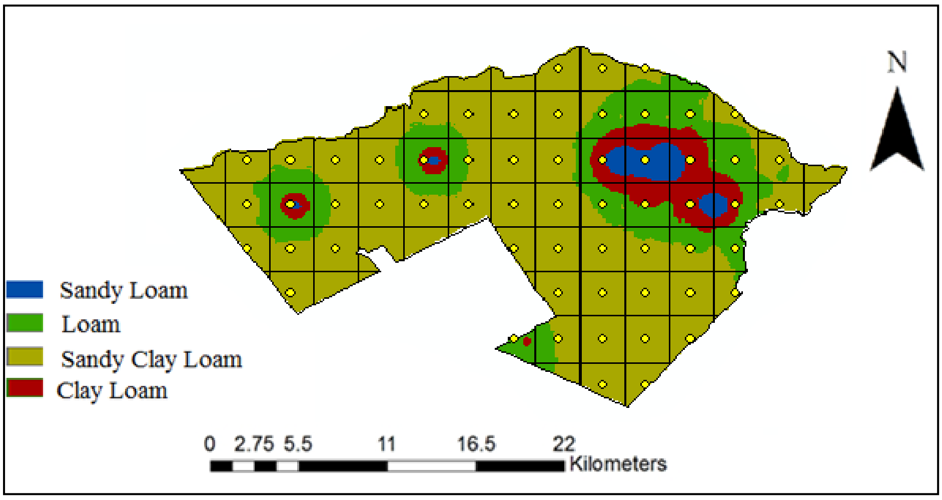


Figure 11. Soil texture.

It is preferred that the landfill site be as far as 2.5-5km away from the airport (Ahmad, et al. 2012; Bagchi,et al.1994; Kontos et al., 2003). Buffer range of 2500m was given lowest score whereas highest score was given to the buffer range >10000m as shown in figure12.

Fourteen different formations were identified in the study area. Digitized map was prepared using Geological map from Survey of Pakistan as shown in figure 13. Based on different geologic and hydro geologic absorption properties of sediments, geological map was reclassified into six classes and ranked accordingly.

World Bank buffer zones distance and their ranking are shown in the table. The layer of railways was classified into five classes. Then, the vector map prepared was converted to a raster map as shown in figure 14.

Digital Elevation Models DEM contains great deal of information in 3D and are extremely useful in studies related to site selection. Slope is one of the most important factors in determining suitable landfill area. It was calculated from 30m SRTM DEM. The potential for slope failure is related to type or nature of topography. Slope failure underneath or adjacent to landfills, results in release of leachate to surrounding areas thus causing environment contamination. According to Bagchi, et al. (1994) land with slopes greater than 15% are considered unsuitable for waste disposal sites whereas Akbari, et al. (2008) suggests a slope less than 20% as most suitable. Wang, et al. (2009) assigned lowest grade to 40-50% slope and highest grade to 0-10% slope. Considering these studies, slope less than 20% was reclassified into 4 classes whereas slope greater than 20% was filtered out.

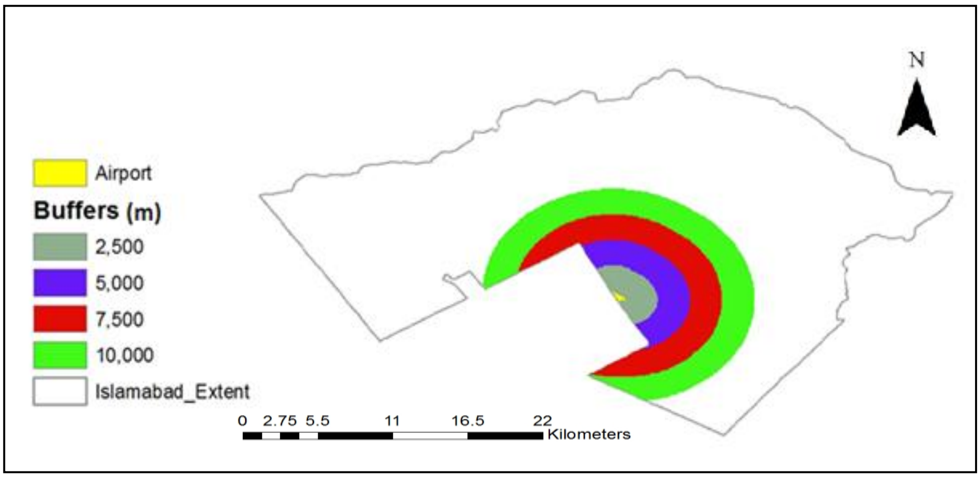


Figure 12 Airport, buffer distance in meters.

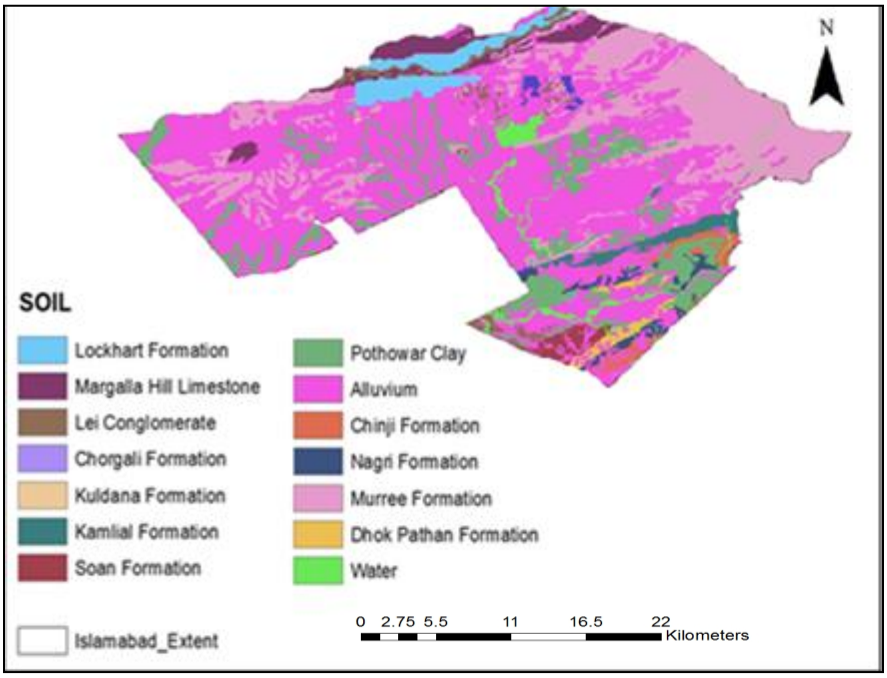


Figure 13. Soil geology.

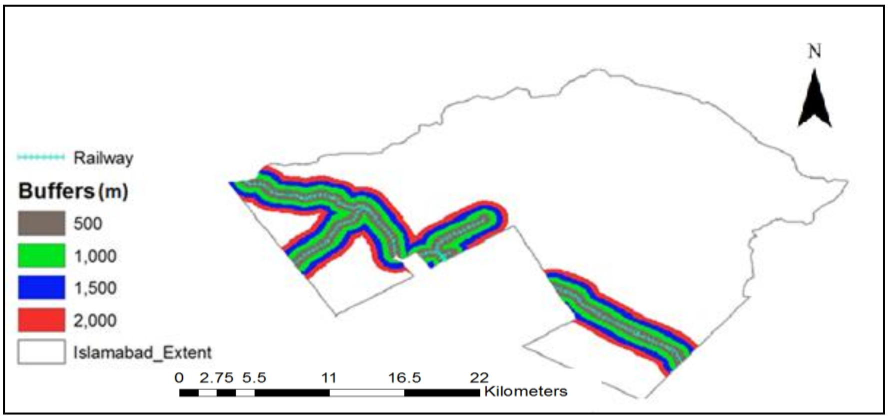


Figure 14. Railway, buffer distance in meters.

Parameters subject to evaluation were assigned a value defined as weight, which indicates the relative importance of parameters considered for study.

According to (Kontos et al, 2003) assignment of weights to parameters accounts for the degree to which evaluating parameters change in range of variation and different degrees of importance attached to these ranges of variation.

After running AHP calculations (Appendix-2), all raster maps with their calculated weight were put into weighted overlay tool. Eight sites were identified as suitable for landfill. For finding out best site from these eight sites, fuzzy ahp was carried out which was solely based on expert knowledge.

