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ATILIM UNIVERSITY 2021

COMBINING ANALYTIC HIERARCHY PROCESS AND RANK ORDER CENTROID WITH GEOGRAPHIC INFORMATION SYSTEM FOR AIRPORT SITE SELECTION: A CASE STUDY IN LIBYA

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
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WAEL ELSHARIDA

DOCTOR OF PHILOSOPHY THESIS
IN
MODELING AND DESIGN OF ENGINEERING SYSTEMS
(MAIN FIELD OF STUDY: INDUSTRIAL ENGINEERING)

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Approval of the Graduate School of Natural and Applied Sciences, Atilim University.

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I certify that this thesis satisfies all the requirements as a thesis for the degree of **Doctor of Philosophy in Modeling and Design of Engineering Systems, Atilim University** .

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This is to certify that we have read the thesis COMBINING ANALYTIC HIERARCHY PROCESS AND RANK ORDER CENTROID WITH GEOGRAPHIC INFORMATION SYSTEM FOR AIRPORT SITE SELECTION: A CASE STUDY IN LIBYA submitted by WAEL ELSHARIDA and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Doctor of Philosophy.

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

COMBINING ANALYTIC HIERARCHY PROCESS AND RANK ORDER CENTROID WITH GEOGRAPHIC INFORMATION SYSTEM FOR AIRPORT SITE SELECTION: A CASE STUDY IN LIBYA

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Choosing airport locations requires thorough and comprehensive decisions to be made. To do so in a professional and logical manner is crucial for the social, economic, and logistic settings intended for any region. The present research takes place in Libya, where airports are just as vital for the economy in terms of tourism and investment by allowing for improved transportation throughout developing market and supplier locations as well as trading between the industrial and financial sectors. For this reason, using the geographic information system (GIS) to determine the appropriate airport site, twenty-three criteria were considered. Besides, two different methods - analytic hierarchy process (AHP) and rank order centroid (ROC) - were utilized to derive the related weights. The comparison of the output maps from these two distinctive approaches appears that both approaches provide identical results. A sensitivity analysis was carried out to evaluate the reliability of the method used and select the best site among the proposed ones based on the result of the highest suitability index for each candidate site. Finally, a business continuity study was applied in this research from the perspective of the location to avoid any potential natural catastrophe, and the result of all candidate sites was deemed ideal as airport sites. This research provides a siting approach and substantial support for decision-makers in the issue of airport locations selection in Libya and other developing countries.

Key words: airport, Libya, GIS, AHP, ROC, sensitivity analysis, business continuity.

ÖZ

HAVALİMANI SAHA SEÇİMİ İÇİN ANALİTİK HİYERARŞİ SÜRECİ VE SIRA DÜZENİ MERKEZİNİN COĞRAFİ BİLGİ SİSTEMİ İLE BİRLEŞTİRİLMESİ: LİBYA'DA BİR VAKA ÇALIŞMASI

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Havaalanı konumlarının seçilmesi, eksiksiz ve kapsamlı kararların alınmasını gerektirir. Bunu profesyonel ve mantıklı bir şekilde yapmak, herhangi bir bölgeye yönelik sosyal, ekonomik ve lojistik ortamlar için çok önemlidir. Mevcut araştırma, gelişmekte olan pazar ve tedarikçi lokasyonları boyunca gelişmiş ulaşımın yanı sıra endüstriyel ve finans sektörleri arasında ticarete izin vererek, havalimanlarının turizm ve yatırım açısından ekonomi için hayati önem taşıdığı Libya'da gerçekleştirilmektedir. Bu nedenle, uygun havalimanı sahasını belirlemek için coğrafi bilgi sistemi (CBS) kullanılarak yirmi üç kriter dikkate alınmıştır. Ayrıca, ilgili ağırlıkları türetmek için iki farklı yöntem - analitik hiyerarşi süreci (AHS) ve sıralama merkezi ağırlıkları (ROC) - kullanılmıştır. Bu iki farklı yaklaşımın çıktı haritalarının karşılaştırılması, her iki yaklaşımın da aynı sonuçları sağladığını göstermektedir.

Kullanılan yöntemin güvenilirliğini değerlendirmek ve her aday site için en yüksek uygunluk indeksinin sonucuna göre önerilenler arasından en iyi yeri seçmek için bir duyarlılık analizi yapılmıştır. Son olarak, bu araştırmada herhangi bir olası doğal afetten kaçınmak için lokasyon perspektifinden bir iş sürekliliği çalışması uygulanmış ve tüm aday sitelerin sonucu havalimanı siteleri olarak ideal kabul edilmiştir. Bu araştırma, Libya ve diğer gelişmekte olan ülkelerdeki havaalanı yer seçimi konusunda karar vericiler için bir konumlandırma yaklaşımı ve önemli bir destek sağlamaktadır.

Anahtar Kelimeler: havaalanı, havalimanı, Libya, CBS, AHS, ROC, duyarlılık analizi, iş devamlılığı.

To my family

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LIST OF SYMBOLS/ABBREVIATIONS

GIS	Geographic Information System
MCDM	Multi-Criteria Decision-Making
GDP	Gross Domestic Product
AHP	Analytical Hierarchy Process
ROC	Rank Order Centroid
MAU	Multi-Attribute Utility
PROMETHEE	Preference Ranking Organization Method For Enrichment Evaluation
SAW	Simple Additive Weighting
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
EU	European Union
MCA	Multi Criteria Analysis
CFD	computational fluid dynamics
DAGF model	Delphi method, AHP rule, Gray correlation and the Fuzzy assessment
ELECTRE	ELimination and Choice Expressing the REality
WLSM	Weighted Least-Square Method
SEM	A structural equation model
MILP	Mixed-integer linear programming
VIKOR	VlseKriterijuska Optimizacija I Komoromisno Resenje
MABAC	Multi- Attributive Border Approximation Area Comparison
MAIRCA	Multi-Attributive Ideal-Real Comparative Analysis
COPRAS	Complex Proportional Assessment
ANN	Average Nearest Neighbor
CSR	Complete Spatial Randomness
SDE	Standard Deviational Ellipse
ANN	Average Nearest Neighbor Distance
NEF	Noise Exposure Forecast

OSM	Open Street Map
DLG	Digital Line Graph
DEM	Digital Elevation Model
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
USGS	U.S. Geological Survey
FAOSOIL	Food and Agriculture Organization of Soil
NASA	National Aeronautics and Space Administration Satellite Imagery
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
VFR	Visual Flight Rules
CI	Consistency Index
λ_{max}	Principal matrix eigenvalue
PCM	Pairwise Comparison Matrix
RI	Random Inconsistency
CR	Consistency Ratio
RR	Rank Reciprocal
EW	Equal Weights
RS	Rank- Sum
GW	Geometric Weights
VSL	Variable-Slope Linear
MI	Marginalization Index

CHAPTER 1

INTRODUCTION

Air transport facilitates the integration of regions within countries into the national – even global – economy by enabling better access to fast growing markets and suppliers and facilitating interactions among various industries and businesses. Further, it can attract new businesses to a region, be it for tourism, manufacturing, or service activities. This, in turn, can stimulate a local economy and support its growth. Air transport also enables the creation of a web of local, auxiliary business activities facilitated by the presence of air transport hubs, benefitting passenger and cargo movement, ground transportation, hotels, or local restaurants. Typically, the convenience of having an airport in relatively close proximity to a city has a positive impact on real state value as well [1].

1.1 Background

Many items of expenditure and applications come into the picture when it comes to choosing an airport all of which need due consideration to select the right place for these facilities. Yet, countries tend to adopt their own individual way of involving the government, public utilities, private enterprises, and assessment methods. According to DeNeufville (1976), there are detail points such as national views of public benefits, those involved in the decision-making process, type of assessment, and the ultimate control when it comes to choosing the site – an issue which is further under spotlight once developing nations face shortage of sound resources and information for proper decision-making [2].

Airports play a crucial role as a utility, whose economics and presence as a whole make them indispensable to be built in the right place. Such a choice, obviously, involves numerous and complicated elements as per the studies on this subject, be it a global issue to a national one [3]. Therefore, airports as crucial infrastructures play a fundamental and leading role in the domestic economy, the rational planning of which can improve the regional comprehensive transportation system and facilitate regional development, both in terms of social and economic aspects [4]. As regards the pre-construction stage, airport site selection is key to its planning to begin with. A sound approach to this task can save construction costs and contribute to the function of airports and the construction of a comprehensive transportation system. Recently, there have been enormous advances in the study and process of facility siting, especially for those perceived as having major impacts in the areas surrounding their final location.

The literature points to airports as being both partially semi-obnoxious and semi-desirable objects [5], [6]. Such structures require positioning in places where there is most demand for their presence in logistic terms so as to save on expenditure and time to commute to and from. On the contrary, though, there are other problems associated with this issue, including noise in the neighboring regions, thereby necessitating their construction as far as possible from residential areas. Such issues are at most the topic of disagreement.

The new analytical tools and state-of-the-art technology have been two of the most important factors in providing a better understanding and obtaining more reliable results when needed in the decision-making process. These factors have also contributed to improving the assessment and management of any type of impact created by the facility under scrutiny [7].

Two separate aspects come into the picture to tackle these issues: namely the ranking problems – that is to be dealt with using multi-criteria analyses – and the location issue – that is treated using mathematical models. These two methods as solutions, still, involve certain disadvantages; for the problems related to choosing the location, one has to determine in advance certain locations for later assessment, along the way risking to accidentally disregard certain optimal solutions. Also, as far as the location is concerned, one may encounter very limited and restricting criteria for selection [8]. As a result, the geographic information systems (GIS) are selected to overcome the above-mentioned disadvantages, facilitate data input, and to enhance the presentation of results.

The GIS facilitates the collection, administration, and investigation of the information. Owing to its scientific background, it can combine numerous forms of data, examine all locations in 3D, and arrange sets of data upon accurate points on maps. Given this exceptional advantage, a GIS offers a better view of the available information in the form of patterns, relations, and settings to make decisions more intelligently [9].

1.2 Significance of the Study

Considering politically-oriented aspects of site selection, a multi-criteria perspective is a must – based on which numerous decision-makers as investors, managers, government agents, regional residents, and financiers come into the picture with different anticipations regarding the choice of site. In case of Libya, which is located in North Africa, it borders the Mediterranean Sea on a 1770-Kilometer-long coastline and has a promising future for tourist and investment. Hence, air transport development is of vital importance since it promotes significantly the country as a main center for connection between Europe and African countries.

This is more so given that the African region is vast and characterized by sparse passenger demand, not to mention the tourist and economic development of the country. Therefore, this study will contribute to the Libyan vision regarding airport planning, and it will offer important outcomes that may result in providing better service for the Libyan public. In addition, it will offer more excellent benefits to all Libyan airline companies when more people prefer airways to travel with, as opposed to choosing the other time-consuming modes of transportation.

Moreover, this work is among the few that use to determine and select the proper location of the airport of multi-criteria analysis combining GIS techniques.

1.3 Research Objectives

This research aims to apply the methods of integration of the multi-criteria decision-making MCDM with GIS to determine the best locations for the construction of an airport. In order to achieve the aim, the following objectives are identified for this research study:

- Reviewing the current locations of all airports considering the coverage area serviced by each airport, and determining the regions outside the range which need to construct a new airport.
- Collecting the relevant criteria based totally on the local features of the study zone, applicable rules, regulations, literature review of previous researches, opinion of experts, and availability of the data including maps, documents, etc., and used them in GIS technique.
- Applying GIS alongside MCDM and preventing the shortcomings associated with the individual use of each approach alone. On the one hand, GIS, which deals basically with natural suitability analysis, has a very restricted capability of combining the decision maker's priorities into the problem-solving process. On the other hand, MCDM, which deals basically with analyzing decision issues and assessing the alternatives based on a decision maker's preferences, needs the ability to handle spatial data (e. g., union, intersection, buffering and overlay) that are decisive to spatial analysis [10]. The complementary nature of applying these two together is the main inspiration behind the present work.
- Comparing the different approaches AHP and ROC which will be used to derive the criteria weights as each may provide different sets of solutions.
- Using sensitivity analysis for evaluating the reliability of the model used, and selecting the best site among the options based on the result of the highest suitability index for each alternative.
- Applying business continuity studies from the perspective of the location to ensure the avoidance of any potential natural catastrophe.

1.4 Area of Study

Libya is situated on the coast of North Africa between 9.38˚E to 25.15˚E and 19.51˚N to 33.17˚N, bounded by the Mediterranean Sea on the north, Egypt on the east, Sudan on the southeast, Niger and Chad on the south, and Tunisia and Algeria on the west, as shown in Figure 1.1. It is the fourth largest country on the continent, with an area of 1,759,540 square km and a population of about 6818624 inhabitants. Most of the country lies in the Sahara Desert, and much of its population is concentrated along the coast and its immediate hinterland. Libya's climate is dominated by the hot arid Sahara, but it is moderated along the coastal littoral by the Mediterranean Sea.

Along the coast, the weather of Mediterranean nature is cool with precipitation in the winter season and hot dry summers [11]. The Libyan economy is based mainly on money earned from oil at almost 69% of the total export revenues, and 60% of Gross Domestic Product (GDP). This income for a relatively insignificant populace position the country among the top GDPs across Africa [12].

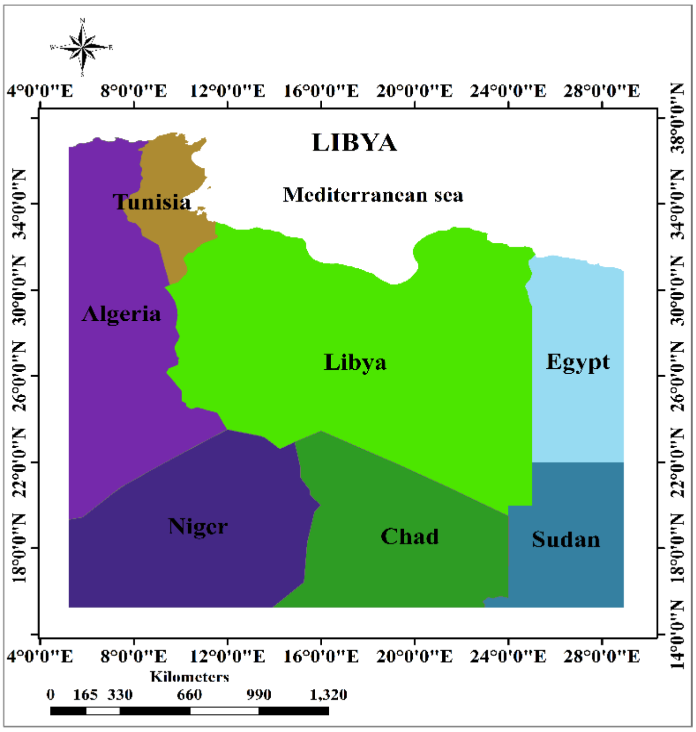


Figure 1.1 Location of Libya (Source [13])

Aside from this, numerous touristic sites appear all over the territory comprising landmarks, sightseeing places on the beach and in the desert, antique constructions and towns ancient artifacts, customs, and ceremonies. These are all of the major contributions to the sector giving the age and genuine quality dating back to before Christ [14].

1.5 Research Questions

This dissertation attempts to determine the best location for the construction of a new airport in Libya to serve residents up to 200 km from the closest airport in that region, with due consideration of the fact that inhabitants reside between two airports at a distance of about 600 km. Also, this airport may represent a significant investment in infrastructure and its contribution to communications can improve tourism and investments as important stimuli to regional development. Several important questions are required to meet this purpose:

- What is the survey approach to collect data (criteria)?
- What is the appropriate method for analyzing the collected data required for the study?
- What are the important elements in the process of determining the best airport location(s)?
- What is the airport's impact on the surroundings (noise, pollution, etc.)?

To answer these questions, the satellite images, local maps, and documents will be generated. These maps contain various physical attributes, environmental impact data, topographic data, and climatic data. These sets of data are analyzed using GIS because it is ideal for this kind of preliminary studies due to its ability to manage large volumes of spatial data from a variety of sources [15].

AHP and ROC are, additionally, the other two different methods used to derive the weights of criteria because AHP attempts to improve the weight assigning process as objectively as possible [16] and it is a very powerful tool to be applied to the complicated decision-making process based on multiple criteria and choices [17].
Similarly, the ROC method is more accurate than other rank-based formula as its fundamentals are simple and effective, thus being a suitable implementation tool [18].
The integration of the capabilities of MCDM with GIS tools is crucial to the feasibility of solving the site selection problem.

1.6 Structure of the Dissertation

The dissertation is delivered in six chapters, mainly in the following way:

It starts with an introductory chapter, followed by chapter 2 which provides a literature review on methods and models used to solve the issue of determination and selection of the airport site locations, along with the experts' opinions of shortcoming and drawbacks of those used methods.

Chapter 3 determines the study zone to construct a new airport based on the data collected and by applying statistical analyses, including both spatial and non-spatial analysis.

Chapter 4 deals with the collected data from a wide diversity of sources that differ in resolution or scale and is prepared by digitizing, scanning, and geocoding of the needed information. Besides, GIS methods such as intersection, union, buffering, interpolation, map algebra, and overlay were performed to prepare these maps. Also, an explanation of the used methods to derivation the weights of criteria in detail.

In chapter 5 which provides discussion and analysis, many processes will be done such as the rasterization, reclassification, and deriving the weights of the input layers, running the model to obtain the output maps result, then the comparison analysis between the two output maps generated by AHP and ROC methods will be carried out to know the percentage of matched and non-matched areas between them. Followed by performing the sensitivity analysis to assess the reliability of the method used, and lastly selecting the best site.

Finally, a business continuity study is applied from the perspective of the location to ensure the avoidance of any potential natural catastrophe. Chapter 6 wraps up the study with conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Finding a facility location is a vital decision for the decision-maker. Such a decision represents the success of the organization. Numerous technologies have been developed in this area, which has resulted in a number of methods for finding the most efficient site. Airport site selection is a strategic planning issue for the transportation system and should be addressed in accordance with the comprehensive domain of the system.

2.2 Background

Obtaining financing to build an airport is complicated, the implementation time is long, and the facility has to work for a very long time. The optimum location is determined taking into account the changing conditions that the enterprise may have to change in the future.

Facility location issues regarding the importance of travelling and arrival time have aroused interest from decision-makers and planners. The first-ever spatial survey was carried out in 1929 by Hotelling [19], who is well-known for the principle of minimal comparison, which proposes that competitive companies with technologies of transport generally head for establishing at the center of the market which involves the linear flow of goods from supplier to the other end customer [19].

Several studies have been presented to locate and choose the best solution to the airport location issue from past to present.

Bambiger and Vandersypen [20] primarily applied qualitative multi-criteria evaluation to the airport location problem, followed by Neufville and Keeney [21] who carried out studies on airport location and performed multi-attribute utility (MAU) method to evaluate two alternative airport locations nearby Mexico City. Then, Keeney [22] andHoward [23] used mathematical decision evaluation methods concentrating on airport location. Keeney used a decision analytic model to assess procedures. The attributes were modified to represent effects after some time. Probability density functions and a utility capacity were surveyed over the six characteristics (safety, cost, access time, social disturbance, noise levels, and capacity of the airport facilities).

Paelinck [24] used a conformable strategy for a multi-criteria examination with augmentations that give its results a more level realism and apply it to the instance of the area of a new airport.

Horner [3] carried out the location-allocation algorithm technique to review the location of airports and airstrips in Ireland, considered distance minimization with respect to population distribution. The author faced difficulties in collecting acceptable data, mainly inside the grid-square form required for Tornqvist.

Saatcioglu [2] used three approaches of programming models to set airport site location with various attributes for each model, the first being used to compute the least number of airports depending on the passengers' number, and the remaining two models being used to locate the optimal airport location type. Despite the approach contained several characteristics, it was constrained to a single period and single objective issue.

Again, Neufville [25] utilized a method to give insurance against risks and was associated with a strategy to deal with uncertainties. Martel [26] developed an approach based on the fixation of goals regarding each criterion introduced in the Preference ranking organization method for enrichment evaluation (PROMTHTEE) outranking method. The satisfaction function would be built by the decision maker for every deviation from the fixed goals.