Buckley's method was implemented to determine the relative importance weights for both the criteria and the alternatives. Using Fuzzy Scale shown in table 4, If Criterion 1 is strongly important to Criterion 2, and then it takes the scale value of (6, 7, 8). Whereas in pair wise comparison of Criterion 2 to criterion 1, get a value of (1/8, 1/7, 1/6).

Prescribed scale values were standardized using average formulae. When comparing TI with all other criteria, 1 expert assigns a value 5 to TI with respect to EI whereas 2nd expert assigned 3 to TI with respect to EI. Average of 5 and 3 is 4, thus 4 was standardized to be equal to (6, 7, 8) = strongly important in linguistic terms.

Pairwise comparison of criterion with respect to eight sites was carried out using expert given scale values as shown in table 5. Pairwise comparsion was further arranged into comparison matrix to find geometric mean as shown in table 6 and table 7. Relative Fuzzy weights of alternatives with respect to criterion were calculated as shown in Table 8. Averaged and normalized relative weights of criterion were calculated using equation 5. Aggregated result for each criterion is shown in table 10.

### 3.2. Environmental Impact Assessment

This research was aimed to identify suitable landfill sites based on environmental ecological parameters and then critical analysis of the sites for selection of most appropriate site using expert knowledge. After the analysis of eight potential sites, Site near sector G-16 was identified as most suitable for construction of landfill.

#### 3.2.1 Characteristics of the site:

New proposed landfill site is located north east, at12.3km away from existing open dumping site in I-12. Its total area is about 234 hectares and is 1500m away from nearby settlement (figure 15). Soil texture in the area is loamy and covered with wild vegetation. Some sections of land are been used by locals for wheat production. Site is located near the suburbs of city (Appendix-1).

#### 3.2.2 Climate and meteorology:

The study area is characterized by humid sub tropical climate with following characteristics:

**Precipitation:** According to Monsoon Rainfall Pakistan Report 2015 of PMD, July 2015 was the wettest month with an average rainfall of 494mm as shown in figure 16.

Table 4: Linguistic terms and their membership functions.

| **Definition** | **Fuzzy Scale** |
|---|---|
| Equally important | (1,1,1) |
| weakly Important | (2,3,4) |
| Fairly Important | (4,5,6) |
| Strongly Important | (6,7,8) |
| Absolutely Important | (9,9,9) |

Table 5: Pair wise comparison of criterion TI with respect to 8 alternatives.

| **No.** | **A.imp (9, 9, 9)** | **S. Imp. (6,7,8)** | **F.imp (4,5,6)** | **W.imp (2,3,4)** | **Alternatives** | **E.imp (1,1,1)** | **Alternatives** | **W.imp (2,3,4)** | **F.imp (4,5,6)** | **S. Imp. (6,7,8)** | **A.imp (9, 9, 9)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1.** | | | | | S1 | ◉ | S2 | | | | |
| **2.** | | | ◉ | | S1 | | S3 | | | | |
| **3.** | | | ◉ | | S1 | | S4 | | | | |
| **4.** | ◉ | | | | S1 | | S5 | | | | |
| **5.** | ◉ | | | | S1 | | S6 | | | | |
| **6.** | | | | ◉ | S1 | | S7 | | | | |
| **7.** | | | | | S1 | ◉ | S8 | | | | |
| **8.** | | | ◉ | | S2 | | S3 | | | | |
| **9.** | | | ◉ | | S2 | | S4 | | | | |
| **10.** | ◉ | | | | S2 | | S5 | | | | |
| **11.** | ◉ | | | | S2 | | S6 | | | | |
| **12.** | | | | ◉ | S2 | | S7 | | | | |
| **13.** | | | | | S2 | ◉ | S8 | | | | |
| **14.** | | | | | S3 | ◉ | S4 | | | | |
| **15.** | | ◉ | | | S3 | | S5 | | | | |
| **16.** | | ◉ | | | S3 | | S6 | | | | |
| **17.** | | | | | S3 | | S7 | ◉ | | | |
| **18.** | | | | | S3 | | S8 | | ◉ | | |
| **19.** | | ◉ | | | S4 | | S5 | | | | |
| **20.** | | ◉ | | | S4 | | S6 | | | | |
| **21.** | | | | | S4 | | S7 | ◉ | | | |
| **22.** | | | | | S4 | | S8 | | ◉ | | |
| **23.** | | | | | S5 | ◉ | S6 | | | | |
| **24.** | | | | | S5 | | S7 | | ◉ | | |
| **25.** | | | | | S5 | | S8 | | | ◉ | |
| **26.** | | | | | S6 | | S7 | | ◉ | | |
| **27.** | | | | | S6 | | S8 | | | ◉ | |
| **28.** | | | | | S7 | | S8 | ◉ | | | |

Table 6: Comparison matrix.

| Alternatives | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
|---|---|---|---|---|---|---|---|---|
| S1 | (1,1,1) | (1,1,1) | (4,5,6) | (4,5,6) | (9,9,9) | (9,9,9) | (2,3,4) | (1,1,1) |
| S2 | (1,1,1) | (1,1,1) | (4,5,6) | (4,5,6) | (9,9,9) | (9,9,9) | (2,3,4) | (1,1,1) |
| S3 | (1/6,1/5,1/4) | (1/6,1/5,1/4) | (1,1,1) | (1,1,1) | (6,7,8) | (6,7,8) | (1/4,1/3,1/2) | (1/6,1/5,1/4) |
| S4 | (1/6,1/5,1/4) | (1/6,1/5,1/4) | (1,1,1) | (1,1,1) | (6,7,8) | (6,7,8) | (1/4,1/3,1/2) | (1/6,1/5,1/4) |
| S5 | (1/9,1/9,1/9) | (1/9,1/9,1/9) | (1/8,1/7,1/6) | (1/8,1/7,1/6) | (1,1,1) | (1,1,1) | (1/6,1/5,1/4) | (1/8,1/7,1/6) |
| S6 | (1/9,1/9,1/9) | (1/8,1/7,1/6) | (1/8,1/7,1/6) | (1/6,1/5,1/4) | (1,1,1) | (1,1,1) | (1/6,1/5,1/4) | (1/8,1/7,1/6) |
| S7 | (1/4,1/3,1/2) | (1/4,1/3,1/2) | (2,3,4) | (2,3,4) | (4,5,6) | (4,5,6) | (1,1,1) | (1/4,1/3,1/2) |
| S8 | (1,1,1) | (1,1,1) | (4,5,6) | (4,5,6) | (6,7,8) | (6,7,8) | (2,3,4) | (1,1,1) |

Table 7: Geometric mean of fuzzy comparison values

.

S1: $r_i = \left(\prod_{j=1}^{n} d_{ij}\right)1/n = ((1*1*4*4*9*9*2*1)^{1/8}, (1*1*5*5*9*9*3*1)^{1/8}, (1*1*6*6*9*9*4*1)^{1/8}) = (2.67, 2.97, 3.22)$

S2: $r_i = \left(\prod_{j=1}^{n} d_{ij}\right)1/n = ((1*1*4*4*9*6*2*1)^{1/8}, (1*1*5*5*9*7*3*1)^{1/8}, (1*1*6*6*9*8*4*1)^{1/8}) = (2.53, 2.87, 3.17)$

S3: $r_i = \left(\prod_{j=1}^{n} d_{ij}\right)1/n = ((6*6*1*1*6*6*4*6)^{1/8}, (5*5*1*1*7*7*3*5)^{1/8}, (4*4*1*1*8*8*2*4)^{1/8}) = (3.64, 3.41, 3.08)$

S4: $r_i = \left(\prod_{j=1}^{n} d_{ij}\right)1/n = ((6*6*1*1*6*4*4*6)^{1/8}, (5*5*1*1*7*5*3*5)^{1/8}, (4*4*1*1*8*6*2*4)^{1/8}) = (3.46, 2.67, 2.97)$

S5: $r_i = \left(\prod_{j=1}^{n} d_{ij}\right)1/n = ((9*9*8*8*1*1*6*8)^{1/8}, (9*9*7*7*1*1*5*7)^{1/8}, (9*9*6*6*1*1*4*6)^{1/8}) = (4.72, 4.39, 4.03)$