Min [27] looked at the multiple and contradictory goals nature of the airport location issue. Despite the author used AHP method with cost/benefit trade-offs and performed the analysis of sensitivity, but the model therewith constrained to a single-period. Liangcai Cai [28] considered the method of AHP combined with technology systems of experts to select the location of an airport.

Min & Wu [29] commentated on de Neufville and Keeney [21] as they did not consider the potential financial profits related to each alternative, significant cost related to clean-up, restitution, insurance and time sensitivity related to cost variation volume and pollution levels. They commentate on [27] because his model was constrained to a single-period, uncapacitated location problem. To control some of those flaws, they developed a dynamic, multi-objective, mixed integer programming model and considered the criteria of cost, noise, economics and accessibility time to the airport. An optimal solution would be gained by including explicit limits which can adequately manage with capacity and financial constraints which previous approaches of MAU or AHP could not do.

Janic & Reggiani [30] found the same outcomes when applying three methods of multi-criteria decision making, including AHP, Simple Additive Weighting (SAW) and the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) on seven preselected airports as potential locations to select the new hub airport for a hypothetical European Union (EU) airline which is supposed to work in the liberalized EU air transport market. It used the same technique to define the different criteria weights for each procedure.

Kleij & Hulscher [31] studied the comparisons between alternative locations for the Amsterdam Schiphol airport. They considered the uncertainties of the information and combined the AHP and Monte Carlo rules and permitted alternative comparisons relying on ecological and morphological aspects. They used this approach because of modeling uncertainty during the assessment of the variations.

Again, Ballis [32] made a case study of airport site selection on the island of Samothraki based on the MCA technique using a new approach relying on the analysis of the relevant criteria. The author built his decision on the engineering rules of the study-team staff and the assessors of the authority involved. Then, applying the AHP method with the previously used criteria, both rules resulted in the same airport location. At every stage, there were three approvals required from local authorities, civil aviation authorities and the environment ministry. New criteria are produced in a different way to weight them.

Fiedorowicz et al. [33] applied the multi criteria analysis (MCA) method to seven selected locations to select the best location close to Warsaw. The location had the possibility of accessibility by railway and motorway, good meteorological conditions, a good air traffic network, appropriate environmental conditions, revenue of airport investment and safety and security.

Kassomenos et al.[34] also studied the optimum site of an airport on an island in the Aegean Sea in Greece using meteorological data. The methodology of three stages to investigate the issue at three scales of motion, studying the synoptic weather regimes was based on meteorological records using the computational fluid dynamics (CFD) model PHOENICS to examine the mesoscale circulations for each of the synoptic schemes. Lastly, microscale circulations were investigated via questionnaires and in situ tests.

Togatlian et al. [35] considered different types of criteria in their AHP model, infrastructure criteria (accessibility, runway length, receiving/flow off, and apron area) which are the most significant in the selection.

Wang et al. [36] constructed the index system of the model and used the expert knowledge system, followed by implementing the model of single-objective optimization and the theory of interval numbers. Then, the airport site location problem which associates to uncertain multi-attribute decision making will be solved.

Ssamula [37] performed the method of multi-criteria decision analysis (MCDA) to choose a hub airport in Africa that has a minimum cost of transport in an effective hub and spoke network. The author detected that the selection of a hub airport alternative was based significantly on the value of routing travelers through that airport.

Ding et al [38] utilized a new method consisted of multi methods, including the Delphi method, AHP rule, Gray correlation, and the Fuzzy assessment (DAGF) model. The Delphi method was used for assessment of the system, followed by AHP for weighting the matrix, the Gray correlation for analyzing the scores of experts, and finally, the Fuzzy method for evaluation of the results. The author considered this way as a comprehensive evaluation for determining the location of the airport, which was scientifically, rationally and more compatible in use.

Postorino & Praticò [39] again used the MCDM method to determine the role/position of airports inside a multi airport system. Sur & Majumder [40] used the mathematical entropy model and construction cost per person as criteria to assist the alternatives for determining the location of the airport in developing countries.

Zhao & Sun [41] applied scheme comparisons of new airport site selections by presenting the multi-objective Lattice Order Decision Making and building Lattice Order Decision evaluation index systems. They then calculated the evaluation index relative weights and determined the overall differences in magnitudes of the schemes. Belbag et al [42] eliminated the ambiguity of linguistic factors arising from uncertainty and affecting the decision-making process, using two methods of ranking methods included fuzzy ELECTRE I, and fuzzy TOPSIS, to determine the suggested airport location using the criteria of climatic, costs, geographical condition, infrastructure, social effects, potential demand, environmental, legal restrictions and regulations, and the possibility of extension.

Carmona-Benítez et al. [43] considered the airport location issue from the view of maximizing the sum of expected air passenger demand as the main factor by using the index of wealth to define air passengers' demand at every point of demand, including the economic parameters that form the marginalization index (MI), the total population and distances to every potential airport location. Carmona also commentated on de Neufville and Keeney [21] because the authors did not use the wealth index per demand point. He also criticized on each of Paelinck [24], Saatcioglu [2], Neufville [25], Min & Wu [29], and Zhao & Sun [41] as they did not consider the maximization of the expected passenger demand as the essential objective in their studies of the airport location problem.

Huang B., et al. [44] used the GIS technique to determine airport location under complex airspace by aggregating the geographic data of the complex airspace region and applying Supermap programming to establish the geographic spatial database. The airspace structure of complicated airspace zones was analyzed, and the air space structure was defined in consonance with the geographic spatial database. Then the airport location was located.

Liao et al. [45] considered the location of the airport issue as a multi-attribute decision-making problem and the decision matrix entries (crisp numbers) which express the opinion of experts would impact the precision of the outcome. They proposed a method of the triangular fuzzy number, which provided an extremely compelling approach to clarify priorities concerning the experts and establish a mathematical model to classify the triangular fuzzy number and solved it.

Yang et al. [46] used two ranking methods, namely the Weighted Least-Square Method

(WLSM) integrated with the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) method to assess the selection of airport location. The first method, WLSM, was approved by the experts to calculate the index weight and convert the linguistic variables into numerical values. The second method used was the TOPSIS method to collect those values and inspect the level of closeness to determine the ranking of alternatives.

Bo et al. [4] benefited from the multilayer fuzzy reasoning model that could move away from assessment disappointment resulting from nonsensicalness in the human mind when indicators change to multi directions.

Merkisz- Guranowska [8] offered a multi-stage way to solve the airport location issue which contained three methods which could permit more development than the existing utilized method. The first method extends the issue of location by adding criteria such as the environmental criterion and developing the genetic algorithm. The second method uses fuzzy set theory and the third evolves the proposed Min and Melachrinoudis [29] method.

Yang et al. [19] extended a quantitative technique to set optimal airport locations taking into consideration the accessibility to airports by airside and surface transportation. A structural equation model (SEM) was applied to examine the connection between the size of an airport catchment territory and its flight network scale.

Fu et al. [47] studied the state of relocating Jinzhou Bay airport in China and the expansion of the current Zhoushuizi airport from the point of view of bird collision risk (intersection between the bird’s flight paths and aircraft routes). Using the Markov chain to analyze the bird flight process and build a model for assessing bird strikes, it was found that planned relocation of the airport is preferable than the development of the existing airport because the airport relocation has a lower value of bird collision risk than the current airport plus more safety.

Hammad et al. [48] evolved an optimization model of a multi-objective (minimizing access time, minimizing noise and pollution, maximizing the coverage of the airport), They applied Mixed-integer linear programming (MILP) model to solve the issue which was formulated as a bilevel program.

Sennaroglu et al. [49] performed a study to select the best location for the military airport among several candidate locations using MCDM methods. AHP technique was used to determine the criteria weights. VIKOR, PROMETHEE, Multi- Attributive Border Approximation Area Comparison (MABAC), Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA), and Complex Proportional Assessment (COPRAS) methods were used for the ranking process. After the comparison of the result, they found all methods provide the same result.

Lastly, Zhao et al. [50] focused on the importance of bird ecological conservation when selecting an airport location by avoiding the construction of an airport on bird migration routes. They carried out a study to decide either extension for the existing airport or relocate to the planned one. The authors assessed the effect of the two airports on the birds' environment using the AHP approach to derive the chosen criteria weights and an expert-based approach to evaluation. The overall environmental impact assessment showed that the planned airport was a favorable choice because it had less impact on the birds' environment.

2.3 Methodology

In this chapter, searches were performed in English language scientific journals for the period between 1969 to 2019 using the science search engine for all databases and only for titles about airport site selection and all papers containing other facilities were ignored. All collected papers were classified according to the year of publication, as shown in Figure 2.1.

All papers were classified according to the methods of determining airport location which giving 42% using the mathematical methods and 58% using the ranking methods, as indicated in figure 2.2.

By determining the used criteria in all gathered papers and classifying them to get the most recurrence provides us with an indicator of the most important criteria (Figure 2.3).

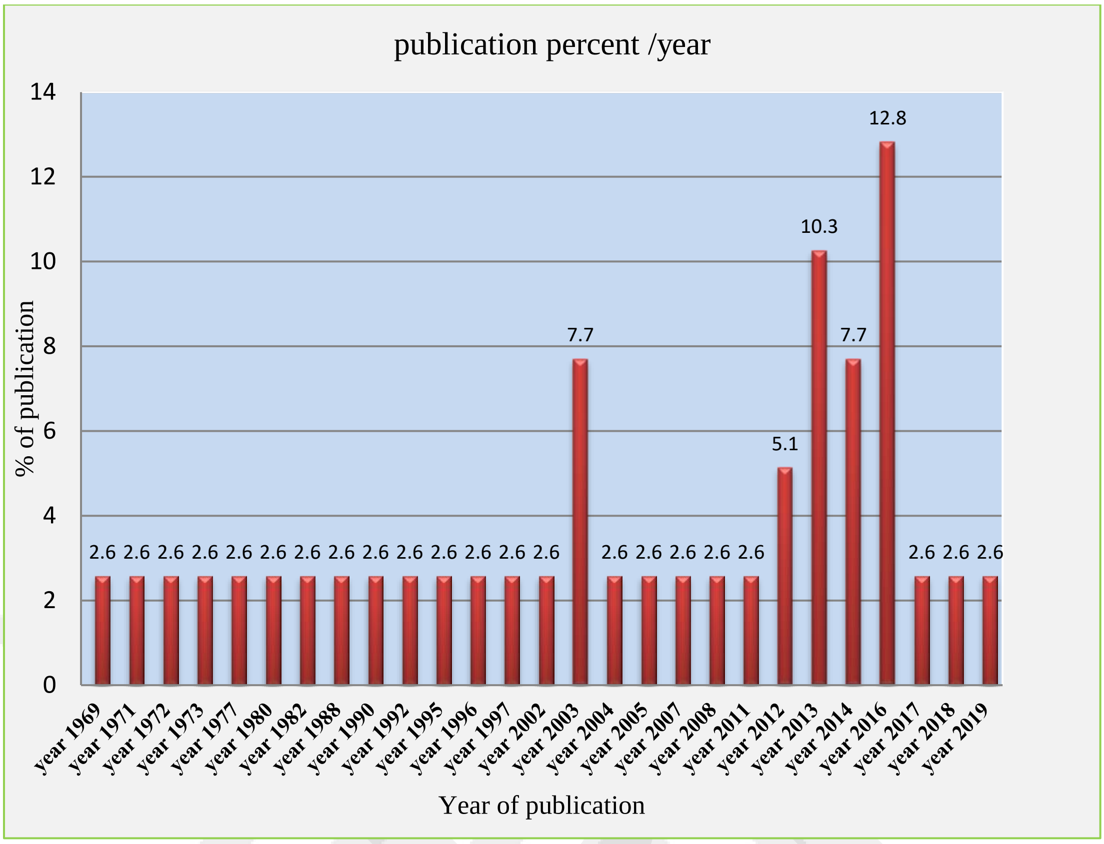


Figure 2.1 Percentage of publication of papers / year

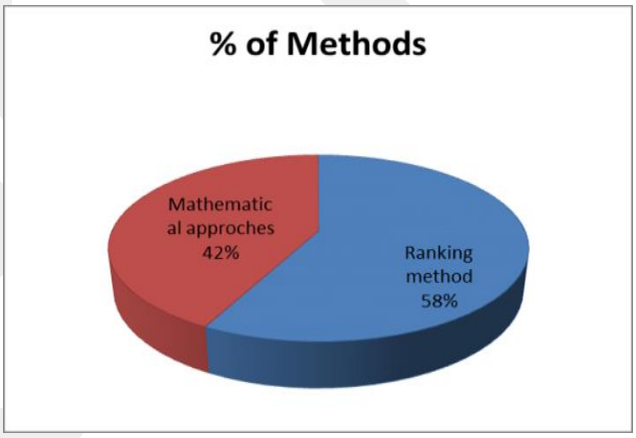


Figure 2.2 Percentage of each method used

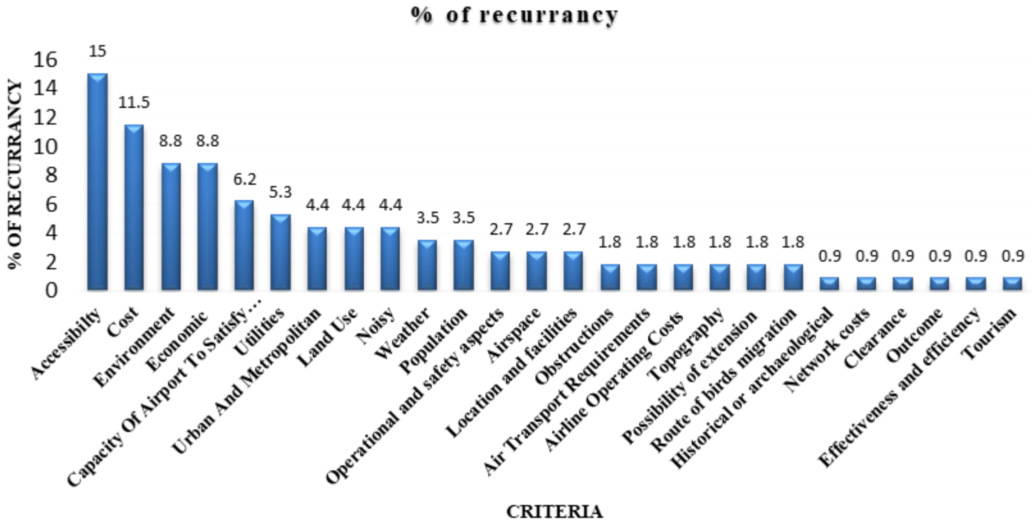


Figure 2.3 Recurrence percentage of each criterion

2.4 Discussion

From the literature review above, the objective is to determine the best location of an airport in a given region by evaluating selected potential locations. This assessment includes the consideration of multiple criteria including the specific characteristics of the area that will accommodate the airport construction.

Some of these criteria become higher in weight in relation to other criteria [32]. Some researchers utilized a single criterion, such as meteorological factors [34], bird collision risk [47], [50], the cost of construction of airport per person [40] or a bi-criterion such as the cost of the airport per person and the cost of buses between cities [2], landside and airside accessibilities [19] as well as multiple criteria, such as cost, noise, economic and accessibility time from communities centers to the airport [29].

Although many authors use one criterion in solving the airport location problem, they acknowledge that they should not be the only criteria taken into account for decision-making, and there must also be other criteria [31], [34].

From the literature above, two different methods of solutions relating to the issue of airport location were defined, namely a ranking approach (factor assessment) and an optimization approach (mathematical approaches).

The former includes selection of the best site among several preselected sites and the latter approach entails finding the best site in a particular region where no preselected sites have been determined [8], [19].

For the ranking approach, the methods of MCA and AHP are often utilized to choose the location of a facility, and sometimes a combination of two or more techniques are implemented, such as the AHP and Monte Carlo approaches [31], AHP, SAW and TOPSIS [30], the Delphi method and AHP [38], fuzzy TOPSIS and fuzzy ELECTRE I [42], and WLSM and the TOPSIS Method [46], and AHP, VIKOR, PROMETHEE, MABAC, MAIRCA, and COPRAS methods [49].

For the mathematical approach, it is often for maximization of profit or minimization of cost [19]. Mathematical approaches include defining several functions of the objective with several frequently conflicting criteria, the large majority of which are to be done by PC programming. For example, airports are considered to be semi-obnoxious and semi-desirable facilities [8], [51]. For further explanation, the cost objective obviously conflicts with the objective of access time and the objective of noise exposure, which clashes with the economic effect objective [29].

In the literature, similarly to the ranking approaches, several mathematical approaches to modeling were used to solve the airport location problem, including the simple gravity model [52], the location-allocation algorithm [3], mathematical programming models [2], dynamic, multi-objective and mixed integer programming model [29], the mathematical entropy model and entropy optimization method [40], the maximum coverage location model [43], and a mixed-integer linear programming (MILP) model [48].

2.5 Drawbacks

From the literature above, some drawbacks were found in both approaches, as summarized as follows:

- In ranking problems, it is mainly to preselected the potential locations of airport which are to be subsequently evaluated, despite it being possible to unintentionally overlook some potentially better locations [8].
- In the optimization issue, the criteria being used seem to be limited. The most criteria considered are the distance to the airport and the population size [8].
- Objective analysis and subjective judgment are the main components of the

methods which require weighted computation. The drawback of subjective judgment is that it is too dependent on the experience of experts. On the other hand, the disadvantage of objective analysis is that the experts' experience and knowledge is disregarded and the results which are obtained through computing devices may deviate from the actual [41].

- The crisp number of the decision matrix does not express the experts decision of therefore, the precision of the decision will be weak [45].
- Applying the AHP method requires checking the consistency index (CI), which is influenced by expert subjective judgment so as to check the degree of consistency [46].
- In models using grids, the disadvantage is that it cannot ignore grids which are not suitable for an airport location due to geographical factors such mountains and buildings, etc., or considerations of urban density such as proximity to densely populated areas [19].

2.6 Conclusion

Finding a facility location is a vital decision for a decision-maker. Such a decision represents the success of the organization. Numerous technologies have been developed in this area, resulting in several methods of finding the most efficient site. To overcome the disadvantages of the above methods and to improve the quality of resolving the airport location issue, GIS technique is widely used as a major tool for spatial analysis, planning, and management because it is a powerful tool in integrating programs and a large volume of non-spatial and spatial data from different sources in the analysis and planning process and using multiple criteria in decision making [15]. In addition to GIS is a useful technique in case of a scarcity of resources and insufficient or inaccurate data needed. Using GIS participates as the prime decision tool for selecting environmentally, geographical, and economically viable sites, making use of huge quantities of non-spatial and spatial data associated with various economic, technical, environmental, and social criteria.

To obtain the weights of criteria maps and use them within the GIS to determine an appropriate location for the airport, many methods of multi-criteria decision-making may be used. AHP and ROC are examples of such techniques. Thus, the integration of GIS and MCDM extremely facilitates the decision-making task [53].

CHAPTER 3

STATISTICAL ANALYSIS

3.1 Introduction

Oftentimes, site selection begins using several stages, it begins with the use of spatial analysis to known some of the information and characteristics of the study area and minimize the examined area to a manageable number of discrete search areas. Because of this analysis, the resulted areas have higher probabilities to contain suitable sites. The resulting zones are more likely to accommodate the right site qualities. Next, these zones are assessed more intricately to choose the best ones. Lastly, these shortlisted zones are examined following pre-determined and site-specific parameters to single out the most appropriate one for airport construction.

All this, naturally, implies that the entire process is intensive as narrowing down continues. Such a stage-by-stage approach is quite common for choosing the right spot due to straightforwardness and the economy of time and financing. What’s more, and mostly in developing countries, the absence of the right information and pre-requisites to choose a location quickly lead to directions where the phased approach is the best available solution. [54].

3.2 Spatial Statistics

Spatial data are obtained using investigatory methods to define and modeling spatial distributions, models, operations, and relationships. Despite its closeness to conventional statistics, such data also accommodate measurements, where closeness plays an important role; that is, items in proximity tend to be more connected as well [55].

The GIS, in this respect, regards the study such data as a discipline applying space-related parameters like distance, area, volume, length, height, orientation, centrality, etc., as they are within calculations [55].

Spatial statistics attempt to provide solutions to these inquiries:

- What are the attributes of distribution patterns?
- What models are shaped according to the features?
- Which are the clusters?
- How do patterns and clusters of different variables compare to one another?

Notice that:

Attributes mean non-spatial data about a geographic feature its name, length, etc.