S6: $r_i = \left(\prod_{j=1}^{n} d_{ij}\right)1/n = ((9*9*8*8*1*1*6*8)^{1/8}, (9*9*7*7*1*1*5*7)^{1/8}, (9*9*6*6*1*1*4*6)^{1/8}) = (4.72, 4.39, 4.03)$

S7: $r_i = \left(\prod_{j=1}^{n} d_{ij}\right)1/n = ((4*4*2*2*4*4*1*4)^{1/8}, (3*3*3*3*5*5*1*3)^{1/8}, (2*2*4*4*6*6*1*3)^{1/8}) = (2.82, 2.97, 3.01)$

S8: $r_i = \left(\prod_{j=1}^{n} d_{ij}\right)1/n = ((1*1*4*4*6*6*2*1)^{1/8}, (1*1*5*5*7*7*3*1)^{1/8}, (1*1*6*6*8*8*4*1)^{1/8}) = (2.41, 2.79, 3.13)$

Sum= (26.97, 26.46, 26.64)

Inverse = 0.037, 0.0377, 0.0375

Ascending order= 0.037, 0.0375, 0.0378

Table 8: Relative fuzzy weights of alternatives.

| | | | |
|---|---|---|---|
| Ws1 | 0.09879 | 1.11375 | 1.21716 |
| Ws2 | 0.09361 | 1.07625 | 1.19826 |
| Ws3 | 0.13468 | 1.27875 | 1.16424 |
| Ws4 | 0.12802 | 1.00125 | 1.12266 |
| Ws5 | 0.17464 | 1.64625 | 1.52334 |
| Ws6 | 0.17464 | 1.64625 | 1.52334 |
| Ws7 | 0.10434 | 1.11375 | 1.13778 |
| Ws8 | 0.08917 | 1.04625 | 1.18314 |

Table 9: Averaged and normalized relative weights of criterion.

| Alternatives | $M_i$ | $N_i$ |
|---|---|---|
| S1 | 0.8099 | 0.115753 |
| S2 | 0.789373 | 0.11282 |
| S3 | 0.859223 | 0.122803 |
| S4 | 0.750643 | 0.107284 |
| S5 | 1.114743 | 0.159323 |
| S6 | 1.114743 | 0.159323 |
| S7 | 0.78529 | 0.112236 |
| S8 | 0.772853 | 0.110459 |
| total | 6.99 | |

Table 10: Aggregated result for each alternative according to criteria.

| Weights | TI | EI | PN | EC | LC | VC | total |
|---|---|---|---|---|---|---|---|
| S1 | 0.115753 | 0.085286 | 0.089633 | 0.177133 | 0.125 | 0.125 | 0.717805 |
| S2 | 0.11282 | 0.085286 | 0.089438 | 0.177133 | 0.125 | 0.125 | 0.714677 |
| S3 | 0.122803 | 0.085286 | 0.089438 | 0.102054 | 0.125 | 0.125 | 0.649581 |
| S4 | 0.107284 | 0.085286 | 0.131094 | 0.102054 | 0.125 | 0.125 | 0.675718 |
| S5 | 0.159323 | 0.085286 | 0.137037 | 0.102054 | 0.125 | 0.125 | 0.7337 |
| S6 | 0.159323 | 0.085286 | 0.137037 | 0.102054 | 0.125 | 0.125 | 0.7337 |
| S7 | 0.112236 | 0.085286 | 0.089438 | 0.177133 | 0.125 | 0.125 | 0.714093 |
| **S8** | 0.110459 | 0.444661 | 0.236883 | 0.102054 | 0.125 | 0.125 | **1.144057*** |

*Since site 8 has highest total so it was most suitable for constructing a landfill.

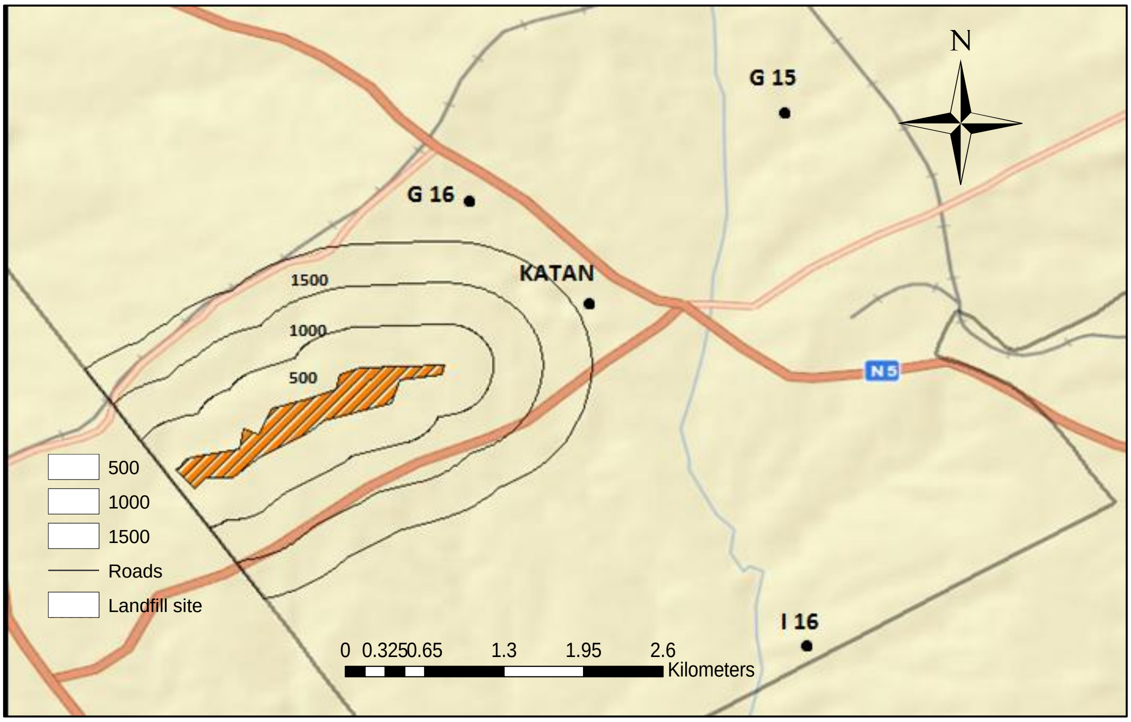


Figure 15. Landfill site distance in meters with respect to nearby settlement.

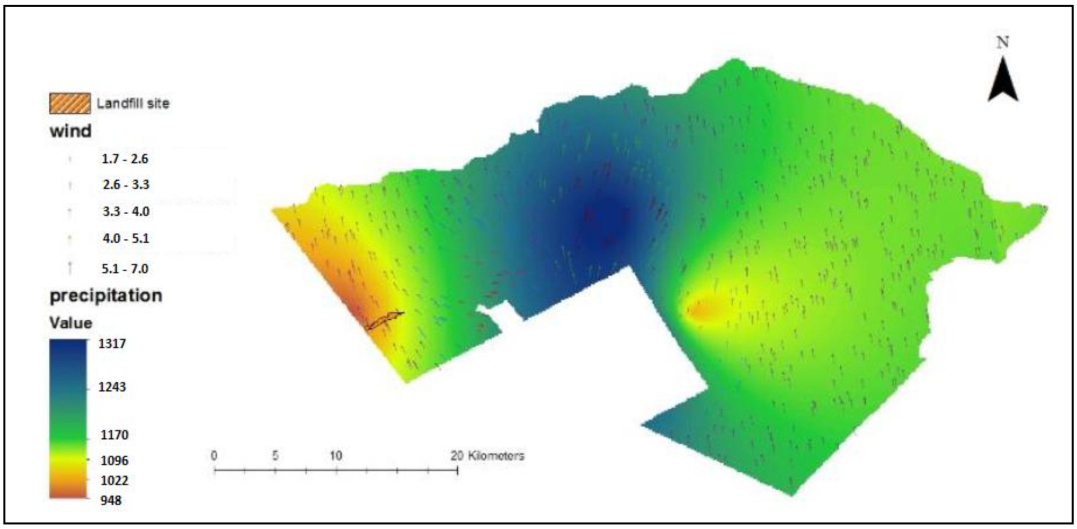


Figure 16. Temperature and Wind speed and Direction at proposed landfill site.

**Humidity**: The relative humidity typically ranges from 22% -96% (very humid) over the course of the year, rarely dropping and reaching as high as 100% (very humid). May usually has the driest air at which relative humidity drops below 27% (dry). December is most humid with 92% humidity.

**Wind:** The average wind speed in the last 20 years is 9.9 km/hr (2.75 m/s). According to available Information, the prevailing wind direction for the period from 1923 to 2015 is in south north direction.

### 3.2.3 Surface and Ground Water:

Locals of Islamabad depends on both surface and ground water resources to meet their water needs. Simly dam is the major source of surface water whereas ground water is accessed using tube wells.

El-Nino years 2015-2016 caused heavy rainfall along with drought conditions and record extreme of heat wave which reduced inflow to Simly dam which in turn has decreased recharge to groundwater has caused lowering of ground water tables. Therefore, much of water table level throughout study area is suitable to create landfill.

### 3.2.4 Biodiversity

Plant species present in the proposed landfill area consist of mainly wild grass and fodder crops as shown in figure 17. Soil texture (figure 18) in the area is loamy and is considered as an active food web for microorganism which assists in healthy plant growth. Hence, part of land is used for cultivating wheat by nearby dwellers.

### 3.2.5 Environment Consequences and Mitigation Measures

Approach of the research is to improve environmental conditions which are at threat due to inappropriate dumping. Numbers of environmental parameters were considered to analyze study area and proposed site was its outcome (figure 19). Nevertheless, further assessment of the site by field survey which takes into account potential environmental impacts should be considered and proper mitigation measures that can reduce the negative impact of waste handling on health must be presented. Output of the checklist revealed key area of potential impact.

### 3.2.6 Air Quality Impact

Decomposition process of waste results in gas emission mainly methane (50-65%) and Carbon dioxide (35-45%). Methane being lighter than air moves through the soil to the surface and a concentration of 5-15% can result in explosion and if released into atmosphere can become a source of ozone depletion. Moreover, gases generated during anaerobic process like ammonia can cause serious odor problems for nearby settlers. Therefore proper gas management system has to be installed for gas extraction which will also minimize odor issues.

Since wind direction at proposed site is away from the settlers so probability of being affected by odor is less. Another alternative is relocation of villagers by providing them better livelihood.

Figure 17. Flora and Fauna.

Figure 18. Soil texture.

Figure 19.  Landfill site.

### 3.2.7 Leachate reduction:

Leachate production requires transport and treatment which can be an expensive practice. One of the common practices to utilize leachate is by installing leachate recirculation pressure Dispersal System, it collects leachate from bottom (where it is securely contained by bottom liner which prevents leachate from contaminating ground water table) and transfer it to subsurface.

This automated process improves leachate quality and help in increasing gas production which can be further used for generating energy. It also prevents leachate from accumulating in empty spaces.

# Chapter 4

# CONCLUSION AND RECOMMENDATIONS

## 4.1. Conclusion

The increasing generation of municipal solid waste in the Islamabad is one of the greatest challenges faced by governmental authorities. The development of our model was triggered by the desire to minimize the impact of landfill sites on the environment, community health and economy. We integrated GIS and multi-criteria evaluation technique, AHP and fuzzy AHP, in the identification of site suitability for landfills. Environmental and economic factors were both considered in the computation process. Intermediate suitability maps were produced for all criteria, which were combined to create the final composite landfill site suitability map. AHP offered an objective weight assignment process. Furthermore, the use of weights provided great flexibility in the aggregation procedure. After identification of eight possible landfill sites using AHP, those sites were further examined under expert based fuzzy AHP for finding out one best landfill site. Results showed site 8 near sector G-16 to be most appropriate for constructing landfill. The site was further analyzed for environmental suitability, outcome of which was that the identified site using spatial techniques along with MCDA models is both socially and environmentally suitable.

The siting process in this study will be very useful for waste disposal site selection in rapid-growing regions.

## 4.2. Recommendations and Limitations

The limitation of the method is that weights were assigned based on literature available which may differ with on ground real world problems. Moreover, fuzzy weights were assigned based on expert knowledge hence, same rating scale may not be applicable in other parts of the world. However, similar methodology can be adopted. Land Use and Land Cover are crucial to site selection however since the selected study area was small and parameters buffer covered all the urban area, results were similar with and without remote sensing data. Hence for more accurate results high resolution LULC remote sensing data can be incorporated.

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# APPENDICES

**Appendix- 1. UNEP environment impact assessment checklist (Training module available at: http://www.unep.or.jp/Ietc/SPC/publications.asp)**

| | |
|---|---|
| **Geology/Soils** | |
| 1. Are there steep slopes (31 – 50%) and/or very steep slopes (above 51%) in the dumpsite?<br>[ ] Yes [redacted] No<br>If yes, indicate their locations on a site map. | |
| 2. What is the dominant type of soil in the area?<br>[ ] sandy [ ] sandy loam[ ] clayey [redacted] Others ***Loamy*** | |
| **Hydrology/Groundwater Resources** | |
| 1. Are there water bodies found inside or near the dumpsite?<br>[ ] Yes [redacted] No | |
| What is the classification of these water bodies based on the environment agency's classifications.<br>[ ] Class A [ ] Class D<br>[ ] Class B [ ] Class E<br>[ ] Class C [redacted] Not yet classified | |
| | |
| Are there communities immediately downstream of these water bodies?<br>[ ] Yes [ ] No | N/A |
| Does the area experience flooding during wet season or typhoons?<br>What might have caused the flooding?<br>[ ] water logged area [ ] low area/elevation<br>[ ] poor drainage [ ] Others ________________________ | N/A |
| Indicate the use of the wells described in item 7.<br>[redacted] drinking purposes [redacted] irrigation<br>[redacted] bathing, washing [ ] Others _________________________ | |
| Is the area proximate to sensitive groundwater resources (e.g. well fields, recharge areas, etc.) ?<br>[ ] Yes[redacted]] No<br>If Yes, how near is the site?<br>***500 meters*** | |
| What is the highest recorded depth of the water table in the vicinity of the site? 31 meters | |
| Is the site located near the shoreline?<br>[ ] Yes[redacted]] No<br>If Yes, indicate its distance: ________________________________ | |

| | |
|---|---|
| Are there existing structures or development around the project site?<br>[redacted] Yes [ ] No<br>If Yes, list them in the space below.<br><br>Small village approx 500meters away from site | |
| <br><br>**BIOLOGICAL COMPONENT** | |
| Are there fishery resources in the water bodies near the site?<br>[ ] Yes [redacted]No<br>If Yes, is the activity commercial in scale or for subsistence only?<br>[ ] commercial only [ ] subsistence only | |
| Is the site proximate to a watershed or forest reservation area?<br>[ ] Yes[redacted]] No<br>If Yes, how near is the site ___________ Km<br>Identify the watershed or forest reservation:<br>____________________________________________________________ | |
| Is the project proximate to an ecosystem?<br>[ ] Yes [ ] No<br>If Yes, what is the type of ecosystem and indicate its corresponding distance from the site.<br>[ ] forest ___________________________________________________<br>[ ] coastal/marine ___________________________________________<br>[ ] grassland ________________________________________________<br>[ ] mangrove ________________________________________________<br>[ ] agriculture _______________________________________________<br>[ ] lake and river ecosystem ___________________________________ | Subject to general climatology, study area soil is well suited for plantation and mostly covered with wild grass unless made barren otherwise |
| | |
| Are there residents in the proposed site who need to be relocated?<br>[redacted] Yes [ ] No<br>If Yes, how many families? ___________________________________ | Small sub urban area located away from wind direction, can be relocated by not necessarily |
| What is the distance of the proposed site with the closest residential area? ***1500meters***___ | |
| What is the distance of the proposed site with the closest institutional establishments (e.g. schools, churches, hospitals, etc) in the area?<br>_________________________________________________ | No institutes nearby |