Features means a single entity that has both geometry and attribute data such as polygons, lines, or points.

Cluster means the collecting of points so that the distance between the points within the clusters is minimal.

The spatial pattern means: the patterns which work with both the distributions of attributes and the spatial configuration of the locations.

To provide answers, the present chapter will employ ArcGIS tools to provide us with the fundamental spatial data related to the dataset as listed below:

3.2.1 Measuring Geographic Distributions

- Calculating geographic centrality using the tools related to central attribute, mean center, and median center.
- Calculating the level of concentration or scattering among the attributes against the geometric mean center using a standard distance tool.
- Shortlisting spatial attributes of geographic items as central tendency, dispersion, and directional patterns by applying the directional distribution or standard deviational ellipse tools.

3.2.1.1 The Central Feature

Locates the most central feature against a point, line, or polygon feature class by adding up the spaces among the items or features and singling out the shortest distance between the features as the focal or central item. In this way, a final group of features can be obtained with only one feature that considers the most centrally located one.

3.2.1.2 The Mean Center

Measures the focal geographic point concerning a series of features which, in turn, can be assigned weights using a numeric field. It shall be pointed out that outliers are likely to change the mean value significantly.

3.2.1.3 The Median Center

Locates the location among a group of items to reduce at most the average Euclidean distance from the items or features within the set of data. In contrast with the mean center tool, this one is not affected by outliers.

It has to be pointed out that the difference between a mean, median, and the central feature is the following:

- The mean identifies the geographic center (or the center of concentration) for a set of features.
- The Median determines the location that minimizes overall Euclidean distance to the features in a dataset.
- The central feature identifies the most centrally located feature in a point, line, or polygon feature class [56].

3.2.1.4 The Standard Distance

Computes the level to which features are concentrated or scattering around the geometric mean center. It shows the concentration or scattering of data. The resulting circle generated can be explained using standard deviation to accommodate up to three standard deviations. Commonly, the bigger this circle is, the larger the level of scattered data becomes.

3.2.1.5 The Directional Distribution

Otherwise known as the standard deviational ellipse tool, it develops such curves to wrap up all spatial attributes related to the geographic features – among them, central inclination, distribution, and directional patterns.

These ellipses centered at the mean center, while the tool measures parameters as directionality, centrality, and dispersion.

This tool is an improvement over the standard distance one, in the sense that it can generate an ellipse to calculate the directional trend in the data along with the central tendency and scattering [55].

3.3 Analyzing Patterns

The Analyzing Patterns toolset is utilized to assess if features or the values concerning features form a clustered, scattered, or arbitrary spatial pattern (see Figure 3.6).

In this way, one outcome can be obtained for the whole dataset at hand. Hence, applying this tool to decide whether the available dataset is dispersed or clustered as explained below:

3.3.1 Average Nearest Neighbor (ANN)

This tool calculates the distance among features' centroid and their closest neighbor's, later to obtain a mean value for all the values to be compared in relation to the expected average for the distance. The outcome is an ANN ratio representing the value related to what has been observed and what was expected. Lower than 1 implies clustering, and exceeding it means a scattered trend [57].

3.3.1.1 Null Hypothesis

Because of all the pattern analysis tools are operated upon assuming that features or the values concerning those features are arbitrarily distributed. It is identified as Complete Spatial Randomness (CSR) and, hence, considered as the null hypothesis used with all the ArcGIS spatial statistics tools.

The pattern analysis tools return z-scores and p-values, which indicate whether the hypothesis may be accepted or not; in the latter case, the data is determined to be either considerably clustered or dispersed by the statistical pattern.

3.3.1.2 P-Values

These represent degrees of likelihood at which arbitrary operations can generate the spatial patterns as detected. P-values range between 0 and 1 and less show that the spatial value is non-arbitrary. A confidence value may be applied to different p-values, as revealed in Table 3.1.

Table 3.1 P – Value and Confidence Level

P- value (Probability)	Confidence Level
< 0.10	90%
< 0.05	95%
< 0.01	99%

3.3.1.3 Scores and Standard Deviation

Z-scores represent standard deviations indicative of the number of deviations as the scale based on which a given element is close to the mean. Accordingly, 0 implies that the element is equal to the mean; 2.5 implies 2.5 deviations distance. There is both the likelihood of positive and negative values. Table 3.2 in the following lists the z-scores associated with confidence.

3.3.1.4 Types of Distributions

Random: this means that all points may appear arbitrarily, and that these locations are independent and not subject to others.

Table 3.2 Z – Score and level of confidence

Z- score (Standard Deviation)	Confidence Level
< - 1.65 or > + 1.65	90%
< -1.95 or > + 1.95	95%
< - 2.58 or > + 2.58	99%

Uniform: implies that points are at the likeliest remote distance from other neighbors, and that proximity is not probable.

Clustered: it means that numerous points are gathered in one area, with the likelihood that certain regions still have a very low number of points within them, if any, points: “unlikely to be distant”.

Typically, the z-scores and p-values are analyzed together. In general, very high or low z scores plus small p-values will allow us to consider rejecting the null hypothesis. See Figure 3.1.

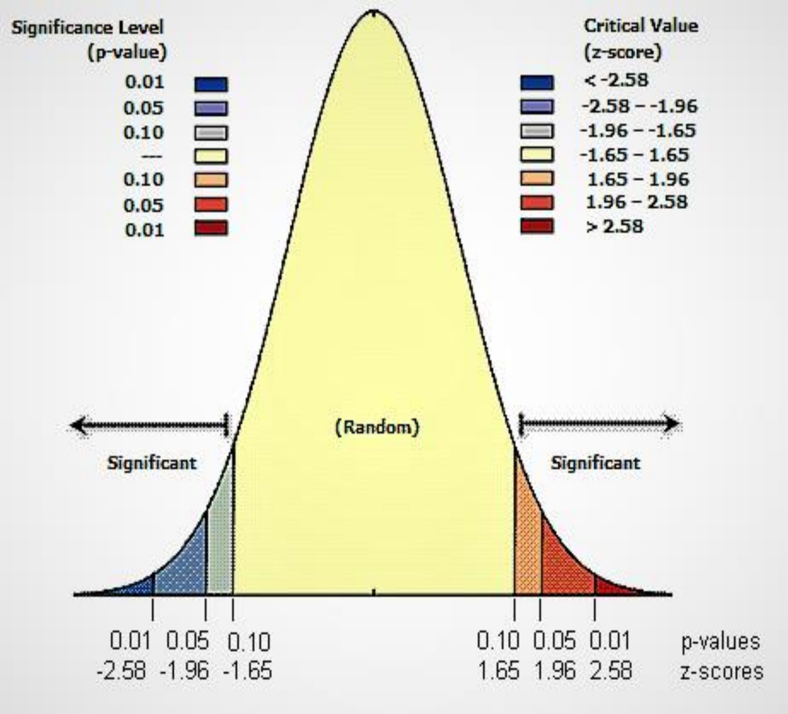


Figure 3.1 P- value and Z- score

(Source: ArcMap GIS 10.5)

3.4 Spatial Analyst Tool

3.4.1 The Linear Directional Mean

Determines the mean direction, length, and geographic center for a group of lines, and the result of this tool is a feature class with a single linear feature [58].

3.4.2 Point Density

Estimates the density of point features surrounding each output raster cell. A neighborhood is defined around each raster cell center and the number of points that locate in the neighborhood is summed and divided by the neighborhood area [59].

3.4.3 Line Density

Measures the density of linear features within an area the output raster cells, and expressed as length unit/area unit [60].

Noting that the rasters are imagery from satellites or scanned maps. A raster comprises of a matrix of cells coordinated into a grid where each cell contains a value which representing information.

3.5 Area of Study

Libya is in North Africa and has a shoreline at the Mediterranean Sea, with neighbors as Egypt, Sudan, Chad, Niger, Algeria, and Tunisia. Its area measures 1,759,540 Sq.km, the 4th biggest in the continent and 17th worldwide. Libya, in a sense, bridges North Africa and the Middle East with its rather flat land, the largely population-free Sahara Desert, and Mediterranean coastline as the most outstanding features.

There are about 6818624 people in Libya – that is, 0.09% of the entire population of the world. It stands 108th in terms population, with about 4 residents per square kilometer, making it 188th as regards worldwide population density [61]. More than 75% of the citizens reside whether in or in the neighborhood of cities, which are numerous but mostly accommodate no more than a million heads.

Tripoli, the biggest, is the capital, followed by Benghazi with about 661689 and

Misrata with 511157 residents and serving as the financial and business hubs of the nation, respectively.

The present chapter includes the GIS analyses of spatial distribution related to cities, airports, roads, and residents. As stated earlier, GIS can be used to comprehensively tackle many issues related to geography and conduct spatial analyses along with other database systems.

For our purpose, we will use the information related to the cities and their position, residents, available domestic and international airports, and the road networks to construct a geo-database related to the region under study. Once processing is completed, we will apply the statistical and spatial analyses.

Applying the spatial and statistical analysis of GIS to know some of the information and characteristics of the study area and minimize the examined area to a manageable number of discrete search areas.

Thus, the resulted areas have higher probabilities to contain suitable sites. Besides, determining the region which has residents and, yet, no airport close to it.

3.6 Data Used for Analysis

3.6.1 Population

The population traditionally reflects the inherent strength of a region (or country) as a source of potential air transport demand [30]. The size of a given community and its distance from the planned site are important factors [8]. The population data surface can be, at the very least, highly beneficial in the initial assessment of the relative merits of particular sites and strategies [3].

3.6.2 Cities

The city of the population is available within specified distances of particular points. They are relevant to any problem where the major issue is the choice of location, the size of the catchment or support population, and accessibility [3].

3.6.3 Existing Airports

Locating the position of the existing international and domestic airports is important in determining the need for a new airport. The identification of a multi-airport system is usually based on the volume of handled passengers and the distance between airports and the main cities [39]. Horner [3] used the techniques developed by Tornqvist to be applied to reviewing the present and potential locations of airports with catchment populations and accessibility measures.

3.6.4 Accessibility (Roads Network)

The airport site should be close to travelers so that air transport can attract more passengers [45]. The distance constitutes the decisive parameter as the shortest distance between the demand-generating point and the one that provides supplements more effectively. Numerous investigations, applying the Stated Preferences data, have revealed that the selection of an airport by travelers relies on whether it is primarily reachable by roads and highways [39], [62].

3.7 Data Collection

The required data was compiled from several resources as indicated in Table 3.3.

Table 3.3 Sources of data

Data	Resources
Populations	[63],[64], [65],[61]
Airports	[66], Google earth pro
Cities	Google earth pro
Road network	[67]

3.8 Data Preparation and Analysis

This section comprises data processing, coding, entry, and application to form digital maps and tables with the help of the ArcGIS 10.5 software:

3.8.1 Determining the Cities Within the Study Area

At this stage, data is handled related to all cities within the study zone for their exact position and number of residents, Accordingly, there are about 82 cities in total, with over 75% of the entire residents living in the north of Libya and proximity to the shoreline (See Figure 3.2).

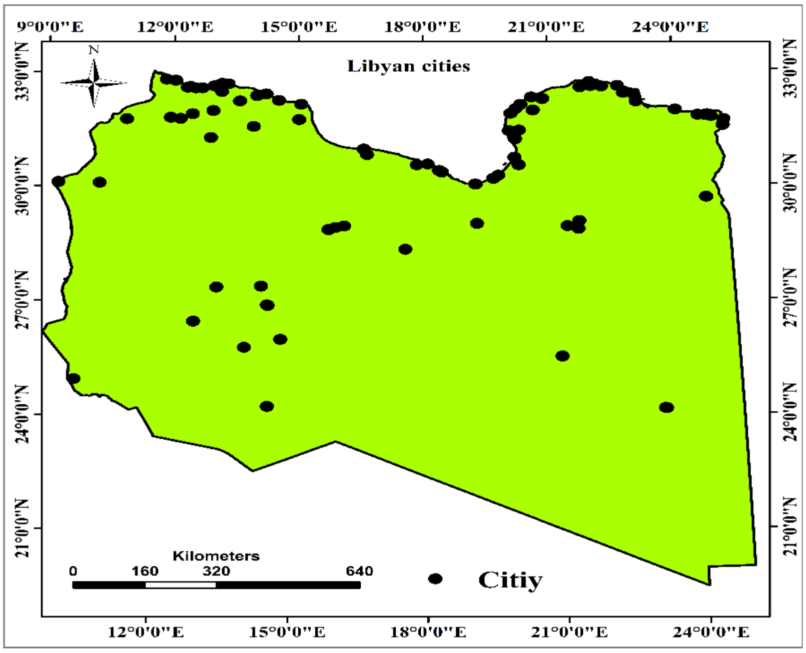


Figure 3.2 Libyan cities distribution

To measure the geographic distributions of the city, spatial statistics analysis was conducted as the following:

3.8.1.1 Central Feature, Mean Center, and Median Center

The spatial mean center of cities is measured by calculating the average coordinates of x and y of all cities. It is useful to detect any changes in distribution or, alternatively, compare the related features [68]. The calculations are as in Equations 3.1a and 3.1b below:

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{3.1a}$$

$$\overline{Y} = \frac{\sum_{i=1}^{n} y_i}{n} \qquad (3.1b)$$

Where x_i and y_i are coordinates for i, and n is the total number of cities.

The median identifies the location by minimizing the overall Euclidean distance to the cities in a dataset.

The central feature identifies the most centrally located city.

Applying the three analyses mentioned above, we obtain the locations as indicated in Figure 3.3. From the obtained result, it can be seen that the mean, median, and central are located close to one another, which means the outlier cities do not affect the location of the mean center of the cities. The coordinates appear in Table 3.4.

Table 3.4 Coordinates of Geographic Distributions

Analysis type	Coordinates	
	X-Coordinate	Y-Coordinate
Mean	1054242.93	3400036.50
Median	1101877.27	3404691.41
Central	1103575.67	3397561.70

3.8.1.2 Standard Distance

This value is an indicator of the level at which cities appear together or scattered around the geometric mean center, as depicted in Figure 3.4. The standard distance represents a circle with a radius equal to 489,192 m and contains about 67% of the cities inside the circle. It can be seen that there is a high concentration of cities around the standard distance along the coastal strip.

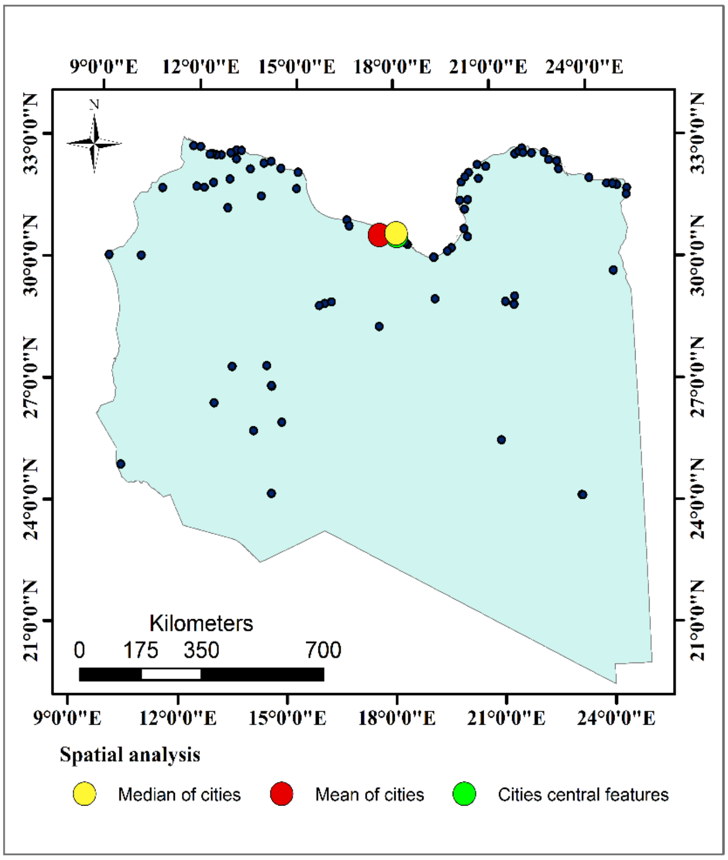


Figure 3.3 Location of Mean, Median, and Central of cities

3.8.1.3 Directional Distribution (Standard Deviational Ellipse, SDE)

Applying the standard deviational ellipse analysis, we can conclude all the geographic spatial characteristics of cities, namely directional patterns, central inclination, and scattering as per Figure 3.5 depicts. In this thesis, SDE is conducted out to analyze quantitatively on the orientation of the cities to determine the manner and extend of residents' distribution over the area in question. These measurements are carried out using Equations 3.2a and 3.2b below:

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}} \tag{3.2a}$$

$$SDE_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^{\ 2}}{n}} \tag{3.2b}$$

According to Table 3.5, the X- distance is much larger than Y- a distance which means the distribution of cites is higher in the direction of X – with the rotation of northeast and southwest with an angle equal to 86.34 and 273.66, respectively.

Table 3.5 The obtained result of directional distribution analysis

Center X (m)	Center Y (m)	X- Distance (m)	Y- Distance (m)	Rotation
1054242.93	3400036.50	587130.34	365917.78	86.34

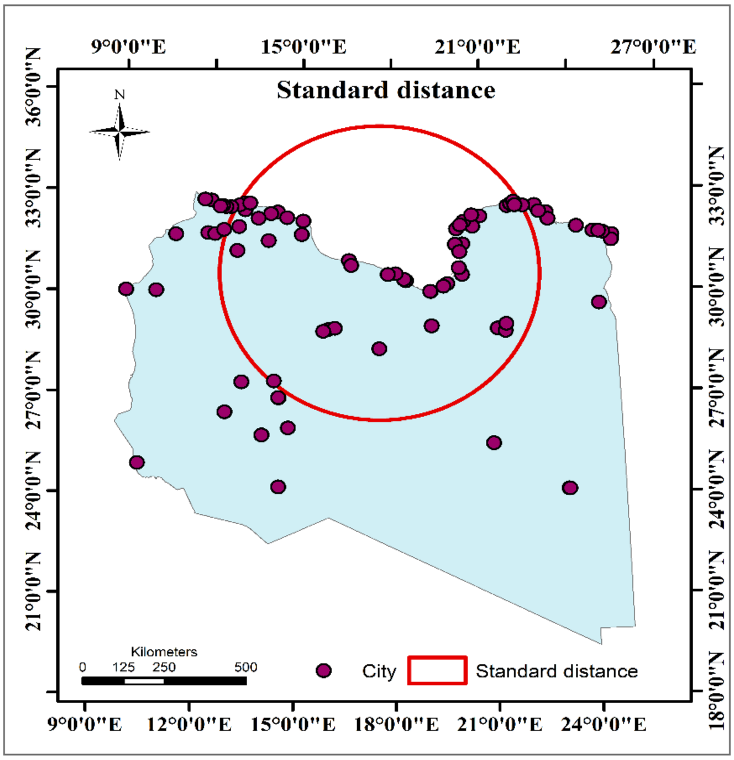


Figure 3.4 Standard distance for all cities

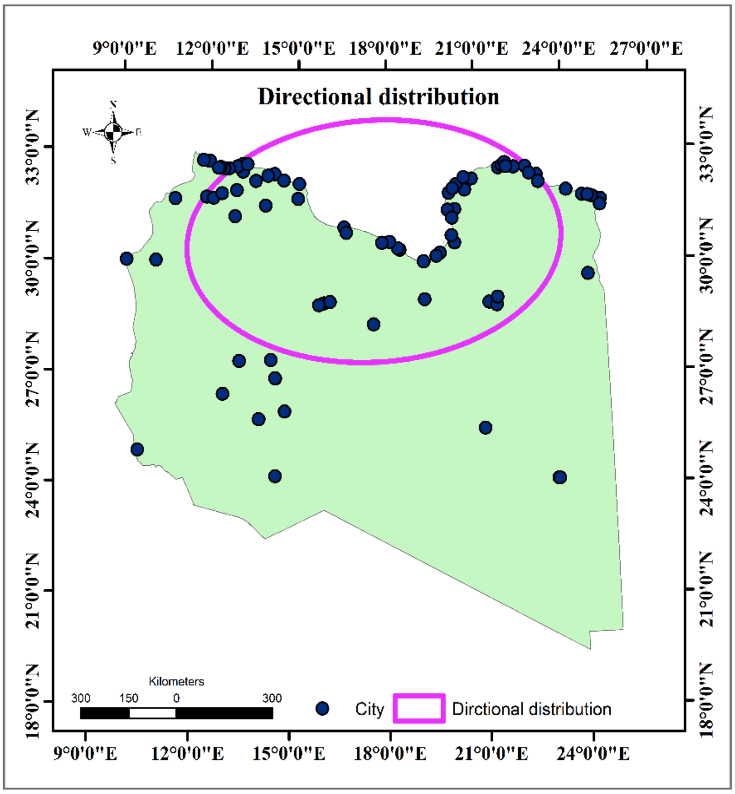


Figure 3.5 Directional distribution (standard deviational ellipse) of cities

3.8.1.4 Analyzing Patterns

Average Nearest Neighbor Distance tool (ANN) is used to calculate the distance between each city centroid and its closest neighbor's centroid position, after that averaging all these nearest neighbor distances values [57]. The ANN ratio implies the observed mean distance divided by the expected mean distance. Since the observed value is 41794.52 m, and the expected mean distance value is 73242.41 m, the calculated ANN ratio equals 0.571.