## Appendix-2. Analytical Hierarchical Process Calculations

### Faults ahp calculation

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| FAULTS | | | | | | | | | | |
| | | >2000 | 1500-2000 | 1000-1500 | 500-1000 | 0-500 | | | | |
| | | a | b | c | d | e | | | | |
| | a | 1 | 4 | 5 | 7 | 9 | | | | |
| | b | 0.25 | 1 | 5 | 6 | 7 | | | | |
| | c | 0.2 | 0.2 | 1 | 4 | 6 | | | CI | 0.1397 |
| | d | 0.142857 | 0.166667 | 0.25 | 1 | 3 | | | CR | 0.124732 |
| | e | 0.111111 | 0.142857 | 0.166667 | 0.333333 | 1 | | | | |
| | sum | 1.703968 | 5.509524 | 11.41667 | 18.33333 | 26 | | | | |
| | | | | | | | total | weight | | |
| | | 0.586865 | 0.726016 | 0.437956 | 0.381818 | 0.346154 | 2.478809 | 0.495762 | | |
| | | 0.146716 | 0.181504 | 0.437956 | 0.327273 | 0.269231 | 1.36268 | 0.272536 | | |
| | | 0.117373 | 0.036301 | 0.087591 | 0.218182 | 0.230769 | 0.690216 | 0.138043 | | |
| | | 0.083838 | 0.030251 | 0.021898 | 0.054545 | 0.115385 | 0.305916 | 0.061183 | | |
| | | 0.065207 | 0.025929 | 0.014599 | 0.018182 | 0.038462 | 0.162378 | 0.032476 | | |
| | | | | | | | | 1 | | |
| | | | | | | | | total | dw | |
| | | | 0.495762 | 1.090144 | 0.690216 | 0.428283 | 0.292281 | 2.996686 | 6.044608 | |
| | | | 0.12394 | 0.272536 | 0.690216 | 0.3671 | 0.22733 | 1.681122 | 6.16844 | |
| | | | 0.099152 | 0.054507 | 0.138043 | 0.244733 | 0.194854 | 0.73129 | 5.297543 | |
| | | | 0.070823 | 0.045423 | 0.034511 | 0.061183 | 0.097427 | 0.309367 | 5.056395 | |
| | | | 0.055085 | 0.038934 | 0.023007 | 0.020394 | 0.032476 | 0.169896 | 5.231477 | |
| | | | | | | | | | 27.79846 | |
| | | | | | | | | | 5.559692 | |

### Roads ahp calculation

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Roads | | | | | | | | | | |
| | | 0-125 | 125-250 | 250-375 | 375-500 | >500 | | | | |
| | | a | b | c | d | e | | | CI | 0.0475 |
| | a | 1 | 4 | 5 | 6 | 7 | | | CR | 0.042411 |
| | b | 0.2 | 1 | 5 | 6 | 7 | | | | |
| | c | 0.17 | 0.2 | 1 | 2 | 4 | | | | |
| | d | 0.14 | 0.17 | 0.2 | 1 | 2 | | | | |
| | e | 0.13 | 0.14 | 0.33 | 0.5 | 1 | | | | |
| | sum | 1.63 | 5.51 | 11.53 | 15.5 | 21 | | | | |
| | | | | | | | total | weight | | |
| | | 0.61 | 0.73 | 0.43 | 0.39 | 0.33 | 2.49 | 0.5 | | |
| | | 0.12 | 0.18 | 0.43 | 0.39 | 0.33 | 1.46 | 0.29 | | |
| | | 0.1 | 0.04 | 0.09 | 0.13 | 0.19 | 0.54 | 0.11 | | |
| | | 0.09 | 0.03 | 0.02 | 0.06 | 0.1 | 0.29 | 0.06 | | |
| | | 0.08 | 0.03 | 0.03 | 0.03 | 0.05 | 0.21 | 0.04 | | |
| | | | | | | | sum | 1 | | |
| | | | | | | | | total | dw | |
| | | | 0.498354 | 1.166256 | 0.544481 | 0.353695 | 0.295656 | 2.858442 | 5.735764 | |
| | | | 0.099671 | 0.291564 | 0.544481 | 0.353695 | 0.295656 | 1.585067 | 5.436428 | |
| | | | 0.083059 | 0.058313 | 0.108896 | 0.117898 | 0.168946 | 0.537113 | 4.932336 | |
| | | | 0.071193 | 0.048594 | 0.021779 | 0.058949 | 0.084473 | 0.284989 | 4.834488 | |
| | | | 0.062294 | 0.041652 | 0.036299 | 0.029475 | 0.042237 | 0.211956 | 5.018309 | |
| | | | | | | | | sum | 25.95733 | |
| | | | | | | | | lambda | 5.191465 | |

## Railway ahp calculation

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rails | | | | | | | | | | |
| | | | | | | | | | | |
| | | >2000 | 1500-2000 | 1000-1500 | 500-1000 | 0-500 | | | | |
| | | a | b | c | d | e | | | CI | 0.06 |
| | a | 1.00 | 1.00 | 3.00 | 6.00 | 8.00 | | | CR | 0.053571 |
| | b | 1.00 | 1.00 | 4.00 | 5.00 | 7.00 | | | | |
| | c | 0.33 | 0.25 | 1.00 | 4.00 | 6.00 | | | | |
| | d | 0.17 | 0.20 | 0.25 | 1.00 | 3.00 | | | | |
| | e | 0.13 | 0.14 | 0.17 | 0.33 | 1.00 | | | | |
| | sum | 2.63 | 2.59 | 8.42 | 16.33 | 25.00 | | | | |
| | | | | | | | | | | |
| | | | | | | | total | weight | | |
| | | 0.380952 | 0.385675 | 0.356436 | 0.367347 | 0.32 | 1.81041 | 0.362082 | | |
| | | 0.380952 | 0.385675 | 0.475248 | 0.306122 | 0.28 | 1.827997 | 0.365599 | | |
| | | 0.126984 | 0.096419 | 0.118812 | 0.244898 | 0.24 | 0.827113 | 0.165423 | | |
| | | 0.063492 | 0.077135 | 0.029703 | 0.061224 | 0.12 | 0.351555 | 0.070311 | | |
| | | 0.047619 | 0.055096 | 0.019802 | 0.020408 | 0.04 | 0.182926 | 0.036585 | | |
| | | | | | | | | 1 | | |
| | | | | | | | | | | |
| | | | | | | | | total | dw | |
| | | | 0.362082 | 0.365599 | 0.496268 | 0.421865 | 0.292681 | 1.938495 | 5.353747 | |
| | | | 0.362082 | 0.365599 | 0.66169 | 0.351555 | 0.256096 | 1.997022 | 5.462322 | |
| | | | 0.120694 | 0.0914 | 0.165423 | 0.281244 | 0.219511 | 0.878271 | 5.309257 | |
| | | | 0.060347 | 0.07312 | 0.041356 | 0.070311 | 0.109755 | 0.354889 | 5.047422 | |
| | | | 0.04526 | 0.052228 | 0.02757 | 0.023437 | 0.036585 | 0.185081 | 5.058921 | |
| | | | | | | | | sum | 26.23167 | |
| | | | | | | | | lambda | 5.246334 | |

## Airport ahp calculation

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| airport | | | | | | | | | | |
| | | | | | | | | | | |
| | | >10,000 | 7500-10,0 | 5000-7500 | 2500-5000 | 0-2500 | | | CI | 0.08 |
| | | a | b | c | d | e | | | CR | 0.071429 |
| | a | 1.00 | 4.00 | 5.00 | 6.00 | 9.00 | | | | |
| | b | 0.25 | 1.00 | 4.00 | 6.00 | 7.00 | | | | |
| | c | 0.20 | 0.25 | 1.00 | 3.00 | 4.00 | | | | |
| | d | 0.17 | 0.17 | 0.33 | 1.00 | 2.00 | | | | |
| | e | 0.11 | 0.14 | 0.25 | 0.50 | 1.00 | | | | |
| | sum | 1.73 | 5.56 | 10.58 | 16.50 | 23.00 | | | | |
| | | | | | | | | | | |
| | | | | | | | total | weight | | |
| | | 0.58 | 0.72 | 0.47 | 0.36 | 0.39 | 2.53 | 0.505129 | | |
| | | 0.14 | 0.18 | 0.38 | 0.36 | 0.30 | 1.37 | 0.274101 | | |
| | | 0.12 | 0.04 | 0.09 | 0.18 | 0.17 | 0.61 | 0.122189 | | |
| | | 0.10 | 0.03 | 0.03 | 0.06 | 0.09 | 0.31 | 0.0611 | | |
| | | 0.06 | 0.03 | 0.02 | 0.03 | 0.04 | 0.19 | 0.037482 | | |
| | | | | | | | sum | 1 | | |
| | | | | | | | | | | |
| | | | | | | | | total | dw | |
| | | | 0.505129 | 1.096402 | 0.610943 | 0.3666 | 0.337334 | 2.916409 | 5.773591 | |
| | | | 0.126282 | 0.274101 | 0.488754 | 0.3666 | 0.262371 | 1.518109 | 5.538509 | |
| | | | 0.101026 | 0.068525 | 0.122189 | 0.1833 | 0.149926 | 0.624966 | 5.114767 | |
| | | | 0.084188 | 0.045683 | 0.04073 | 0.0611 | 0.074963 | 0.306664 | 5.019053 | |
| | | | 0.056125 | 0.039157 | 0.030547 | 0.03055 | 0.037482 | 0.193861 | 5.172178 | |
| | | | | | | | | sum | 26.6181 | |
| | | | | | | | | lambda | 5.323619 | |