According to the statistical explanation, as the value is less than 1.0, then the pattern is considered as clustered. Referencing to Table 3.1 and Table 3.2 for z-score and p-values, it can be stated with 99% confidence that this pattern is not random (see Figure 3.6). Since the pattern of cities is significantly clustered, it may make sense to construct an airport in each cluster or to construct it in the middle of all the clusters.

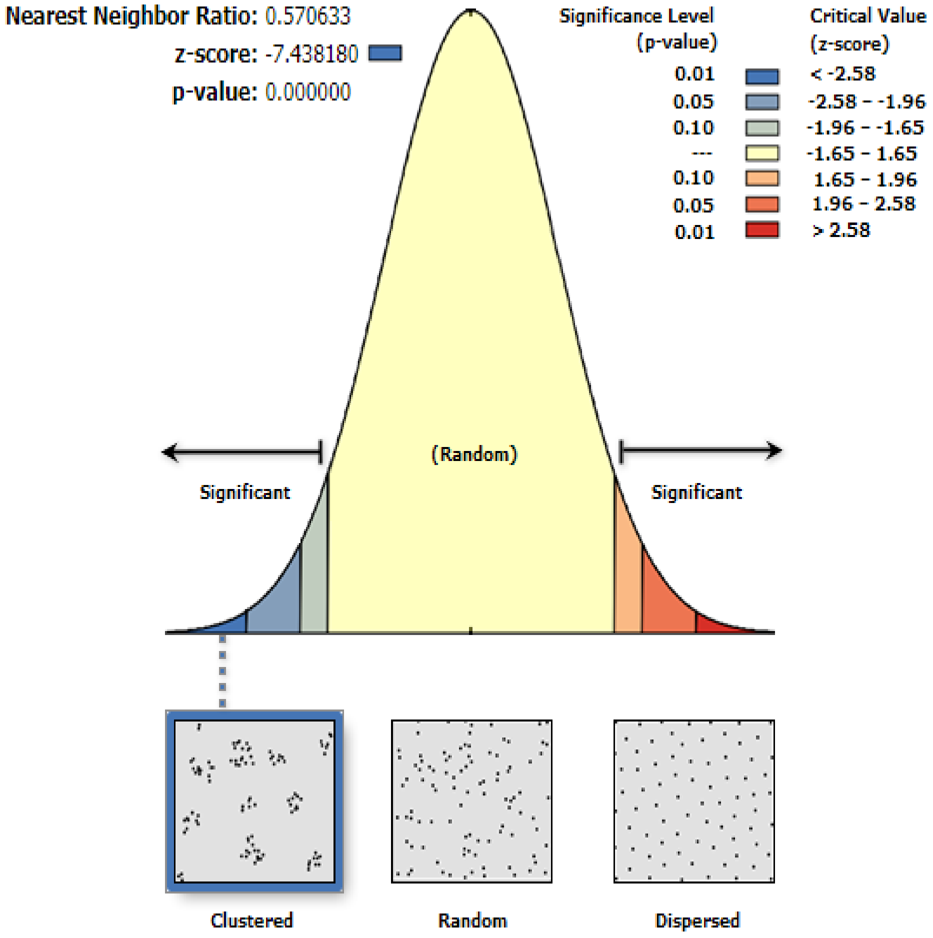


Figure 3.6 Average nearest neighbor result

3.8.2 Population Data

As stated earlier, the population of Libya is about 6818624 based on the latest data released by the United Nations. This is equivalent to 0.09% of the total world population (see Table 3.6). Despite its vast area, more than 75% of the population is concentrated in the northern regions along the sea coasts [69]. Figure 3.7 illustrates the population density in each city with different colors and sizes. Also, Figure 3.8 shows the dispersion of the population represented as dots. Accordingly, more than 90% of the country is desert with very low population [70].

Table 3.6 The statistical data of population

Count of cities	82
Minimum number of inhabitants	1521
Maximum number of inhabitants	1170555
Sum of inhabitants	6818624
Mean	83154
Standard Deviation	164796

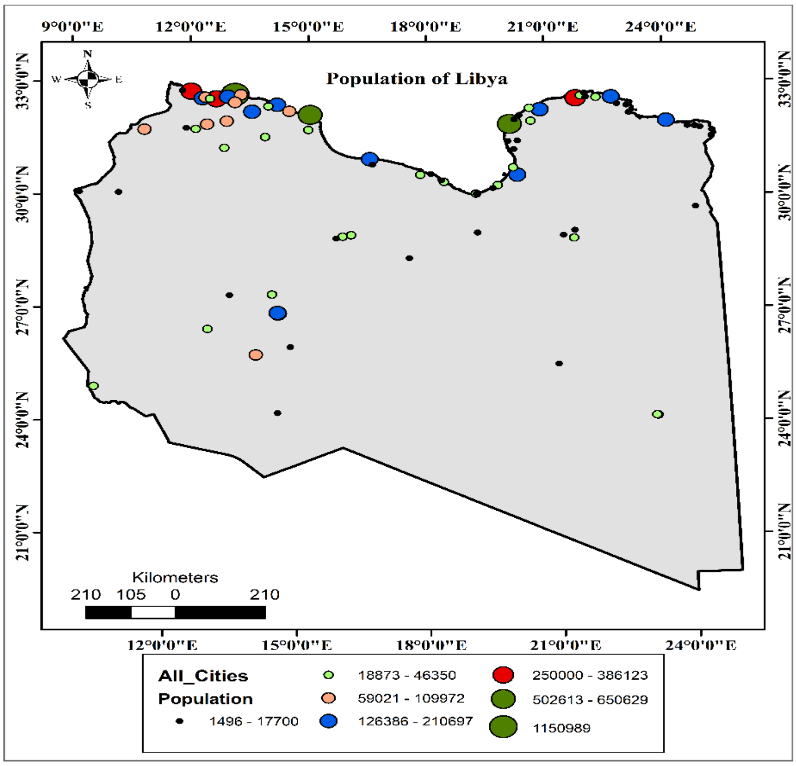


Figure 3.7 Gradation of the population

3.8.3 Airports Analysis

According to the Libyan Airports Authority, the number of operating airports reached 21, including 10 international airports and 11 domestic airports. Figure 3.9 below shows the location and type of each.

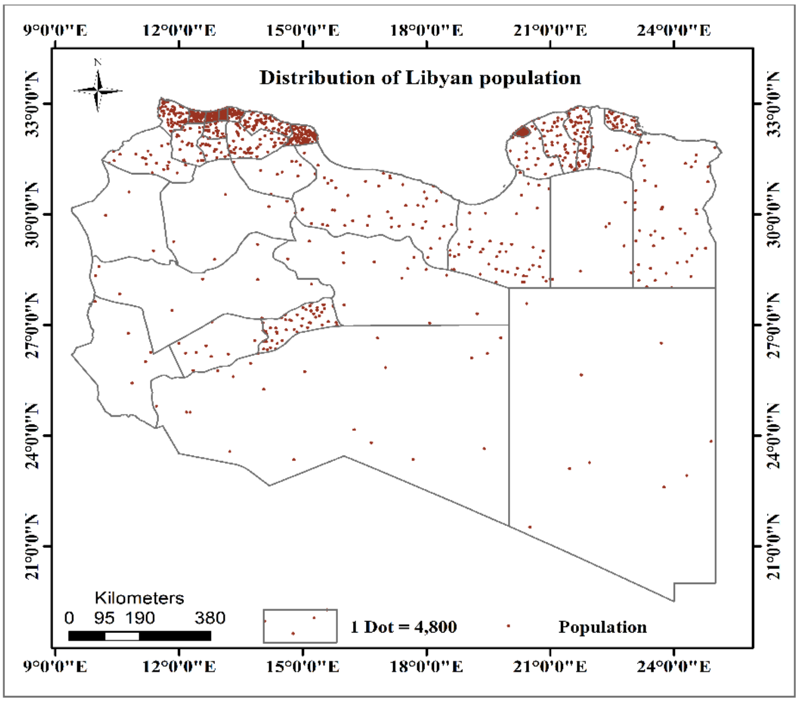


Figure 3.8 Population distribution by dots

3.8.3.1 Airports Mean Center

Figure 3.9 shows the location of the mean center of airports with the shortest average distance from all other airports.

3.8.4 Accessibility (Roads Networks)

In general, the network density of roads in Libya is sufficient, estimated at about 34,000 km of paved routes, from which 15,500 km is of the main highway, and 18,500 km as secondary and agricultural roads; still, there many routes that have no asphalt, and the main expressways along the shoreline or heading southward converge to form one-lane tracks as they leave the main towns. Consequently, they can be congested and hard to travel by, particularly in nighttime and rainy days.

Adding to these complexities are layers of sand carried on the wind, and farm and wild animals often attempting to pass across the main roads and those in the countryside[71].

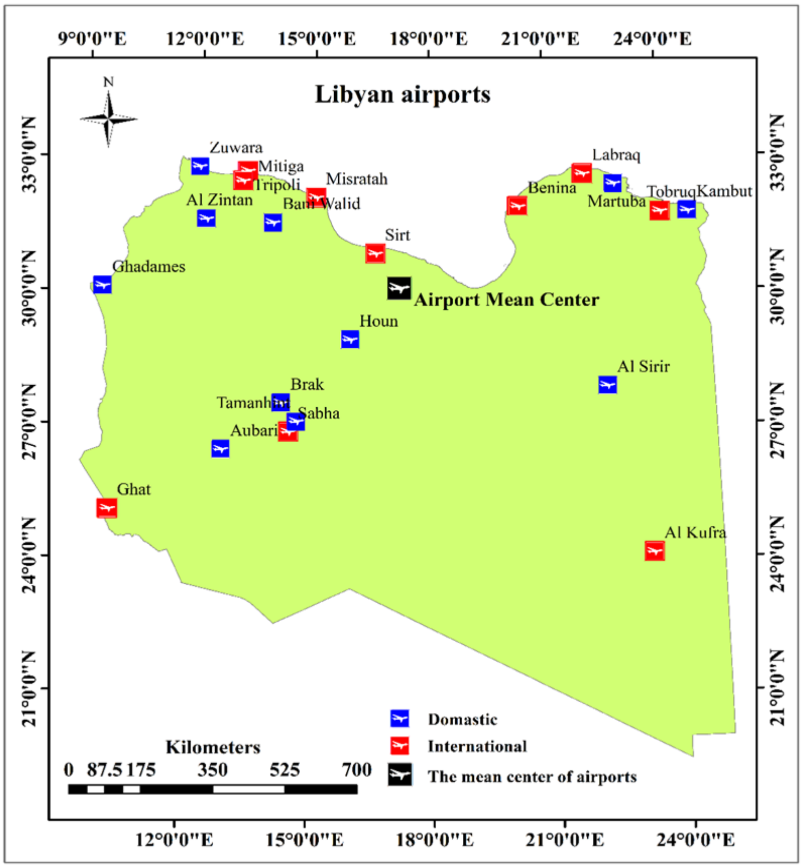


Figure 3.9 Libyan airports

3.8.4.1 Line Density Analysis

Performing the analysis of the line density tool, the density of roads per unit of area is demonstrated in Figure 3.10. The heavy density of roads that has a blue color is mostly located in the north strip, where there is a high percentage of the population.

3.8.4.2 Linear Directional Mean Analysis

In this analysis, measuring the trend for roads is carried out by calculating the average angles. The Linear Directional Mean tool identifies the mean direction or the mean orientation for a set of roads. For the Libyan system of roads, the linear directional mean is east-west, with an orientation angle equal to 91.33441 from the north. See Figure 3.11. It is obvious that the linear directional mean is pointed to the direction where there are a high population and traffic.

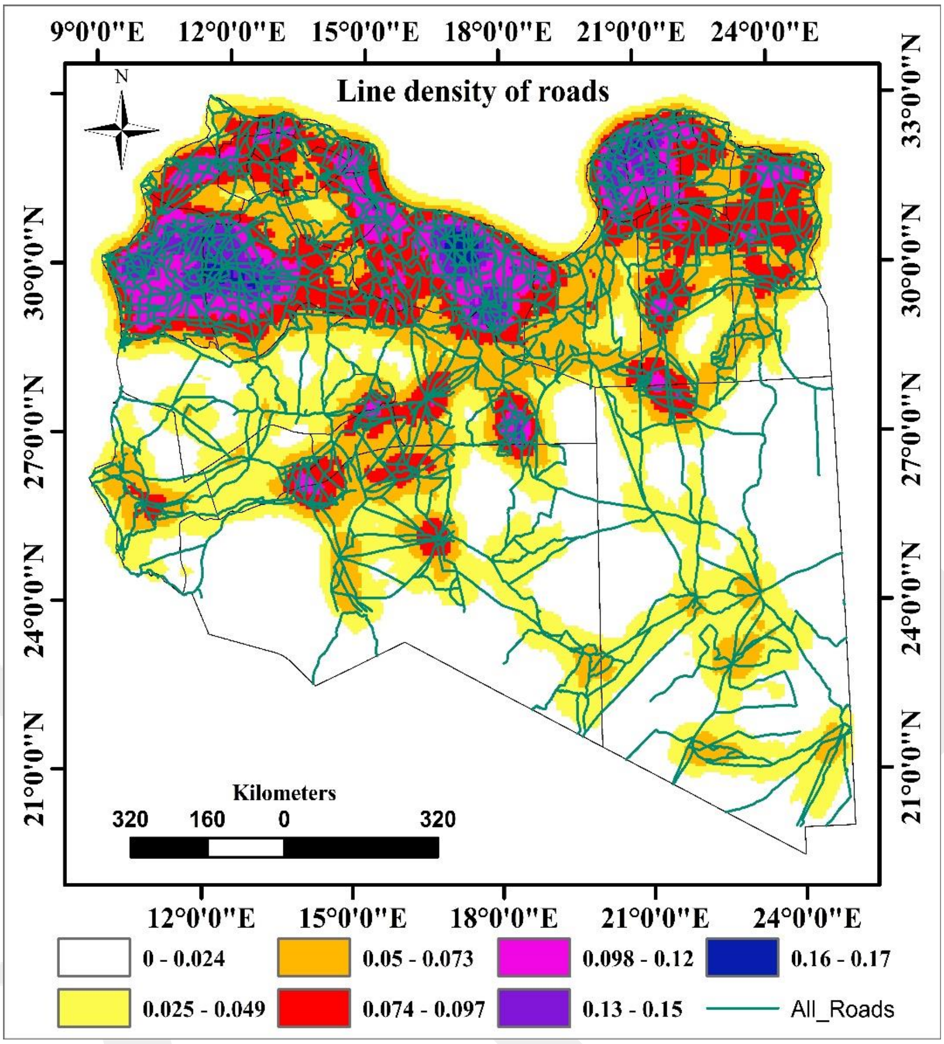


Figure 3.10 Line density analysis for roads

3.9 Determining of the Suitable Area

From the previous analyses, the obtained results appear in Figure 3.12, bringing to attention that the region with the most important characteristics is located just mid-north and nearest to the coastal strip.

The mean center and median were close to each other, which means the outlier cities did not affect the location of the mean. Additionally, the standard distance with one standard deviation contains about 67% of the cities concentrated and distributed around it in the coastal strip.

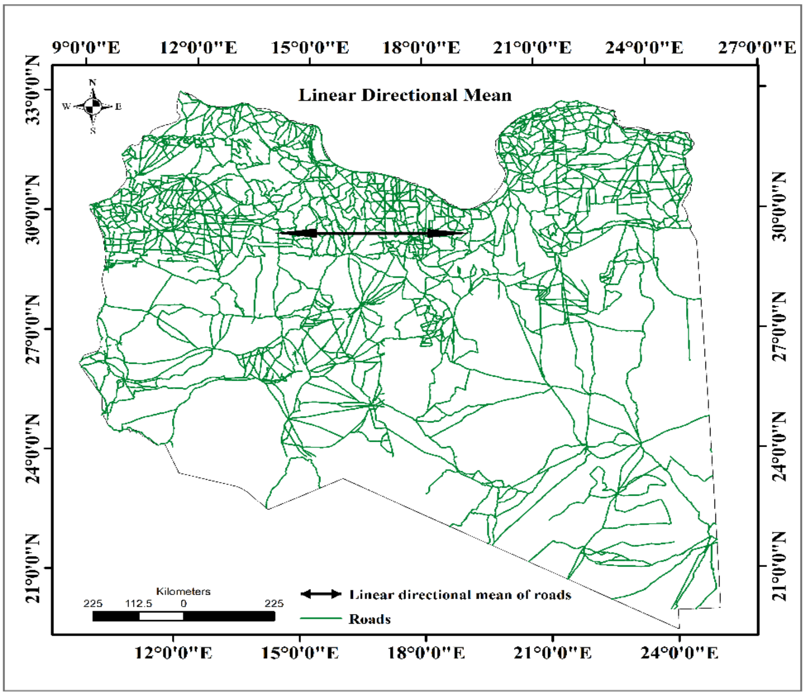


Figure 3.11 Linear directional mean for roads

The directional distribution (standard deviational ellipse) with the X-axis is much larger than that with the Y- axis, thereby implying that the distribution of cities is higher in the direction of X – with the rotation of northeast and southwest with an angle equal to 86.34 and 273.66, respectively.

The analyzing patterns toolset shows that the cities are within a clustered spatial pattern. Then, it makes sense to either construct an airport in each cluster, or to construct one at the center of all the clusters.

The total number of civil airports was 21, including 10 international airports and 11 domestic airports.

The mean center of international airports is near the location of the mean center of all cities.

The density of road networks is concentrated in the northern region along the coastal road, as indicated in Figure 3.12 with green color. Also, the linear directional mean of major roads is east-west with an orientation angle equal to 82.83 degrees from the north.

To examine the sufficient number of existing airports and the possibility of finding an additional location of airport to cover the shortage if there is, by considering each

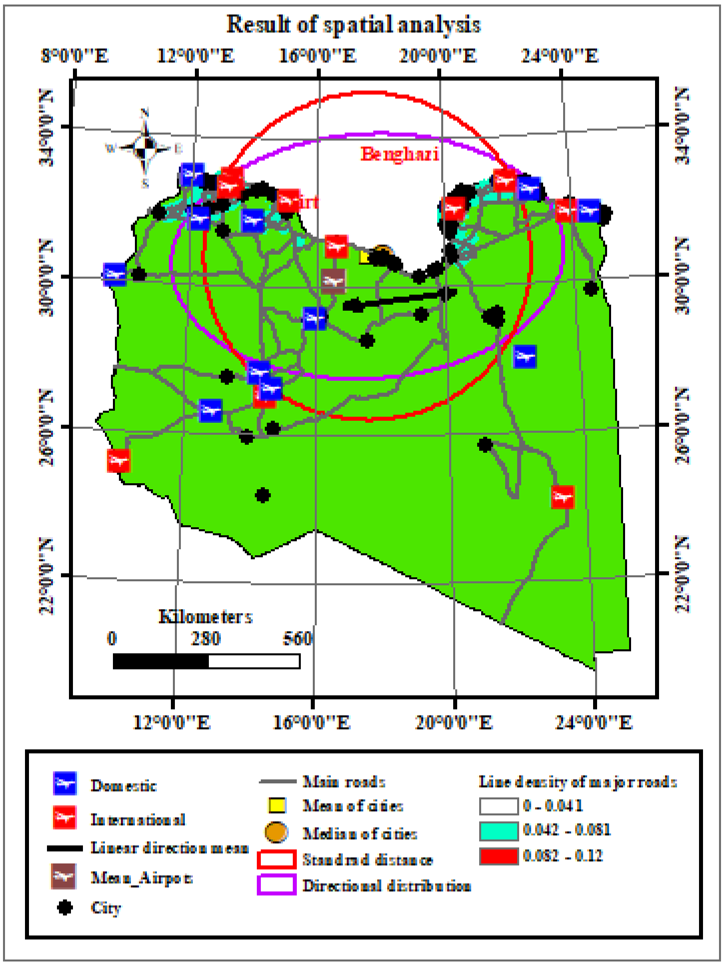


Figure 3.12 All results of spatial analyses

existing airport to serve the surrounding area with a radius of about 150 km [39]. Input layers of population, cities, and airports were prepared, then applying GIS software according to the following steps:

a) Apply a buffer zone command from the ArcMap GIS analysis toolbox for every airport with a maximum radius of 150 km to cover all surrounding cities as indicated in Figure 3.13.
b) Using the “erase” command from the ArcMap GIS analysis toolbox, we separate the cities which lie in the covered area of the airport and arrange the remaining cities in a separate layer, as shown in Figure 3.14.

From Figure 3.14, thirteen cities are found to lie outside the covered area of the existing airports and far away from the nearest one at a distance of over 150 km. Most of these cities are located in the zone between Benghazi airport and Sirte airport with almost 600 km in between.

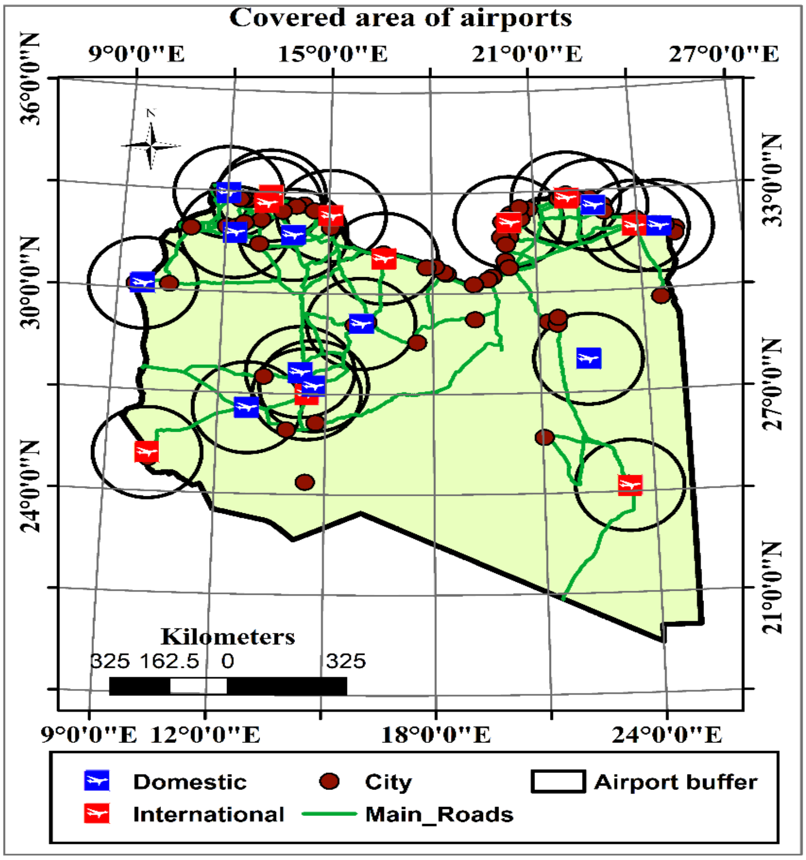


Figure 3.13. Cities outside the airports' range area

Dividing the cities located outside the covered area by airport range into two groups, we obtain one which is the clustered cities located near the coastal strip with a population of about 306,863 and requiring a new airport; the other group is that of dispersed cities far away from airports with low populations. In this scenario, they can be connected to the nearest airport.

Referencing the obtained map as the outcome of the statistical analysis, and comparing it with the one concerning the location of clustered cities outside the range of airport service, it can be seen that these cities are not far from the mean center locations of all cities and the mean center of airports, hence the strong recommendation to construct a new airport there because it is approximately mid-way to the cities of Benghazi and

Sirte that are about 600 km apart. Additionally, there is no civil airport in that zone, not to mention the population of about 306,863 inhabitants without any air transportation facilities.

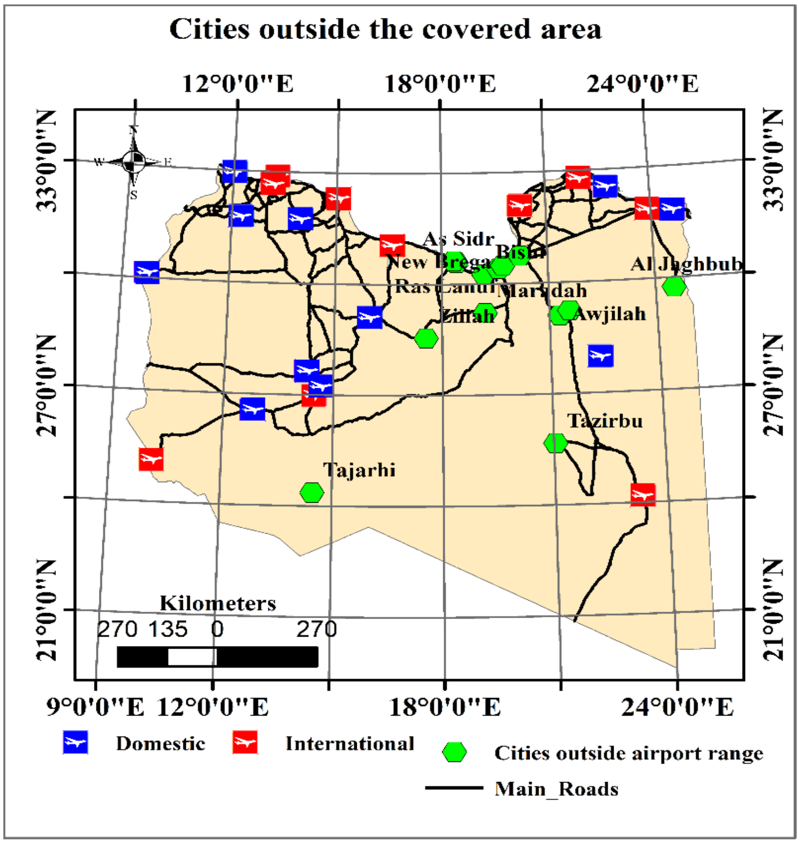


Figure 3.14 Cities outside of the covered area of the airport

3.10 Conclusion

To sum up, the required study zone as indicated in figure 3.16 is determined based on the following:

1- The results of the spatial analysis process (need due to the population demography - besides the suitable location of mean, median centers of cities and airports located in that region, etc.).

2- It is approximately mid-way to the cities of Benghazi and Sirte that are about 600 km apart. Additionally, there is no civil airport in that zone, not to mention the population of about 306,863 inhabitants without any air transportation facilities.

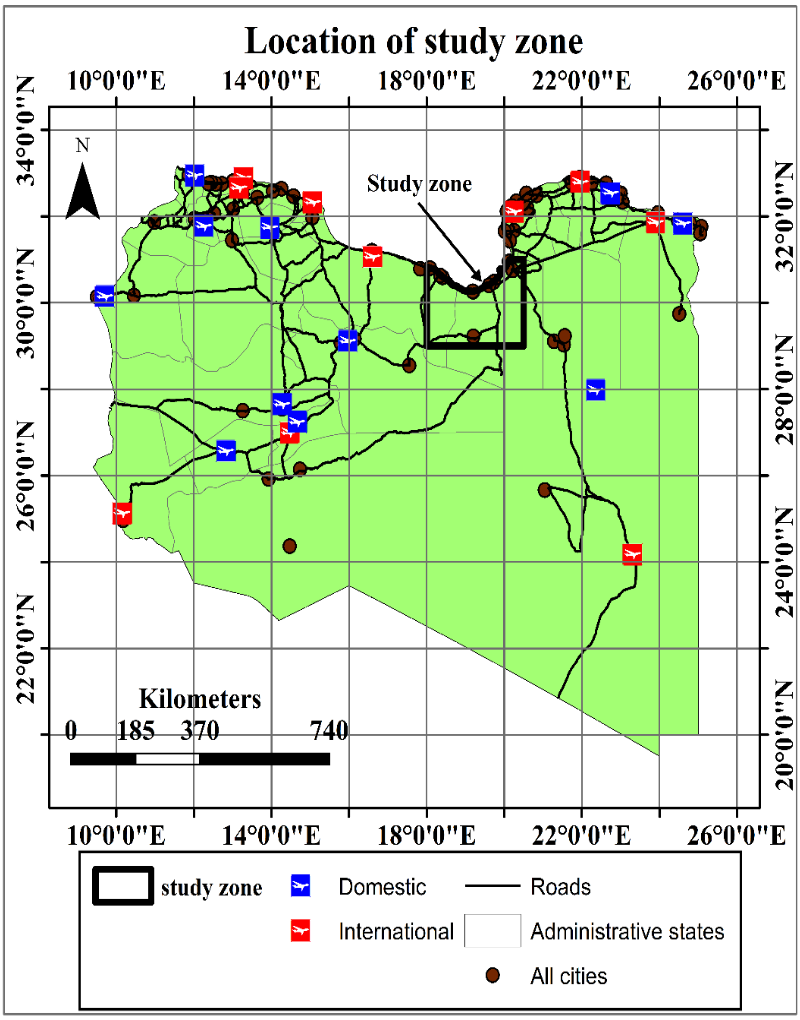


Figure 3.15 Location of the selected study zone

CHAPTER 4

DATA COLLECTION AND METHODOLOGY

4.1 Introduction

Site selection is the most important step in the construction of new airports. A typical investigation comprises a thorough examination of all pertinent factors. The site selection process involves multiple criteria, some main factors and others secondary. Yet again, some of these criteria become higher in priority concerning others. In this chapter, all the collected data related to airport site selection will be investigated and applied in decision-making.

4.2 Study Area

From the result of the previous chapter, the study zone is determined to be located in the northern part of Libya between longitude lines from18˚00' 00" to 20˚30' 00" E and latitude lines from 29˚00' 00" to 31˚00' 00" N. It is about 42,254 km^2, which represents 2.4 % of the total land area of Libya with a population of about 306,863 inhabitants in 2019, representing 4.50 % of the total national population.

The main income sources of this population are petroleum industries. The study zone, one of the most important in this respect and closest to the coast of the Mediterranean Sea, has a rather dry climate – that is, in particular between April and October - and more precipitation between November and March. There is about 320 mm of rain in this region the year around at a temperature varying between 5° C in the cold season to as high as 40° C in the warm season, averaging 21 C° annually.

It should be noted that the study zone is situated in the coastal part of Libya, where more than 75 % of the total national population resides. This location is near the location of the mean center of cities; near the mean center of airports, within the standard distance and the directional distribution, and between two existing airports with a distance of about 600 km between them.

4.3 Study Plan

The methods used for determining the airport location are the GIS (Esri ArcGIS version 10.5 software), the AHP and ROC, and the remote sensing methods according to the flowchart illustrated in Figure 4.1.

This flow chart indicates the steps of determining the appropriate location of airport, starting by collected the relevant criteria, then manipulating those criteria using GIS operations such as projecting, rectifying, rasterizing, reclassifying, and standardizing, followed by assigning the weights derived from the methods of AHP and ROC to criteria, then adding all the re-classified maps of criteria and overlaying all criteria weights in the model. And finally obtaining the output map which containing the suitability index classes of the locations.

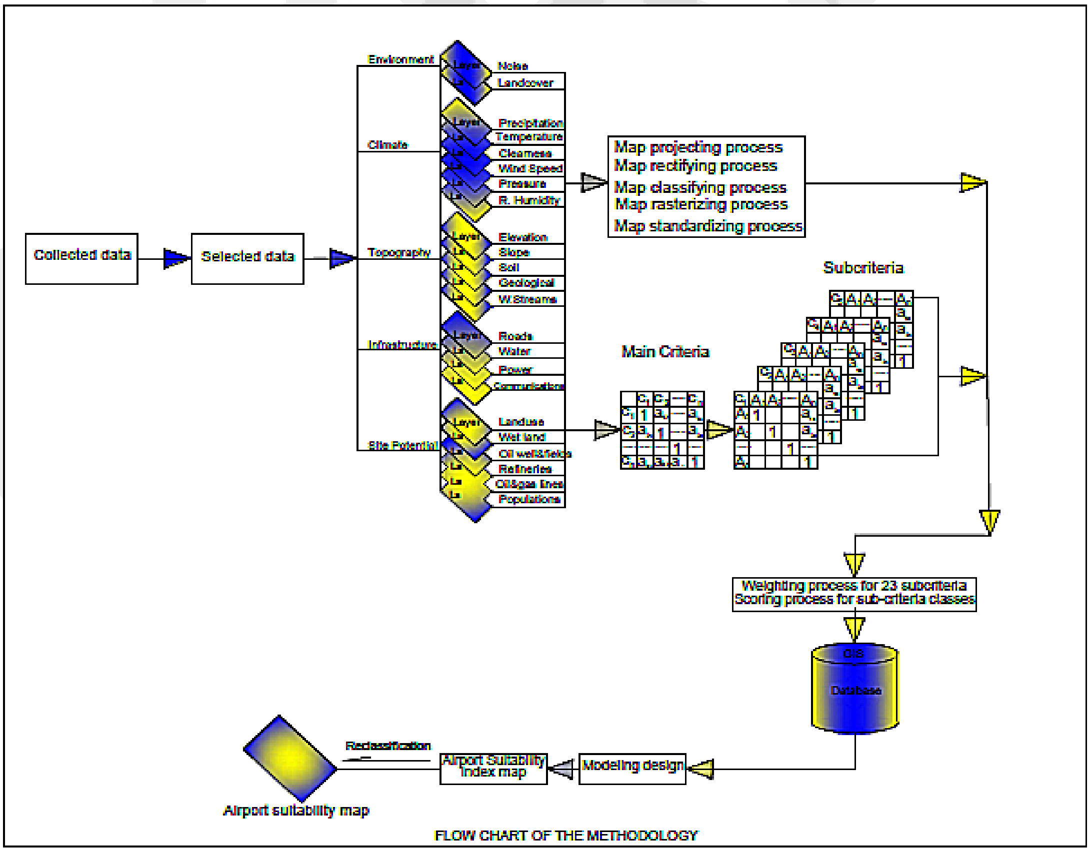


Figure 4.1 Flow chart of the methodology

4.4 Collected Data

The choice of the relevant data has been based totally on the local features of the study zone, applicable rules, regulations, literature review of previous researches, expert opinion, and availability of the data including maps, documents, etc. The decision criteria used for selecting airport locations were classified into five main categories; namely, environmental considerations, topographical conditions, climatic factors, infrastructure facilities, and operational conditions. Each main criterion includes sub-criteria. Thus, the total number of the applied criteria is twenty-three as the following:

4.4.1 Noise Impacts and Air-Pollution

Noise impacts and air pollution are the most important factors that must be taken into consideration during studying the construction and operation of a new airport or the expansion of an existing one.

These studies must be conducted based on the acceptable levels of air and water quality, noise levels, ecological processes, and demographic development of the region to determine how the airport requirements can best be met with the least counter-effect on the stated factors [72].

Among these, noise generated by aircraft tops the list of concerns, with numerous successful attempts to tackle it by using better engines and adjusting flight operations. A different alternative entails appropriate site and land selection and utilization [73]. Aircraft noise in the vicinity of airports is a major source of nearby residents' complaints.

This noise may stem from the vibration of running engines, air flows through the engines and friction between airflow and the aircraft surface. Its extent is often related to the number of flights, aircraft types, flight routes, flight hours, etc. [29]. Assessments in this regard contain noise models based on the noise exposure forecast (NEF) markers, as well as on the kind of craft, flight frequencies, durations, time of day, and others [32].

Feitelson [74] constructed noise contour maps to measure the impact of aircraft noise on the surrounding communities and determine which specific communities were subject to noise exposure.

Min et al. [29] considered the severity of noise by breaking it down into three levels: intolerable, bothersome, and indifferent. Concerning decibels, noise exceeding 85 decibels is considered intolerable.

This level of noise can annoy communities residing inside a radius of 2.5 to 9 miles. On the other hand, noise ranging from 60 to 85 decibels is considered bothersome. Since 50-decibel noise is equivalent to normal conversation, a noise level of fewer than 50 decibels are considered indifferent. From this perspective, the total number of residents living inside a radius of 9 to 10 miles may represent the population size affected by bothersome noise.

Airports impact their surroundings in significant ways and, hence, play an important role in choosing the right spot for the purpose; however, many nations across the world regulate these constructions also based on environmental and wildlife concerns, underground reservoir contamination, animals under threat and sensitive historical sites, and even unfavorable application of land.

4.4.1.1 Air Pollution

Air pollution is further intensified by increased commercial activity in airports and their related operations [73]. This concerns the likely effect of airport-triggered releases of gases into the air as regarded as detrimental by local or regional standards. There has already been made a relation between low-quality air and health-related issues, thus ranking this subject alongside noise pollution very high in certain areas. In the same way, set for noise factors, an International Civil Aviation Organization (ICAO) has devised restrictions and standards for air quality control which are to be complied with by engine designers when making aircraft (ICAO, 2008b); these standards take into account hydrocarbons, nitrogen oxides, carbon monoxide, and smoke emissions [75].

The dire consequences of air pollution emanate themselves in the form of people’s well-being, comfort, hygiene, damage to ground, water, flora and fauna, private and public possessions, visibility, livability, architectural deterioration, and forms of commuting by the public.

This issue has been described by experts as the appearance of non-native material within the atmosphere, or changes that occur in the natural environment and its inhabitants.

4.4.2 Land Cover

The information related to the land cover determines the portions of the area under investigation being forests, agriculture land, water types, wetlands, impervious surfaces, or else.

Water types are either of swampy or simply open nature as lakes, ponds, etc. Such a variety in terms of coverage determines the form of application and is decided upon based on satellite and aerial imagery, coming together to form maps to further make sense of the area by decision-makers.

For accurate decisions, though, one may need to see the variation of the landcover at issue by means of maps over a number of years related to a host of factors as follows: city developments, water resources, and quality, the likelihood of floods and storms, shrinking marshland, likely increase in sea level, sites needing protection, fluctuations in the patterns of coverage, ecological impacts, demographic and population movements [76].

Land cover, in short, constitutes a major criterion for site selection as any operation is likely to change it drastically. For instance, Airports are not to be raised around marshlands or wooded regions, of which grading is at the lowest concerning the criteria. The present study attempts to re-arrange the land cover to 10 classes, as shown in Figure (4.2), based on the preference of constructing the airport on and excluding water- or residentially-covered areas.

4.4.3 Population

Population is used as an indicator of demand for three reasons; First, there is the essentially practical consideration that population statistics are the only readily available data which can be used to construct a countrywide demand surface.

Second, for some freight items, which are handled by airports, the minimization of transportation costs is desirable. Therefore, the centrality of the airport concerning the population, in general, may be an important consideration in these activities.

Third, population distribution may be seen as an expression of the underlying potential of a possible location and its hinterland to support an airport [3]. These locations require thorough scrutiny as for neighboring residential areas, while runways are arranged in a way so that flight tracks do not pass over heavily-populated areas, while aircraft are below certain heights.