## Ground water ahp calculation

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Ground water | | | | | | | | | | |
| | | | | | | | | | | |
| | | suitable | | | | unsuitable | | | | |
| | | a | b | c | d | e | | | CI | 0.11125 |
| | a | 1.00 | 4.00 | 5.00 | 8.00 | 9.00 | | | CR | 0.09933 |
| | b | 0.33 | 1.00 | 5.00 | 6.00 | 7.00 | | | | |
| | c | 0.20 | 0.20 | 1.00 | 8.00 | 9.00 | | | | |
| | d | 0.14 | 0.17 | 0.25 | 1.00 | 6.00 | | | | |
| | e | 0.11 | 0.14 | 0.20 | 0.33 | 1.00 | | | | |
| | sum | 1.79 | 5.51 | 11.45 | 23.33 | 32.00 | | | | |
| | | | | | | | | | | |
| | | | | | | | total | weight | | |
| | | 0.559503 | 0.726016 | 0.436681 | 0.342857 | 0.28125 | 2.346307 | 0.469261 | | |
| | | 0.186501 | 0.181504 | 0.436681 | 0.257143 | 0.21875 | 1.280579 | 0.256116 | | |
| | | 0.111901 | 0.036301 | 0.087336 | 0.342857 | 0.28125 | 0.859645 | 0.171929 | | |
| | | 0.079929 | 0.030251 | 0.021834 | 0.042857 | 0.1875 | 0.362371 | 0.072474 | | |
| | | 0.062167 | 0.025929 | 0.017467 | 0.014286 | 0.03125 | 0.151099 | 0.03022 | | |
| | | | | | | | | 1 | | |
| | | | | | | | | | | |
| | | | | | | | | total | dw | |
| | | | 0.469261 | 1.024463 | 0.859645 | 0.579793 | 0.003358 | 2.93652 | 6.25775 | |
| | | | 0.15642 | 0.256116 | 0.859645 | 0.434845 | 0.004317 | 1.711343 | 6.681912 | |
| | | | 0.093852 | 0.051223 | 0.171929 | 0.579793 | 0.003358 | 0.900155 | 5.235625 | |
| | | | 0.067037 | 0.042686 | 0.042982 | 0.072474 | 0.005037 | 0.230216 | 3.17653 | |
| | | | 0.05214 | 0.036588 | 0.034386 | 0.024158 | 0.03022 | 0.177492 | 5.873358 | |
| | | | | | | | | | 27.22517 | |
| | | | | | | | | | 5.445035 | |

## Precipitation ahp calculation

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Precipitaion: | | | | | | | | | | |
| | | 948-1022n | 1022-1095 | 1095-1165 | 1165-1243 | 1243-1317.6mm | | | | |
| | | a | b | c | d | e | | | | |
| | a | 1.00 | 4.00 | 5.00 | 6.00 | 8.00 | | | CI | 0.04 |
| | b | 0.25 | 1.00 | 3.00 | 4.00 | 5.00 | | | CR | 0.035714 |
| | c | 0.20 | 0.33 | 1.00 | 1.00 | 3.00 | | | | |
| | d | 0.17 | 0.25 | 1.00 | 1.00 | 2.00 | | | | |
| | e | 0.13 | 0.20 | 0.33 | 0.50 | 1.00 | | | | |
| | sum | 1.74 | 5.78 | 10.33 | 12.50 | 19.00 | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | total | weight | | |
| | | 0.574163 | 0.691643 | 0.483871 | 0.48 | 0.421053 | 2.650729 | 0.530146 | | |
| | | 0.143541 | 0.172911 | 0.290323 | 0.32 | 0.263158 | 1.189932 | 0.237986 | | |
| | | 0.114833 | 0.057637 | 0.096774 | 0.08 | 0.157895 | 0.507138 | 0.101428 | | |
| | | 0.095694 | 0.043228 | 0.096774 | 0.08 | 0.105263 | 0.420959 | 0.084192 | | |
| | | 0.07177 | 0.034582 | 0.032258 | 0.04 | 0.052632 | 0.231242 | 0.046248 | | |
| | | | | | | | | 1 | | |
| | | | | | | | | | | |
| | | | | | | | | total | avg | |
| | | | 0.530146 | 0.951945 | 0.507138 | 0.505151 | 0.369987 | 2.864368 | 5.402981 | |
| | | | 0.132536 | 0.237986 | 0.304283 | 0.336767 | 0.231242 | 1.242815 | 5.222211 | |
| | | | 0.106029 | 0.079329 | 0.101428 | 0.084192 | 0.138745 | 0.509723 | 5.025479 | |
| | | | 0.088358 | 0.059497 | 0.101428 | 0.084192 | 0.092497 | 0.42597 | 5.059527 | |
| | | | 0.066268 | 0.047597 | 0.033809 | 0.042096 | 0.046248 | 0.236019 | 5.103288 | |
| | | | | | | | | | 25.81349 | |
| | | | | | | | | | 5.162697 | |

## Waterways ahp calculation

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| water ways | | | | | | | | | |
| | | | | | | | | | |
| | | >1000 | 750-1000 | 500-750 | 250-500 | 0-250 | | **CI** | **0.15** |
| | | a | b | c | d | e | | **CR** | **0.133929** |
| | a | 1.00 | 5.00 | 6.00 | 7.00 | 9.00 | | | |
| | b | 0.20 | 1.00 | 5.00 | 5.00 | 6.00 | | | |
| | c | 0.25 | 0.20 | 1.00 | 2.00 | 3.00 | | | |
| | d | 0.14 | 0.17 | 0.33 | 1.00 | 3.00 | | | |
| | e | 0.13 | 0.14 | 0.20 | 0.33 | 2.00 | | | |
| | sum | 1.72 | 6.51 | 12.53 | 15.33 | 23.00 | | | |
| | | | | | | | | | |
| | | | | | | | total | weight | |
| | | 0.58 | 0.77 | 0.48 | 0.46 | 0.39 | 2.68 | 0.54 | |
| | | 0.12 | 0.15 | 0.40 | 0.33 | 0.26 | 1.26 | 0.25 | |
| | | 0.15 | 0.03 | 0.08 | 0.13 | 0.13 | 0.52 | 0.10 | |
| | | 0.08 | 0.03 | 0.03 | 0.07 | 0.13 | 0.33 | 0.07 | |
| | | 0.07 | 0.02 | 0.02 | 0.02 | 0.09 | 0.22 | 0.04 | |
| | | | | | | | | 1.00 | |
| | | | | | | | | | |
| | | | | | | | | total | dw |
| | | | 0.535355 | 1.255938 | 0.620293 | 0.463416 | 0.394855 | 3.269858 | 6.10783 |
| | | | 0.107071 | 0.251188 | 0.516911 | 0.331012 | 0.263237 | 1.469418 | 5.849884 |
| | | | 0.133839 | 0.020676 | 0.103382 | 0.132405 | 0.310147 | 0.700449 | 6.77533 |
| | | | 0.076479 | 0.041865 | 0.034461 | 0.066202 | 0.131618 | 0.350625 | 5.296271 |
| | | | 0.066919 | 0.035884 | 0.020676 | 0.022067 | 0.03 | 0.175547 | 4.001276 |
| | | | | | | | | sum | 28.03059 |
| | | | | | | | | lambda | 5.606118 |