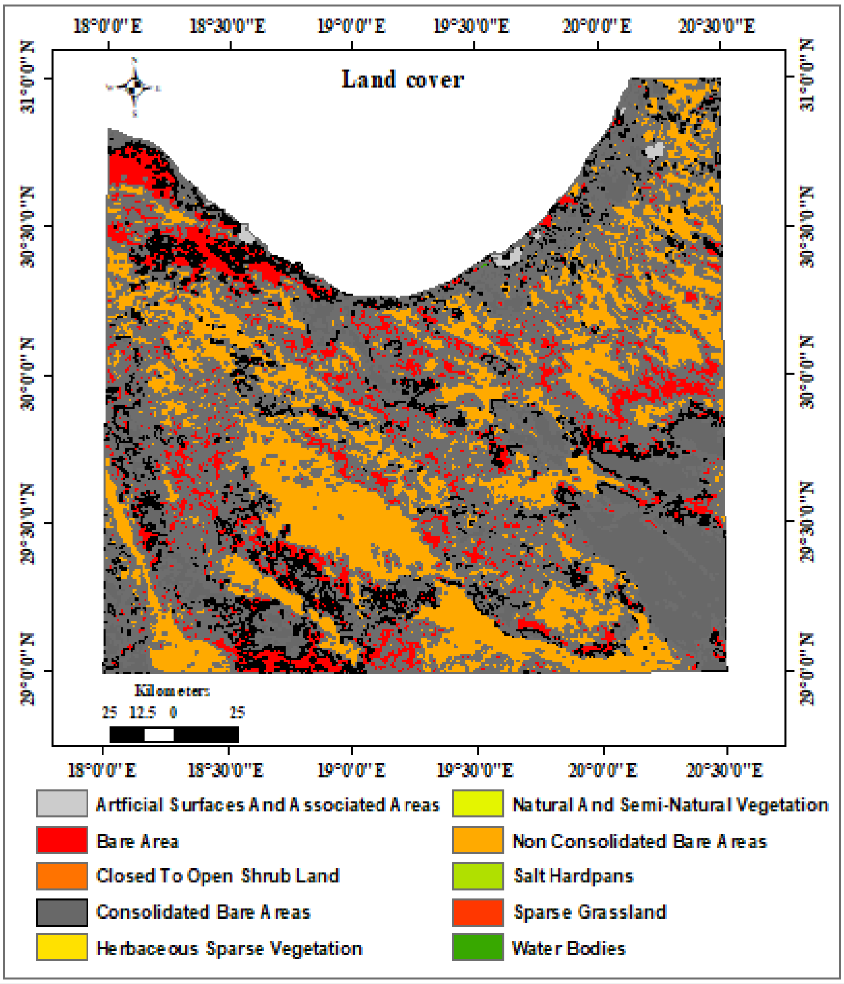


Figure 4.2. Land cover of study zone

In the meantime, proximity to a city and business center is key. Thus, a compromise between these two conflicting issues will be in demand to obtain the site with the best over-all feature [72].

4.4.4 Accessibility

Another issue is accessibility to ground transport considering the location of roads, railways, and public transport routes. Air transportation is not a door-to-door service. Accordingly, airport services are greatly affected by the proximity of an airport to business and population centers, as well as the severity of traffic congestion leading into and out of the airport. Also, Harvey [77] observed that other access characteristics such as public transit access, parking convenience, and connecting flight frequency had a significant effect on air travelers 'airport choice.

For this reason, the exact location is to be chosen as an already reachable option for commuters and not requiring additional developments. Travelers are more interested in quick access and on-land arriving times and not just the period spent in the air, making airport accessibility major criteria, especially for short and local flights. The following map is extracted from the open street map (OSM) Digital Line Graphs (DLGs), showing the main road networks of all the study zone. Among the major considerations for any airport must be the volume of traffic likely to be generated by the population in its hinterland and accessibility for the user.

It may not be possible to locate an airport precisely at the point of maximum accessibility which, depending on the scale of analysis, could be a city center. However, the airport must be close to such a point or else served by a particularly efficient transport system. Figure 4.3 indicates the main and secondary roads.

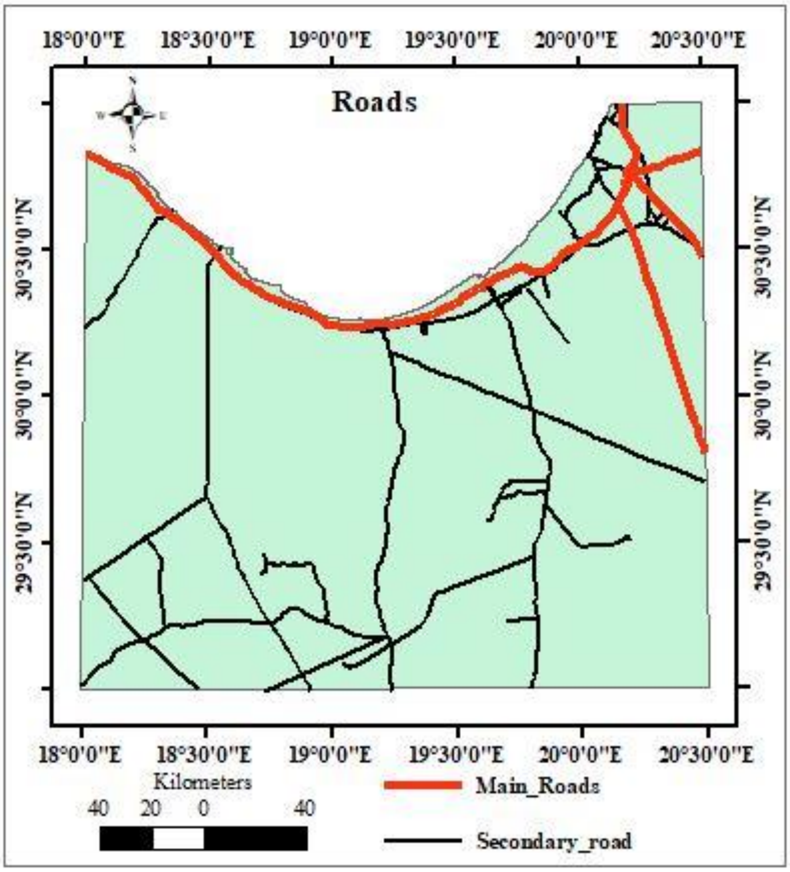


Figure 4.3 Main and secondary roads in study zone

4.4.5 Land Use

Land use planning and management is an important factor in ensuring that facilities and activities near airports are appropriate for aviation activities.

Its essential objective is to reduce the residents affected by aviation noise during the landing and take-off process by identifying land-use partitions around airports [78]. Constructing an airport will be a major conflict if intended in highly populated or financially active areas or those that are planned to be as such in the near future [32]. For this reason, plans for land-use help identify and determine a zoning mechanism to designate land in accordance to certain standards as housing, farming, manufacturing, and empty zones – with the latter obtaining the top grade for appropriateness, and the second and third categories obtaining the least as depicted in Figure 4.4.

An airport needs a location that is compatible with the surroundings, which are to remain as they were and not impacted by air operations in any way. Such criteria,

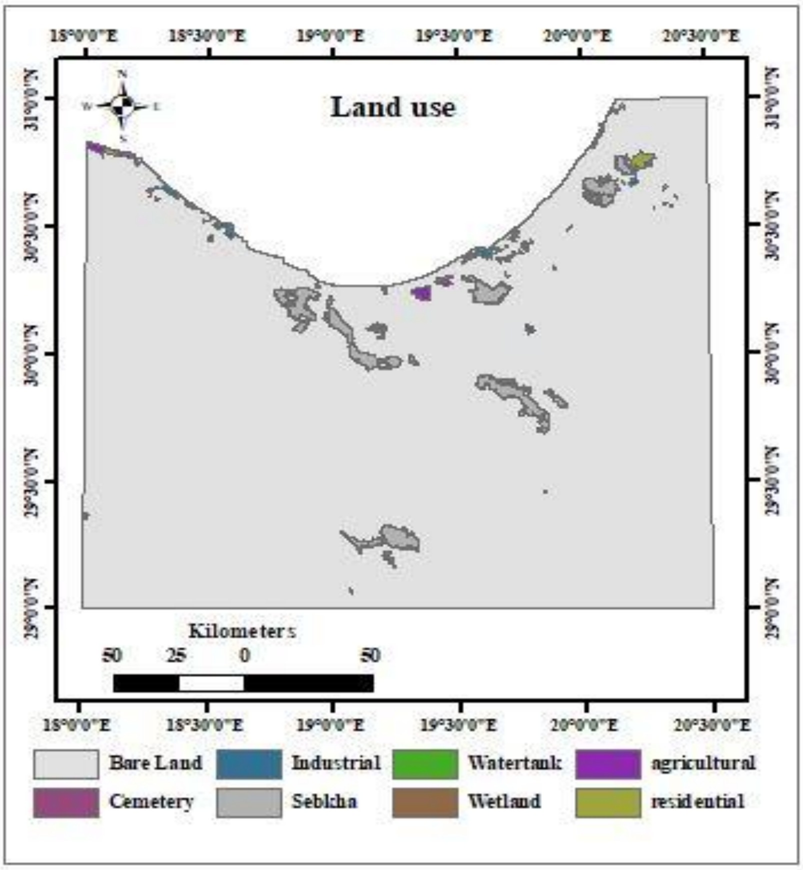


Figure 4.4 Land use map of study zone

naturally, might call for hefty designation of land areas to make control mechanisms more applicable and possible for the sake of environmental impact concerns or issues related with obstruction [72].

Land use around airports can as well have an effect on secure and effective operations inside the airport itself, neighboring residents, and overall environmental contact with the on-goings. As a result, any such activities that might jeopardize either side by either one deserves thorough analyses when planning is carried out.

Airports vary depending on the nearby environments; Natural surroundings like forests, plains, streams, wetlands, and bays are found in different degrees in the surroundings of airports. Mostly, the existence of natural areas affects the selection of airport locations. In other cases, the selection dependent on various factors, but the presence of natural areas can add additional benefits.

Amazing nature can be used to advantage not only in minimizing noise impacts but also in contributing natural elements and interest to the airport. Though, along streams, ponds, or water ports come the dangers of wildlife as birds – even resulting in catastrophic events in some cases [78].

4.4.6 Elevation

More elevation means less atmospheric pressure and, henceforth, necessitating longer runway lengths to allow for added velocity and easier lift-off for airplanes. Such an increase is not linear and depends on the aircraft load as well as the atmospheric temperature, added to in higher elevations.

As regards the design, a rough assessment is that up to 1524 m from the sea level, the span of a runway has to be added by an average of %7 for every 305 m of elevation, concerning places with very warm weather conditions or much higher elevations – that is, the two extremes – this ratio stands at about %10. As a result, while an airplane needs 1524 m of runway to take off at an airport at sea level, the same airplane may need 2286 m or more at an airport 1524 m above sea level, especially during periods of high temperatures [73].

For our purposes, a digital elevation model (DEM) at 30 x 30 m resolution obtained from the area under investigation and downloaded from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) [79] is employed for related altitude and slope data. See Figures 4.5 and 4.6.

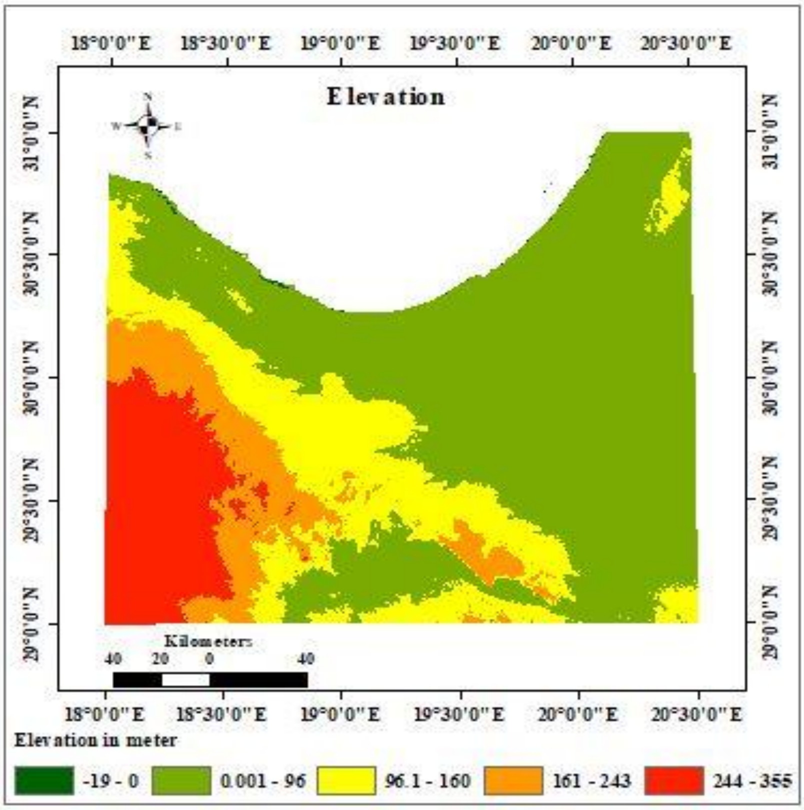


Figure 4.5 Study zone elevation

4.4.7 Slope

Grading and drainage are fundamental to building and up-keep of airports, hence considered in selecting the location.

The actual land slope and related flattening procedures give rise to the incline and appearance of the area in general as well as the system of drainage. The likelihood of floods at the sites should be analyzed.

The natural slope and drainage feature anywhere are key to proper planning and building as they indicate the required earthworks and grading operations needed to come up with the right level and thus the cost of preparing the site.

An area in agreement with the ideal slope and elevation for proper draining can greatly reduce certain overheads in financial terms [72]. In this respect, runways are inclined in terms of the change in height between the final points of the runway over its span based on standard units of measurement. Often written in percentage, slopes are defined in two ways: the first one is the degree of slope indicates the angle between the ground level and horizontal plane; the second one is percentage slope which indicates the percentage ratio of elevation change on horizontal distance change. As for runways, the approximate slope cannot exceed 1% at code number 3 or 4 and 2% at code number 1 or 2 [80].

Furthermore, an uphill gradient needs more runway length than a downhill gradient or a level; the specific amount relies on the altitude of the airport and the degree of temperature [72]. In this work, the slope map is obtained using DEM and Arc Map GIS. Figure 4.6 highlights slope levels by percentage.

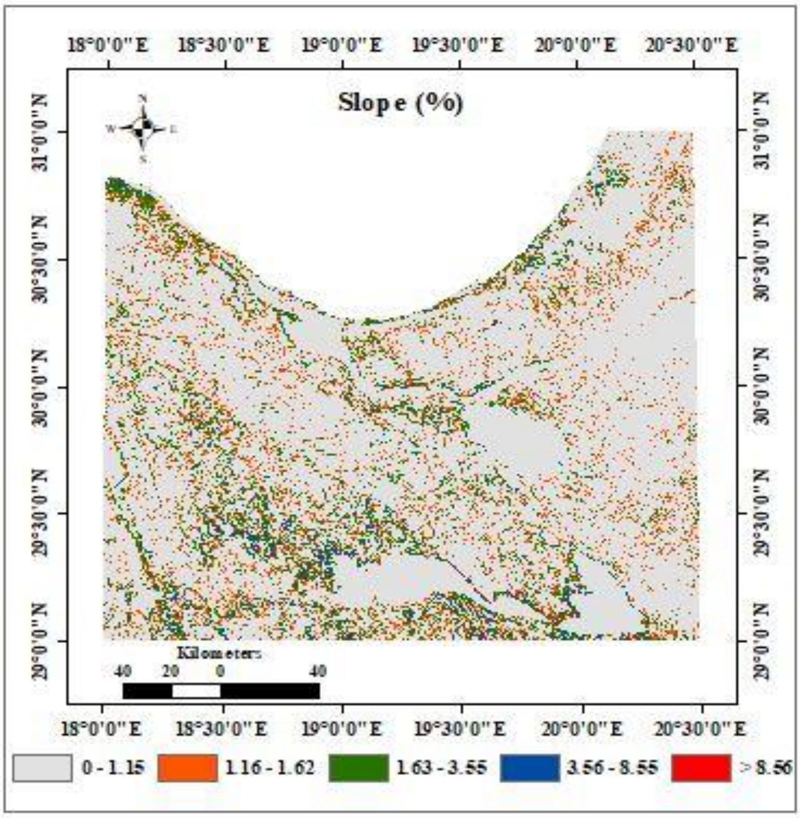


Figure 4.6 Study zone slope

4.4.8 Soil Properties

Studying the soil properties requires investigation for a soil survey as regards the compositions of the various layers of soil, the subgrade elevation, drilling, boring, and testing to evaluate the physical properties of the soil; and an investigation to assess the availability and suitability of the site materials for use in the construction of the subgrade and pavement.

For tests of this nature, drilling and boring reveal the rock and soil texture, which is later examined for precise identification, grading and size of particles, plastic and liquid limits, moist-density properties, shrinking, permeability, and strength characteristics.

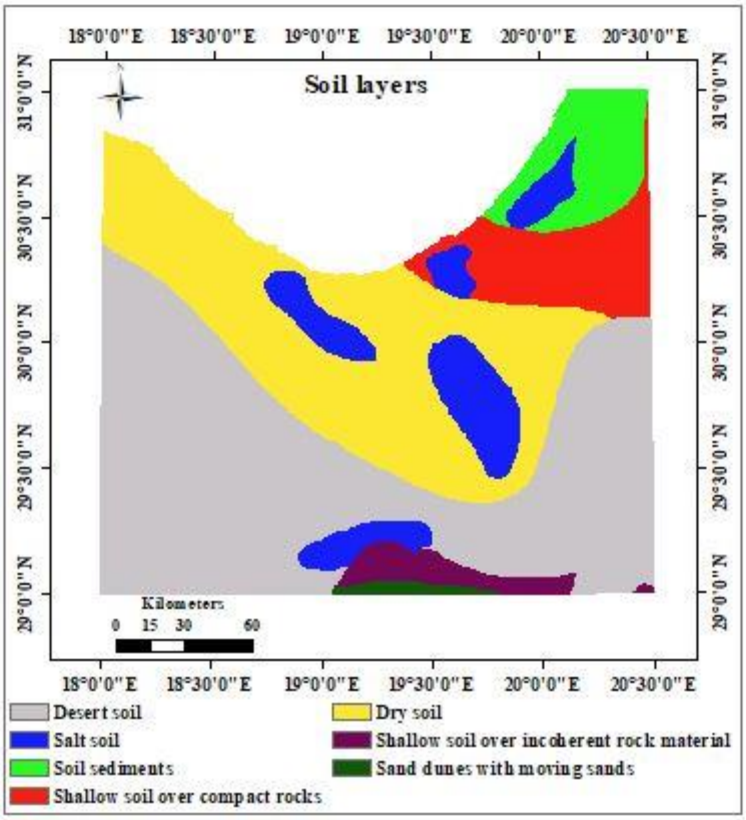


Figure 4.7 Soil layers of study zone

Concerning the practice in the U.S., these tests are carried out in various ways and with reference to the U.S. Geological Survey (USGS) geodetic maps, drilling and boring of soil, and aerial photography [73]. The soil data used in this study is obtained from the Atlas of Libya and Geo-Network satellite images [81].

Seven classes of soil in the study zone were found. These classes were classified according to a global unique food and agriculture organization of soil (FAOSOIL) code namely, desert soil, salt soil, soil sediments, shallow soil over compact rocks, dry soil, shallow soil over incoherent rock material, and dunes with moving sands, as indicated in Figure 4.7.

It is paramount to classify the local soil available in potential locations as regards the expenses; an overall soil survey is also vital to plotting the different types of texture and the possibility of rocky areas – all requiring professional analyses and consultation.[72].

4.4.9 Faults

Scientists do not yet fully comprehend the hazards of earthquake-generated failures in buildings around fault lines, where movements trigger major spikes on the records of the velocity-time of tremors. Such pulse-resembling movements can happen at airport sites near fault lines, which can generate cracks in the direction of the site with speeds equal to that of the shear wave, ending up in interloping wave fronts [82]. Figure 4.8 shows the faults locating in the study zone.