## Surface water ahp calculation

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| surface water | | | | | | | | | |
| | PC matrix | | | | | | | | |
| | | >1000m | 750-1000n | 500-750m | 250-500m | 0-250m | | **CI** | **0.1125** |
| | | a | b | c | d | e | | **CR** | **0.1** |
| | a | 1.00 | 4.00 | 5.00 | 6.00 | 8.00 | | | |
| | b | 0.25 | 1.00 | 4.00 | 7.00 | 9.00 | | | |
| | c | 0.20 | 0.17 | 1.00 | 3.00 | 6.00 | | | |
| | d | 0.17 | 0.14 | 0.20 | 1.00 | 4.00 | | | |
| | e | 0.13 | 0.11 | 0.17 | 0.25 | 1.00 | | | |
| | sum | 1.74 | 5.42 | 10.37 | 17.25 | 28.00 | | | |
| | | | | | | | | | |
| | criterion weights | | | | | | total | weight | |
| | | 0.574163 | 0.737921 | 0.482315 | 0.347826 | 0.285714 | 2.427939 | 0.49 | |
| | | 0.143541 | 0.18448 | 0.385852 | 0.405797 | 0.321429 | 1.441099 | 0.29 | |
| | | 0.114833 | 0.030747 | 0.096463 | 0.173913 | 0.214286 | 0.630241 | 0.13 | |
| | | 0.095694 | 0.026354 | 0.019293 | 0.057971 | 0.142857 | 0.342169 | 0.07 | |
| | | 0.07177 | 0.020498 | 0.016077 | 0.014493 | 0.035714 | 0.158552 | 0.03 | |
| | | | | | | | | 1 | |
| | | | | | | | | | |
| | | relative criterion weights | | | | | | total | dw |
| | | | 0.485588 | 1.152879 | 0.630241 | 0.410603 | 0.253684 | 2.932994 | 6.04009 |
| | | | 0.121397 | 0.28822 | 0.504193 | 0.479036 | 0.285394 | 1.67824 | 5.82278 |
| | | | 0.097118 | 0.048037 | 0.126048 | 0.205301 | 0.190263 | 0.666767 | 5.289774 |
| | | | 0.080931 | 0.041174 | 0.02521 | 0.068434 | 0.126842 | 0.342591 | 5.006166 |
| | | | 0.060698 | 0.032024 | 0.021008 | 0.017108 | 0.03171 | 0.16255 | 5.126062 |
| | | | | | | | | sum | 27.28487 |
| | | | | | | | | lambda | 5.456975 |

*Continued*

## Geology ahp calculation

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | a | b | c | d | e | f | | CI | 0.047 |
| | a | 1.00 | 4.00 | 5.00 | 7.00 | 8.00 | 9.00 | | CR | 0.037903 |
| | b | 0.25 | 1.00 | 3.00 | 4.00 | 6.00 | 7.00 | | | |
| | c | 0.20 | 0.33 | 1.00 | 2.00 | 3.00 | 4.00 | | | |
| | d | 0.14 | 0.25 | 0.50 | 1.00 | 2.00 | 3.00 | | | |
| | e | 0.13 | 0.17 | 0.33 | 0.50 | 1.00 | 2.00 | | | |
| | f | 0.11 | 0.14 | 0.25 | 0.33 | 0.50 | 1.00 | | | |
| | | 1.83 | 5.89 | 10.08 | 14.83 | 20.50 | 26.00 | | | |
| | | | | | | | | | | |
| | | | | | | | | total | weight | |
| | | 0.546756 | 0.678788 | 0.495868 | 0.47191 | 0.390244 | 0.346154 | 2.92972 | 0.488287 | |
| | | 0.136689 | 0.169697 | 0.297521 | 0.269663 | 0.292683 | 0.269231 | 1.435483 | 0.239247 | |
| | | 0.109351 | 0.056566 | 0.099174 | 0.134831 | 0.146341 | 0.153846 | 0.70011 | 0.116685 | |
| | | 0.078108 | 0.042424 | 0.049587 | 0.067416 | 0.097561 | 0.115385 | 0.45048 | 0.07508 | |
| | | 0.068345 | 0.028283 | 0.033058 | 0.033708 | 0.04878 | 0.076923 | 0.289097 | 0.048183 | |
| | | 0.060751 | 0.024242 | 0.024793 | 0.022472 | 0.02439 | 0.038462 | 0.19511 | 0.032518 | |
| | | | | | | | | | 1 | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | 0.488287 | 0.956989 | 0.583425 | 0.52556 | 0.385462 | 0.292665 | 3.232388 | 6.619858 |
| | | | 0.122072 | 0.239247 | 0.350055 | 0.30032 | 0.289097 | 0.227629 | 1.528419 | 6.388451 |
| | | | 0.097657 | 0.079749 | 0.116685 | 0.15016 | 0.144548 | 0.130073 | 0.718873 | 6.160807 |
| | | | 0.069755 | 0.059812 | 0.058342 | 0.07508 | 0.096366 | 0.097555 | 0.45691 | 6.08564 |
| | | | 0.061036 | 0.039875 | 0.038895 | 0.03754 | 0.048183 | 0.065037 | 0.290565 | 6.030472 |
| | | | 0.054254 | 0.034178 | 0.029171 | 0.025027 | 0.024091 | 0.032518 | 0.19924 | 6.126996 |
| | | | | | | | | | | 37.41222 |
| | | | | | | | | | | 6.235371 |

## Soil texture ahp calculation

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| soil texture | | | | | | | | |
| | | | | | | | CI | 0.116 |
| | | a | b | c | d | | CR | 0.12 |
| | a | 1.00 | 6.00 | 7.00 | 9.00 | | | |
| | b | 0.17 | 1.00 | 4.00 | 6.00 | | | |
| | c | 0.14 | 0.20 | 1.00 | 4.00 | | | |
| | d | 0.11 | 0.17 | 0.25 | 1.00 | | | |
| | sum | 1.42 | 7.37 | 12.25 | 20.00 | | | |
| | | | | | | | | |
| | | | | | | total | weight | |
| | | 0.703911 | 0.81448 | 0.571429 | 0.45 | 2.539819 | 0.634955 | |
| | | 0.117318 | 0.135747 | 0.326531 | 0.3 | 0.879596 | 0.219899 | |
| | | 0.100559 | 0.027149 | 0.081633 | 0.2 | 0.409341 | 0.102335 | |
| | | 0.078212 | 0.022624 | 0.020408 | 0.05 | 0.171245 | 0.042811 | |
| | | | | | | | 1 | |
| | | | | | | | | |
| | | | 0.634955 | 1.319393 | 0.716346 | 0.385301 | 3.055995 | 4.812934 |
| | | | 0.105826 | 0.219899 | 0.409341 | 0.256867 | 0.991933 | 4.510858 |
| | | | 0.090708 | 0.04398 | 0.102335 | 0.171245 | 0.408268 | 3.989515 |
| | | | 0.070551 | 0.03665 | 0.025584 | 0.042811 | 0.175595 | 4.10162 |
| | | | | | | | | 17.41493 |
| | | | | | | | lambda | 4.353732 |
| | | | | | | | | |

Slope ahp calculation

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| slope | | | | | | | | |
| | | | | | | | | |
| | | 0-5 | 10 | 20 | | | CI | 0.085 |
| | | a | b | c | | | CR | 0.146552 |
| | a | 1.00 | 5.00 | 9.00 | | | | |
| | b | 0.20 | 1.00 | 4.00 | | | | |
| | c | 0.17 | 0.14 | 1.00 | | | | |
| | sum | 1.37 | 6.14 | 14.00 | | | | |
| | | | | | | | | |
| | | | | | total | weight | | |
| | | 0.73 | 0.81 | 0.64 | 2.19 | 0.729506 | | |
| | | 0.15 | 0.16 | 0.29 | 0.59 | 0.198282 | | |
| | | 0.12 | 0.02 | 0.07 | 0.22 | 0.072212 | | |
| | | | | | | 1 | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | 0.729506 | 0.991411 | 0.649907 | 2.370824 | 3.249903 | |
| | | | 0.145901 | 0.198282 | 0.288847 | 0.633031 | 3.192576 | |
| | | | 0.121584 | 0.028326 | 0.072212 | 0.222122 | 3.075979 | |
| | | | | | | | 9.518458 | |
| | | | | | | lambda | 3.172819 | |