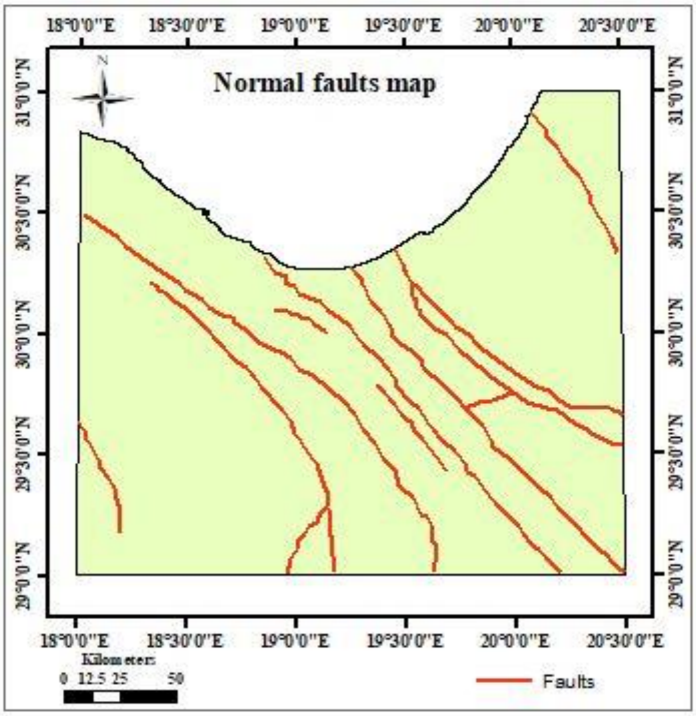


Figure 4.8 Location of normal faults

4.4.10 Water Streams

Since airports consist of wide areas of paved surface, rainwater runs off quickly and suffuses away that may have accumulated on these surfaces. Moreover, the large quantities of water can create flash floods that can cause runway or taxiway closures if the airport location is not selected properly.

The stream water map used in this study is derived from the digital elevation model (DEM) with a 30 X 30 m resolution of the study area, downloaded from United States geological Survey (USGS) Satellite Imagery and earth explorer satellite, with the goal to obtain contour lines and slope information, and the location of streams as indicated in Figure 4.9.
These streams are divided into five grades, with 1 as the least danger to 5 as the most and indicating a collection of all streams.

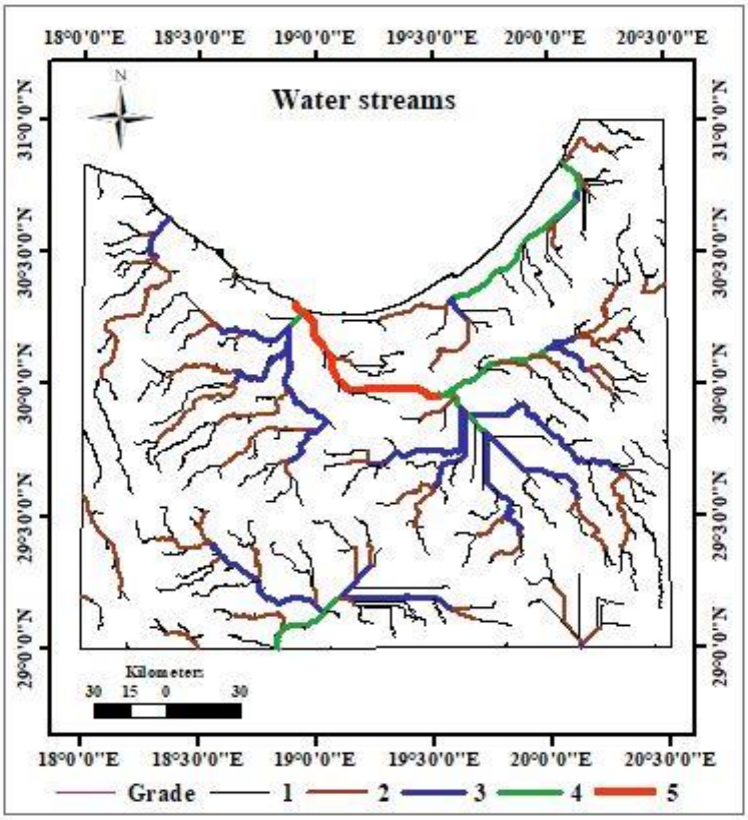


Figure 4.9 Water streams of the study zone

4.4.11 Precipitation

The aviation sector and its associated area of operations unit are highly influenced by the weather, which can have a negative impact on the ground. Major delays are caused in this way.

Adverse weather conditions reinforce traffic disturbances across the entire airspace system which leads to a lot of field fees, maintenance, crew costs, and likely passenger compensation [83]. For this reason, operational capabilities of sites are measured in this way and, especially concerning weather patterns featured with wind, precipitation, ice, mist, and reduced visibility.

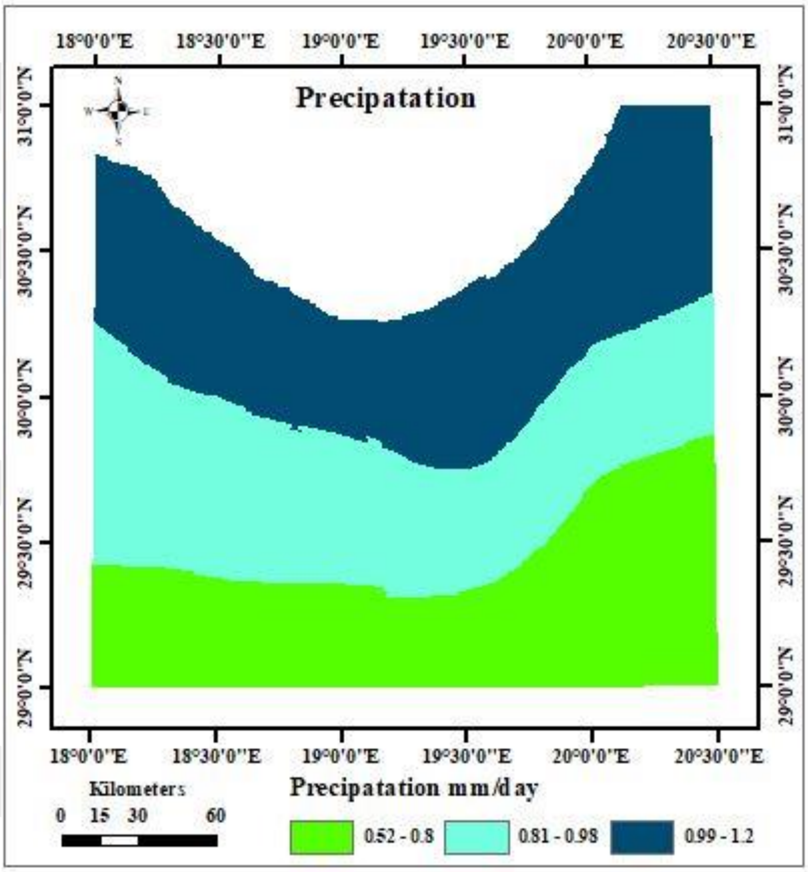


Figure 4.10 Precipitation map of study zone

Rainfall, snow, and ice can greatly affect runway operations due to reduced vision, lower braking efficiency, and removing ice from aircraft bodies. Increasingly intense weather patterns including snowstorms and thunderstorms can even halt all airfield operations [84].

The meteorology maps used in this study are derived from the National Aeronautics and Space Administration Satellite Imagery (NASA) [85] covering the data from 20 locations inside the area of study for 15 years from 2000 to 2015 used as input to the GIS software to implement interpolation between the point locations using the tool Kriging. Figure 4.10 indicates the precipitation map of the study zone.

4.4.12 Wind

The higher the headwind down a runway direction the shorter the length; on the other hand, a tailwind required increase in the length of runway required.

To design airports, it is preferable to utilize no wind, especially if only light winds occur at the airport site [72].

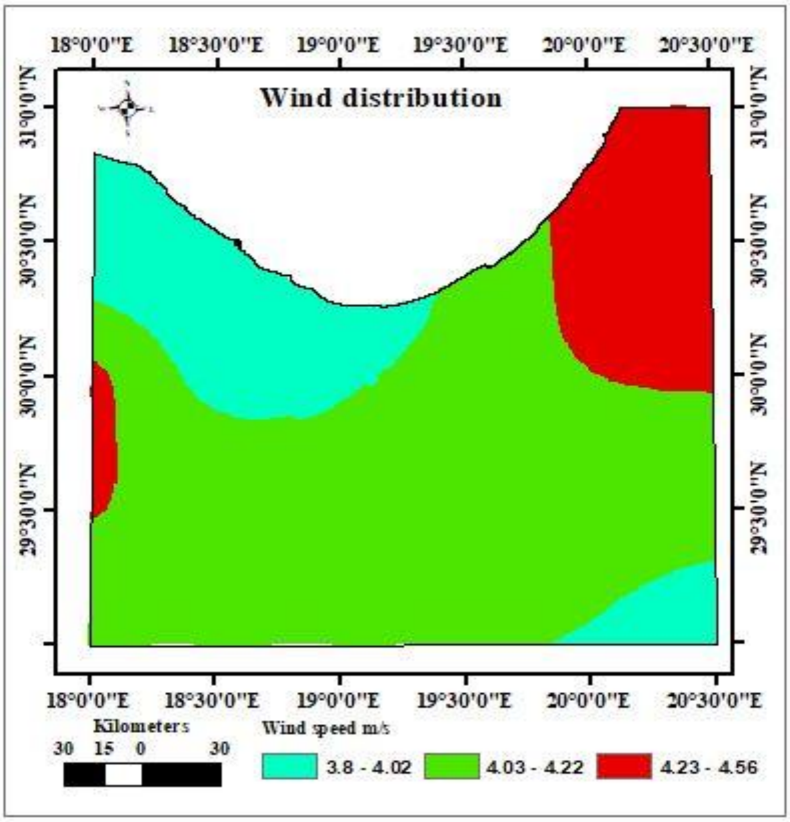


Figure 4.11 Wind distribution map

According to ICAO, runways are to be closed once the crosswinds component goes beyond the values as indicated below:

37 km/h (20 knots) for runways of 1500m or more and excluding low brake response, such as in rain or snow time; in this case, the limit is 24 km/h or 13 knots [86].

For this reason, both Federal Aviation Administration (FAA) and International Civil Aviation Organization (ICAO) assert that comprehensive historical wind records should be collected at each proposed or actual airport location, preferably including up to 10 uninterrupted years [87].

For our purpose, data was collected from NASA satellite imagery for 15 years from2000 to 2015, and the related figures for wind speed appear in Figure 4.11, revealing that it does not exceed 17 Km/hr. in the study zone.

4.4.13 Temperature

Warmer weather requires longer airstrips due to reduced air densities, in turn, reducing in a lower output of thrust [72]. The reference temperature of an aerodrome is measured by calculating the monthly mean of the daily maximum temperatures for the hottest month of the year (the warmest month is that which has the highest monthly mean temperature) [78].

Separately, dew formation at colder times indicates the likelihood of fog – a feature that is common in shorelines where humidity is high. This phenomenon appears in lower temperatures with changing degrees of appearance in accordance to geographic location. As for high air temperatures, it influences the physics of how airplanes fly which implies airplanes take-off performance is often reduced on hot days.

The quantity of lift generated by the craft's wing is influenced by the air density. Air density-based totally on the temperature of air and elevation; higher air temperature and greater elevations each reduce density [83]. Figure 4.12 shows the temperature distribution of the study zone.

4.4.14 Atmospheric Pressure

The atmosphere represents an important factor in determining the runway length, regarded as a whole in the form of atmosphere to accommodate factors as density, pressure, and temperature [80].

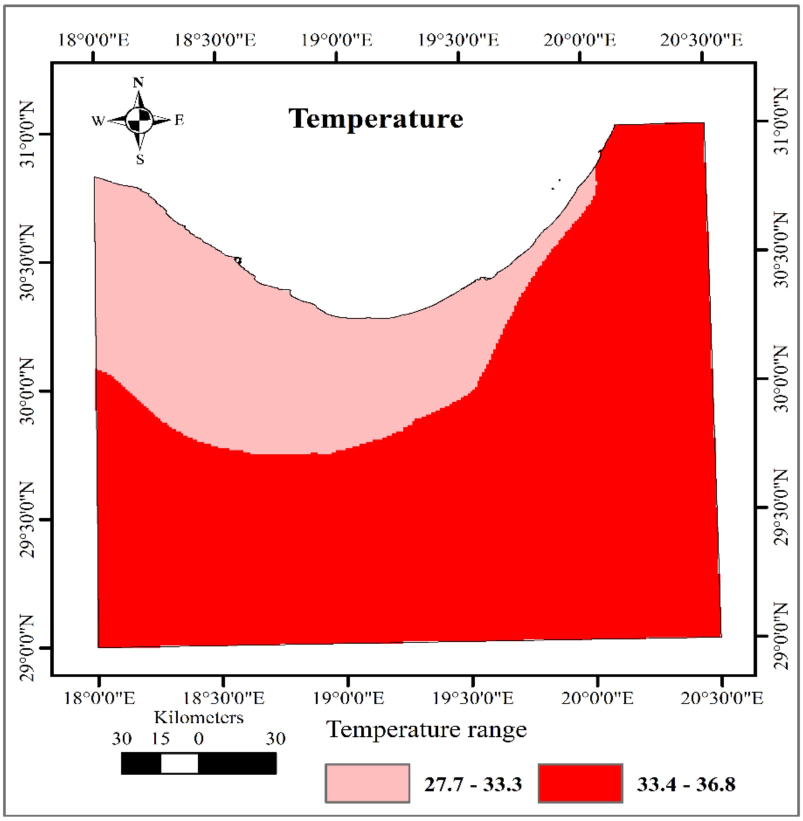


Figure 4.12 Study zone temperature

In case of local conditions being different as compared to the sea level standard atmospheric conditions, flatter runways are more appropriate.

The degree of runway slope reduction relies on the variation between regional conditions and the standard atmospheric conditions of sea level, and on the performance properties and operational needs of the aircraft for which the runway is designed [86].

Factors that influence the length of runway specifications include the following: atmosphere (relative moisture, ambient pressure, and temperature), aircraft configuration, aircraft mass, the slope, wind, and the conditions of runway. When devising the curves and figures for take-off and landing requirements, and tables, It is common rules to associate these factors with standard relative humidity and zero gradient slope, the more the altitude and relatively less pressure, the more extended the runway [80]. Figure 4.13 below indicate the map of the measured atmospheric pressure in the study zone.

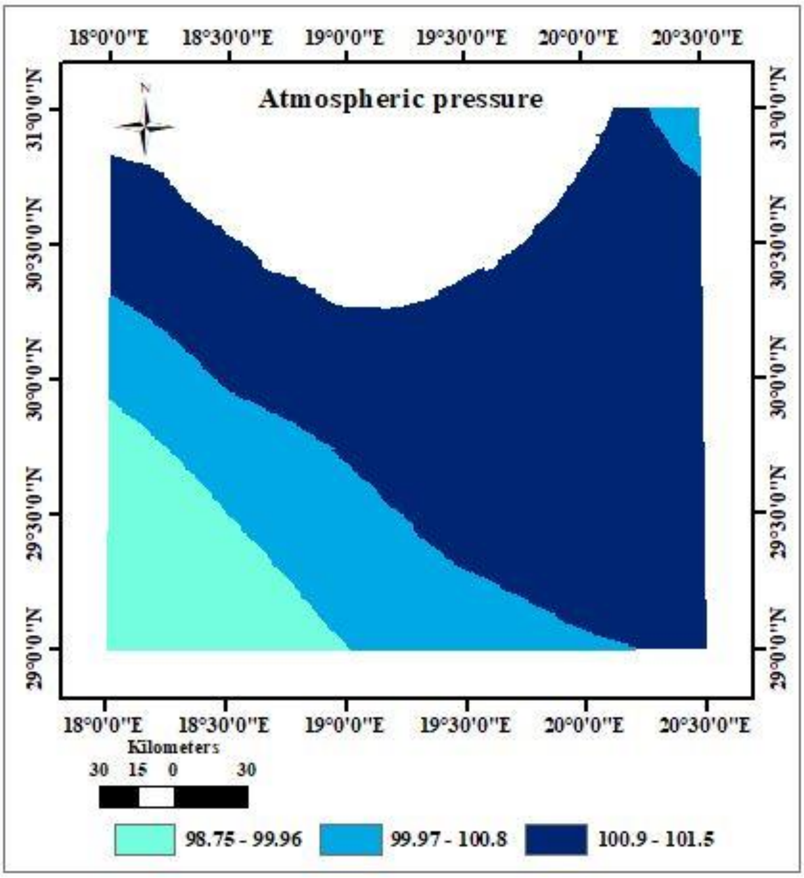


Figure 4.13 Atmospheric pressure of study zone

4.4.15 Relative Humidity

The relative humidity is one of the local conditions which should be taken into considerations [80]. Oftentimes, fog is a product of relative humidity at about 100% and resulting by increased moisture or declining ambient air temperature.

At aerodromes where temperature and humidity are both high, some addition to the runway length may be necessary, even though it is not possible to determine the exact amount [80]. As a whole, though, it may be asserted that fog represents clouds that are near the ground and compromises the view field around.

Based on such an elaboration, fog is simply atmospheric air restricting the view to under 1 km as assessed near the surface [88]. Figure 4.14 shows the relative humidity of the study zone.

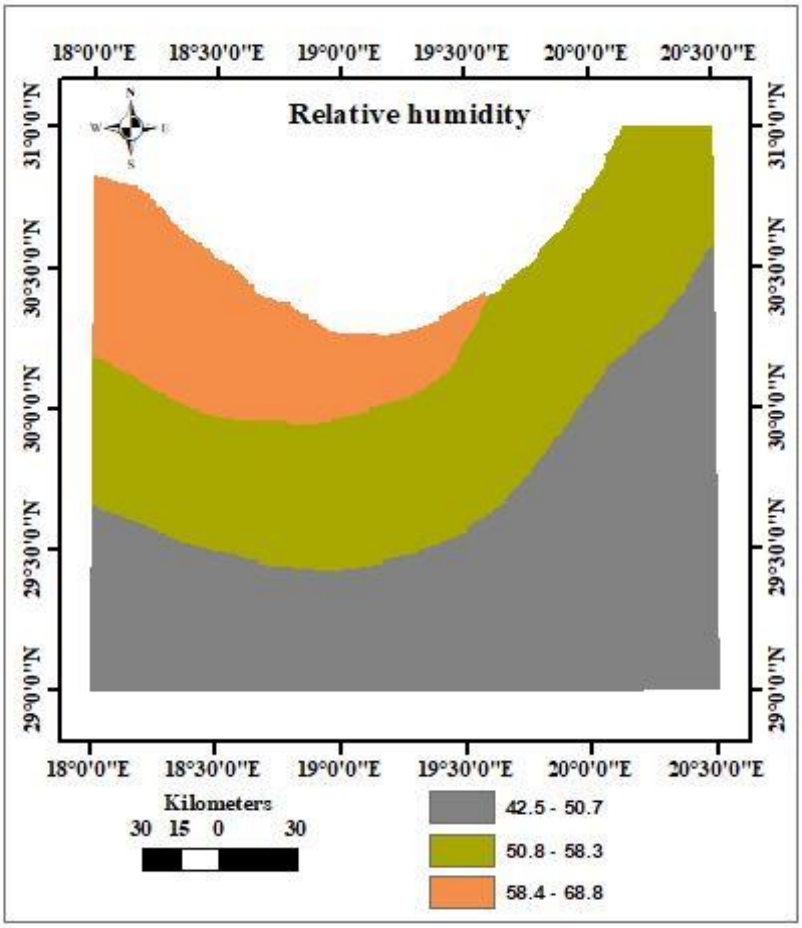


Figure 4.14 Relative humidity of study zone

4.4.16 Clearness

The clearness index represents the degree of the atmosphere clearness. It is the fraction of the sun's radiation that is transferred via the atmosphere to reach the ground. Its value ranges from zero to one and without dimension, obtained by dividing radiation at the ground level with that in the upper atmosphere [89].

Naturally, a reduced field of view restricts the number of take-off and landings allowed, hence necessitating the control of such restrictive occurrences as fog, exhaust fumes, and smog generated in any form. As for foggy weather, it occurs in places with the least wind, such as valleys; it is the prime factor behind low visibility below three miles and is a foremost popular and harmful weather for aviation.

The speed with which fog is formed makes it in particular dangerous [83]. Figure 4.15 contains the clearness index in the study zone.