Ahp calculation of eleven criteria (Groundwater, precipitation, slope, soil texture, geology, faults, roads, airport, waterways, surface water and railways)

| | GW | pp | Slope | S-texture | soil | F | RD | Airport | WB | SW | Railways | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J | K | | | |
| A | 1.00 | 1.00 | 2.00 | 3.00 | 1.00 | 6.00 | 7.00 | 8.00 | 5.00 | 7.00 | 8.00 | | | |
| B | 0.50 | 1.00 | 2.00 | 1.00 | 6.00 | 4.00 | 5.00 | 6.00 | 9.00 | 7.00 | 8.00 | | | |
| C | 0.25 | 0.50 | 1.00 | 1.00 | 2.00 | 3.00 | 5.00 | 6.00 | 7.00 | 8.00 | 9.00 | | | |
| D | 0.33 | 1.00 | 0.25 | 1.00 | 3.00 | 4.00 | 5.00 | 6.00 | 7.00 | 8.00 | 9.00 | | | |
| E | 1.00 | 0.17 | 0.50 | 0.33 | 1.00 | 3.00 | 4.00 | 5.00 | 6.00 | 7.00 | 8.00 | | | |
| F | 0.17 | 0.25 | 0.33 | 0.25 | 0.33 | 1.00 | 6.00 | 5.00 | 7.00 | 8.00 | 9.00 | | | |
| G | 0.14 | 0.14 | 0.20 | 0.20 | 0.25 | 0.17 | 1.00 | 3.00 | 4.00 | 6.00 | 8.00 | | | |
| H | 0.13 | 0.13 | 0.17 | 0.17 | 0.20 | 0.20 | 0.33 | 1.00 | 4.00 | 6.00 | 7.00 | | | |
| I | 0.20 | 0.11 | 0.14 | 0.14 | 0.17 | 0.14 | 0.25 | 0.25 | 1.00 | 3.00 | 4.00 | | | |
| J | 0.14 | 0.33 | 0.13 | 0.13 | 0.14 | 0.13 | 0.17 | 0.17 | 0.33 | 1.00 | 4.00 | | | |
| K | 0.11 | 0.11 | 0.11 | 0.11 | 0.13 | 0.11 | 0.14 | 0.13 | 0.25 | 0.20 | 1.00 | | | |
| | 3.97 | 4.74 | 6.83 | 7.33 | 14.22 | 21.75 | 33.89 | 40.54 | 50.58 | 61.20 | 75.00 | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | **total** | **weight** | |
| | 0.251773 | 0.210967 | 0.29287 | 0.409335 | 0.070334 | 0.275917 | 0.206533 | 0.197328 | 0.098847 | 0.114379 | 0.106667 | 2.23495 | 0.203177 | |
| | 0.125887 | 0.210967 | 0.29287 | 0.136445 | 0.422005 | 0.183945 | 0.147524 | 0.147996 | 0.177924 | 0.114379 | 0.106667 | 2.066608 | 0.187873 | |
| | 0.062943 | 0.105483 | 0.146435 | 0.136445 | 0.140668 | 0.137959 | 0.147524 | 0.147996 | 0.138386 | 0.130719 | 0.12 | 1.414558 | 0.128596 | |
| | 0.083924 | 0.210967 | 0.036609 | 0.136445 | 0.211002 | 0.183945 | 0.147524 | 0.147996 | 0.138386 | 0.130719 | 0.12 | 1.547516 | 0.140683 | |
| | 0.251773 | 0.035161 | 0.073218 | 0.045482 | 0.070334 | 0.137959 | 0.118019 | 0.12333 | 0.118616 | 0.114379 | 0.106667 | 1.194937 | 0.108631 | |
| | 0.041962 | 0.052742 | 0.048812 | 0.034111 | 0.023445 | 0.045986 | 0.177028 | 0.12333 | 0.138386 | 0.130719 | 0.12 | 0.936521 | 0.085138 | |
| | 0.035968 | 0.030138 | 0.029287 | 0.027289 | 0.017584 | 0.007664 | 0.029505 | 0.073998 | 0.079077 | 0.098039 | 0.106667 | 0.535216 | 0.048656 | |
| | 0.031472 | 0.026371 | 0.024406 | 0.022741 | 0.014067 | 0.009197 | 0.009835 | 0.024666 | 0.079077 | 0.098039 | 0.093333 | 0.433204 | 0.039382 | |
| | 0.050355 | 0.023441 | 0.020919 | 0.019492 | 0.011722 | 0.006569 | 0.007376 | 0.006166 | 0.019769 | 0.04902 | 0.053333 | 0.268164 | 0.024379 | |
| | 0.035968 | 0.070322 | 0.018304 | 0.017056 | 0.010048 | 0.005748 | 0.004917 | 0.004111 | 0.00659 | 0.01634 | 0.053333 | 0.242737 | 0.022067 | |
| | 0.027975 | 0.023441 | 0.016271 | 0.015161 | 0.008792 | 0.00511 | 0.004215 | 0.003083 | 0.004942 | 0.003268 | 0.013333 | 0.12559 | 0.011417 | |
| | | | | | | | | | | | | | 1 | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | total | dw |
| | | 0.203177 | 0.187873 | 0.257192 | 0.42205 | 0.108631 | 0.510829 | 0.340592 | 0.315058 | 0.121893 | 0.154469 | 0.091338 | 2.713102 | 13.35337 |
| | | 0.101589 | 0.187873 | 0.257192 | 0.140683 | 0.651784 | 0.340553 | 0.24328 | 0.236293 | 0.219407 | 0.154469 | 0.091338 | 2.624461 | 13.96931 |
| | | 0.050794 | 0.093937 | 0.128596 | 0.140683 | 0.217261 | 0.255415 | 0.24328 | 0.236293 | 0.17065 | 0.176536 | 0.102755 | 1.816201 | 14.12329 |
| | | 0.067726 | 0.187873 | 0.032149 | 0.140683 | 0.325892 | 0.340553 | 0.24328 | 0.236293 | 0.17065 | 0.176536 | 0.102755 | 2.024391 | 14.3897 |
| | | 0.203177 | 0.031312 | 0.064298 | 0.046894 | 0.108631 | 0.255415 | 0.194624 | 0.196911 | 0.146271 | 0.154469 | 0.091338 | 1.493341 | 13.74695 |
| | | 0.033863 | 0.046968 | 0.042865 | 0.035171 | 0.03621 | 0.085138 | 0.291936 | 0.196911 | 0.17065 | 0.176536 | 0.102755 | 1.219004 | 14.31794 |
| | | 0.029025 | 0.026839 | 0.025719 | 0.028137 | 0.027158 | 0.01419 | 0.048656 | 0.118147 | 0.097514 | 0.132402 | 0.091338 | 0.639125 | 13.13558 |
| | | 0.025397 | 0.023484 | 0.021433 | 0.023447 | 0.021726 | 0.017028 | 0.016219 | 0.039382 | 0.097514 | 0.132402 | 0.079921 | 0.497953 | 12.64411 |
| | | 0.040635 | 0.020875 | 0.018371 | 0.020098 | 0.018105 | 0.012163 | 0.012164 | 0.009846 | 0.024379 | 0.066201 | 0.045669 | 0.288505 | 11.83438 |
| | | 0.029025 | 0.062624 | 0.016075 | 0.017585 | 0.015519 | 0.010642 | 0.008109 | 0.006564 | 0.008126 | 0.022067 | 0.045669 | 0.242006 | 10.96685 |
| | | 0.022575 | 0.020875 | 0.014288 | 0.015631 | 0.013579 | 0.00946 | 0.006951 | 0.004923 | 0.006095 | 0.004413 | 0.011417 | 0.130208 | 11.40445 |
| | | | | | | | | | | | | | | 143.8859 |
| | | | | | | | | | | | | | lambda | 13.08054 |
| | | | | | | | | | | | | | | |
| | | | | | | | | | CI | 0.208 | | | | |
| | | | | | | | | | CR | 0.137748 | | | | |