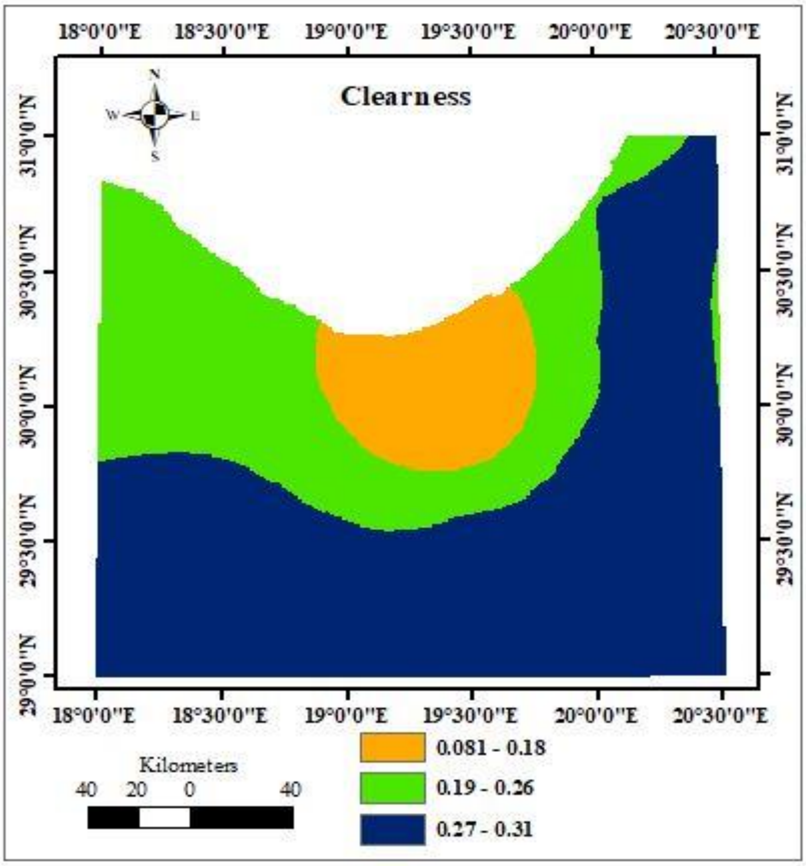


Figure 4.15 Clearness index

4.4.17 Distance from Refineries and Industrial Plants

There are other considerations, such as local features, that can impact site selection processes; namely, factory operations generate exhaust moving in particular directions on prevailing wind and, in this way, visibility in some areas may be restricted and Visual Flight Rules (VFR) operations precluded. Separately, power plants and power lines interfere with site design due to emissions of hot exhaust, which in turn generate turbulence.

This impediment has to be avoided and taken into account as much as possible as not to disturb flight routes. Also, landfills and incinerators may emit smoke, creating a visibility problem [78]. The locations of the oil refineries and factories are indicated in figure 4.16.

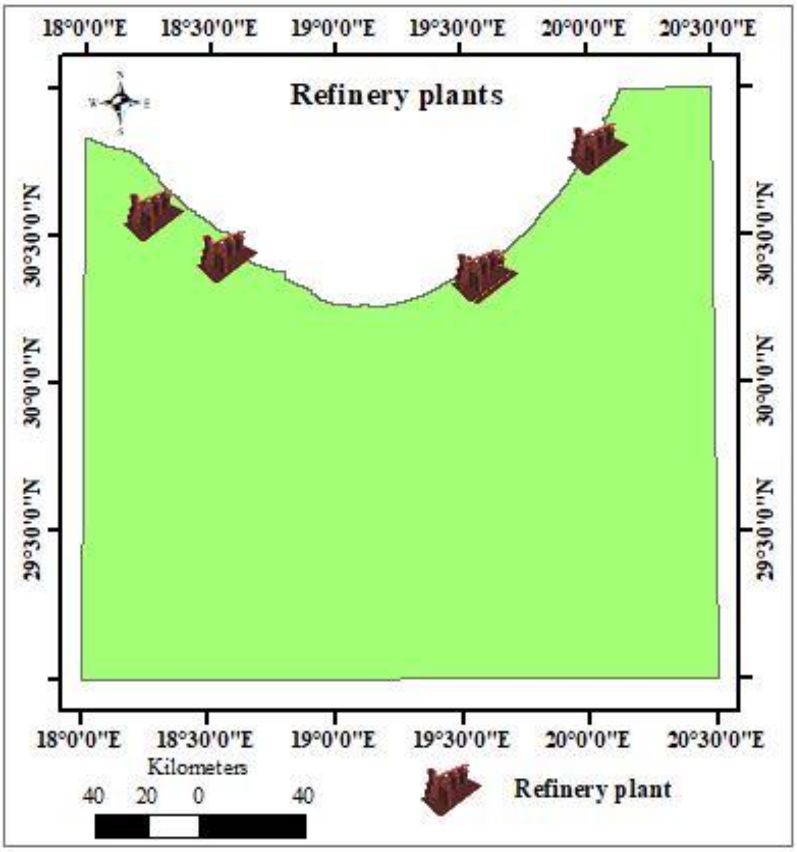


Figure 4.16 Oil refineries and factories location in study zone

4.3.18 Distance from Wetland and Wildlife

Locations near wildlife sites, lakes, streams, shorelines, dumpsites, sewage accumulation sites, and others are not suitable due to the danger of bird strikes [72] – particularly, once fast and oversized airplanes tend to frequent the airport. Such areas are to be selected based on the path of migratory flocks, especially of larger birds like swans and geese.

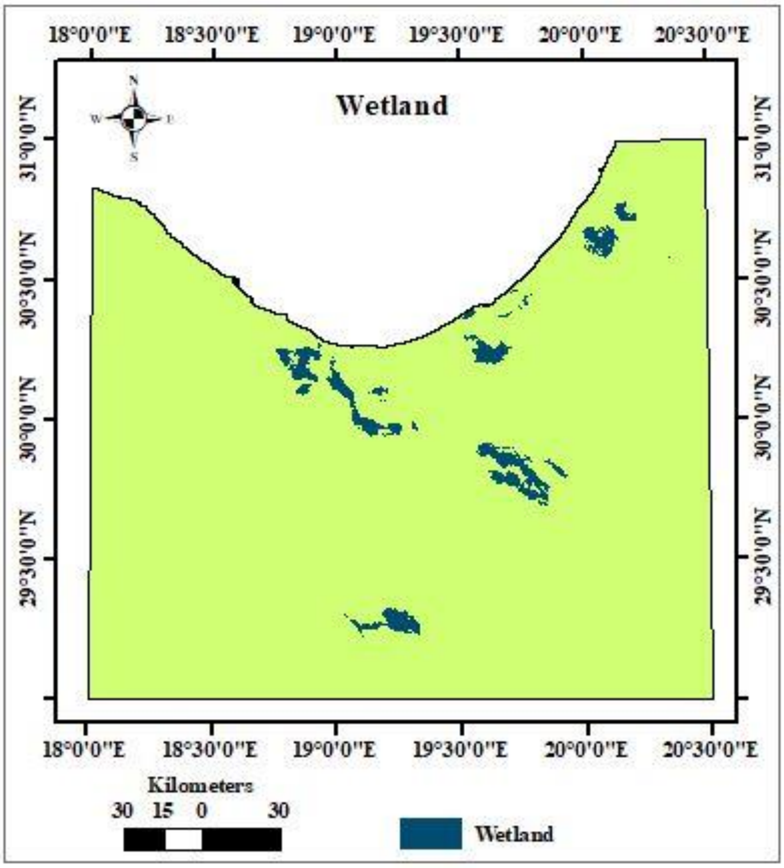


Figure 4.17 Wetland location in study zone

Farming land inside or around an airport can also attract wildlife which can represent a hazard to aviation. For example, birds are attracted by certain crops [78]. Thus, Collision with wildlife is among the major disturbances that airport operations can experience, and it threatens the safety of all and can bring about considerable losses to both aircraft and individuals[84].

Such strikes are behind many high-profile events, among them the 2009 landing of in the Hudson River by an Airbus A320, which hit a group of birds on their migratory route from Canada while taking off from New York. There have been other minor incidents involving wildlife around shorelines, marshlands, and even cities with noteworthy impediments in operational terms [84].

4.4.19 Proximity to Water Resources

These resources have to be taken into account to reduce the undesired consequences associated. Water serves as a lifeline of airport sites and can be provided from surface water, wetlands, floodplains, groundwater, and other specific means as wells and underground aquifers.

The supplies are intended for human consumption by both airport and nearby neighborhoods, as well as for entertainment facilities, logistics, business and factories, farming, and aquatic environments hosting flora and fauna.

The available sources are often a part of the landscape itself – which implies that interference with them can impact any other affiliated regions and parts of the entire ecosystem [78]. Thus, Potential airport sites should, if possible, be adjacent to water supplies, whose abundance can facilitate site selection by excluding the need for additional supplements and bring down the expenses associated with [72]. Figure 4.18 indicate the locations of water supplies pipes of the great man-made river project.

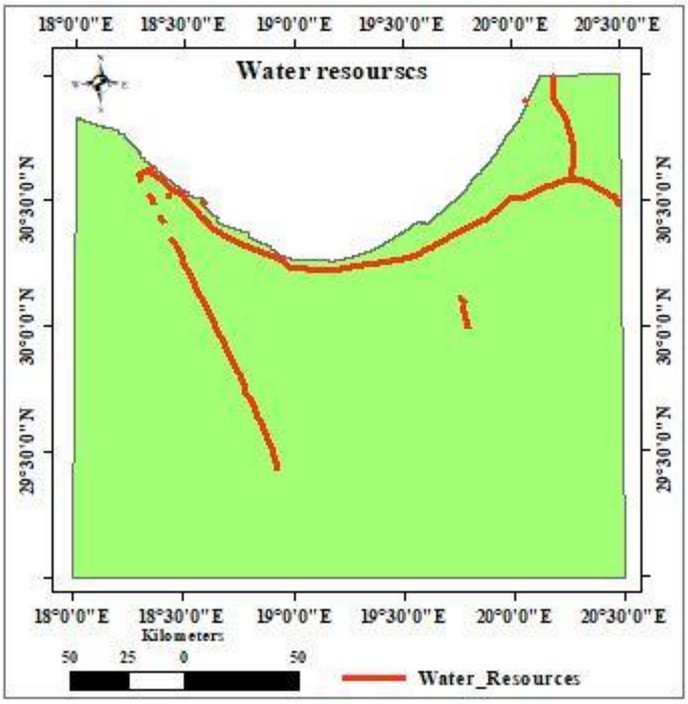


Figure 4.18 Water resource locations

4.3.20 Proximity to Communications Stations

Aerodromes, in terms of functioning and safety, are heavily dependent upon telecommunication facilities for visual audio and information transactions among numerous stations. These facilities require precise cabling schemes to join them with regional hubs and both primary and auxiliary equipment centers for ideal accessibility and task designation.

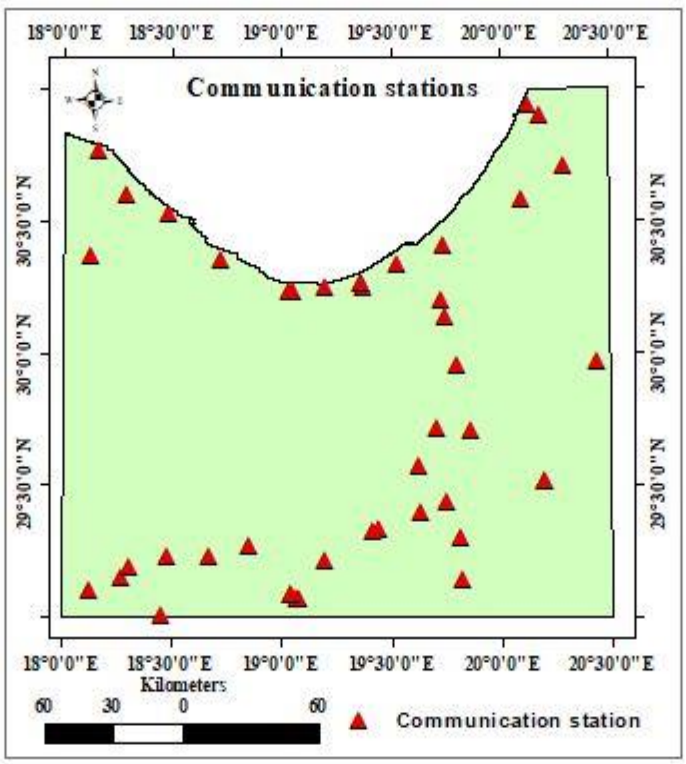


Figure 4.19 Communication stations location

Telecommunications are required for many parts of an airport and, in many cases, for the more distant and remotely-controlled transmitter and receiver stations [72]. Figure 4.19 shows the distribution of communication stations in study zone.

4.3.21 Proximity to Power Lines

Sufficient primary power supply is necessary for airports to guarantee flawless operations and utilities. Such secure measures are based on the degree of reliability of and the overall attributes of the energy provided, which comes by means of connections to one or more external sources, additional regional power plants and a system of distribution that comprise voltage transforming and switching facilities.

In addition, many other airport facilities supplied from the same source require to be taken into account while planning the electrical power system at airports [86]. Figure 4.20 shows the location of power line.

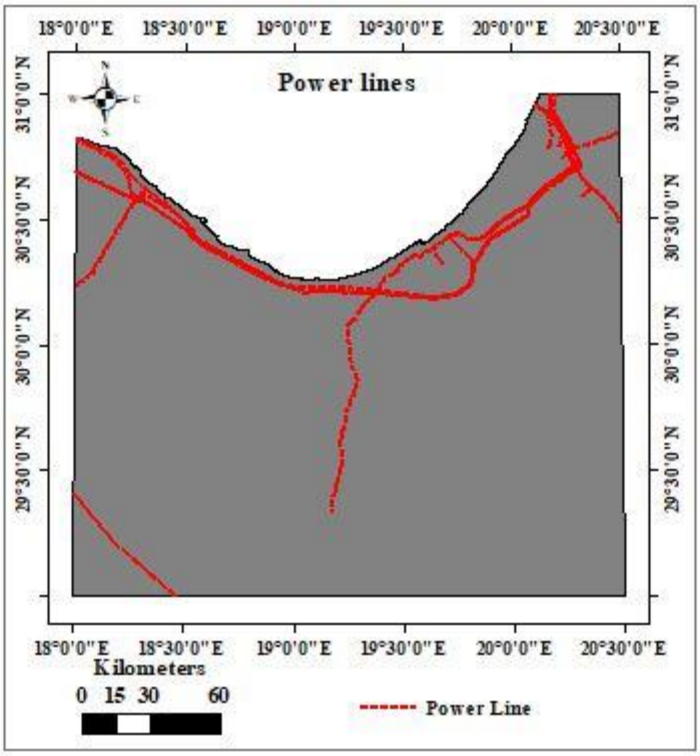


Figure 4.20 Power lines location

4.3.22 Proximity to Cities Center

Social and economic conditions are considered from the perspective of travelers. The airport site should be close to travelers so that air transport can attract more passengers. In this sense, an airport needs a location properly picked in consideration of the residents in the neighboring areas, while the airstrip itself required designing in a way that diverts the flight route away from such human concentrations and at acceptable altitudes.

However, airports require locations such that they are close enough cities and business centers for better service; as stated before, a common arrangement in this respect can serve for both goals and overall satisfaction with the chosen site. Figure 4.21 represents the regions of populations marked with nodes.

Specifically, the population within each region is assumed to be located at its centroid; additionally, the distances to the potential airport sites are measured from the centroids.

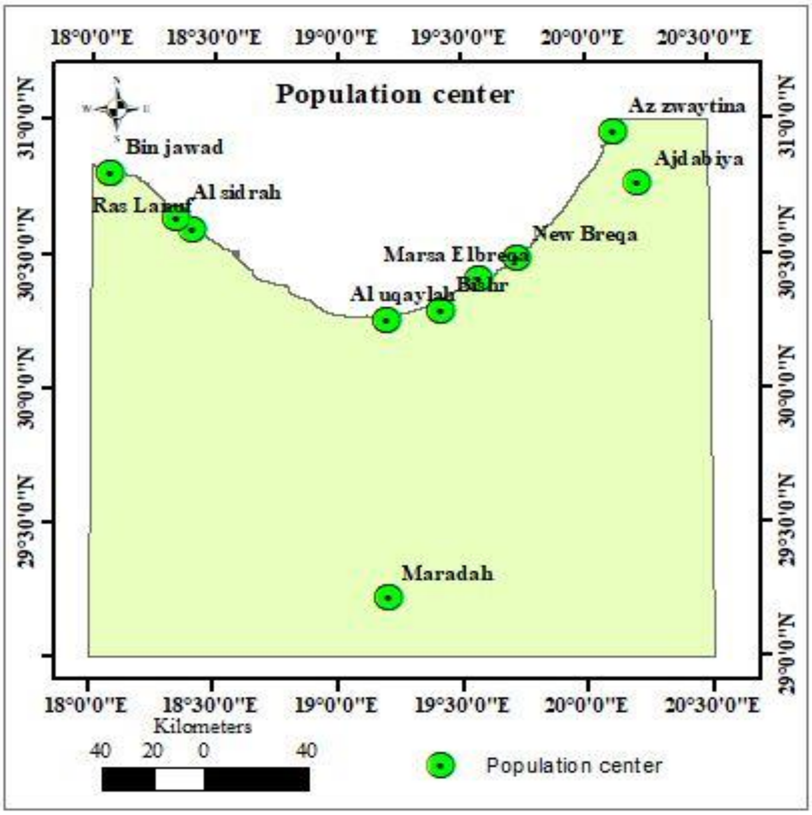


Figure 4.21 Cities centers

4.4.23 Distance from Lines of Oil and Gas

Within the area under investigation, there are oil and gas pipelines in various distances, bringing to the fore the likelihood of leakage or fractures forming due to wear and tear or even intended acts of sabotage.

These mixtures, if achieving a certain degree of combination with air, can be ignited and cause massive explosions and fires with considerable life and asset loss. Therefore, in this study locations of pipelines of gas and oil were determined as indicated in

Figures 4.22, based on which a safe distance was selected to avoid such incidents [90].

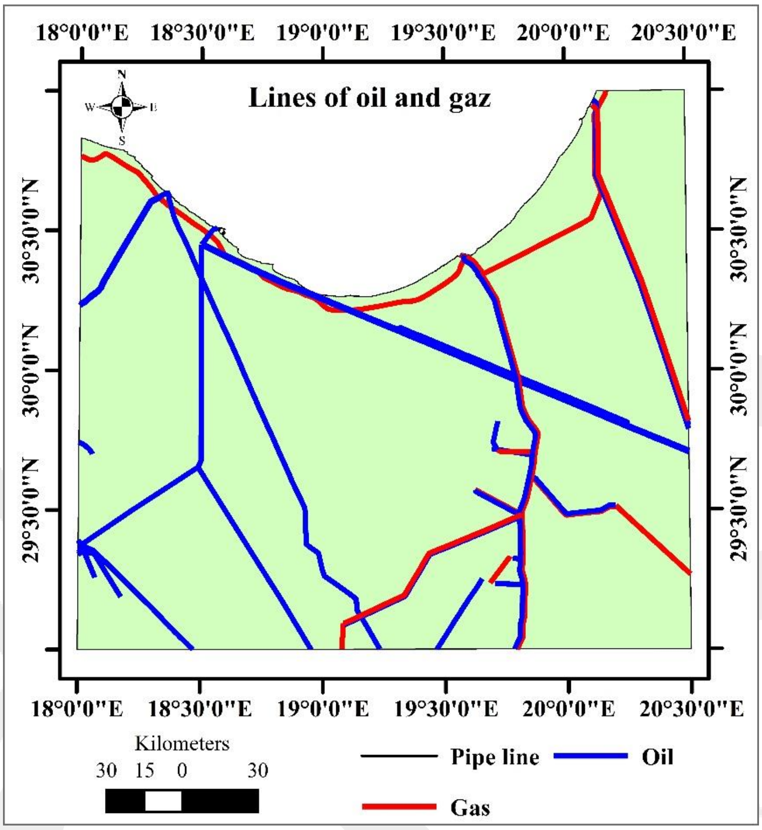


Figure 4.22 Location of oil and gas pipe lines

4.4.24 Distance from Discovery Wells and Oil Fields

Researches have taken into account the impact of the distance from oil and gas operations on the wellbeing of individuals; in most cases, there are impacts as such – in detail, the more proximity, the higher the likelihood of contact with toxic material and, hence, the bigger the danger to wellbeing [91].

A fair distance should be maintained between the field wells of oil and the site of the airport. Figure 4.23 shows the locations of discovery wells and the activated fields of oil in the study zone.

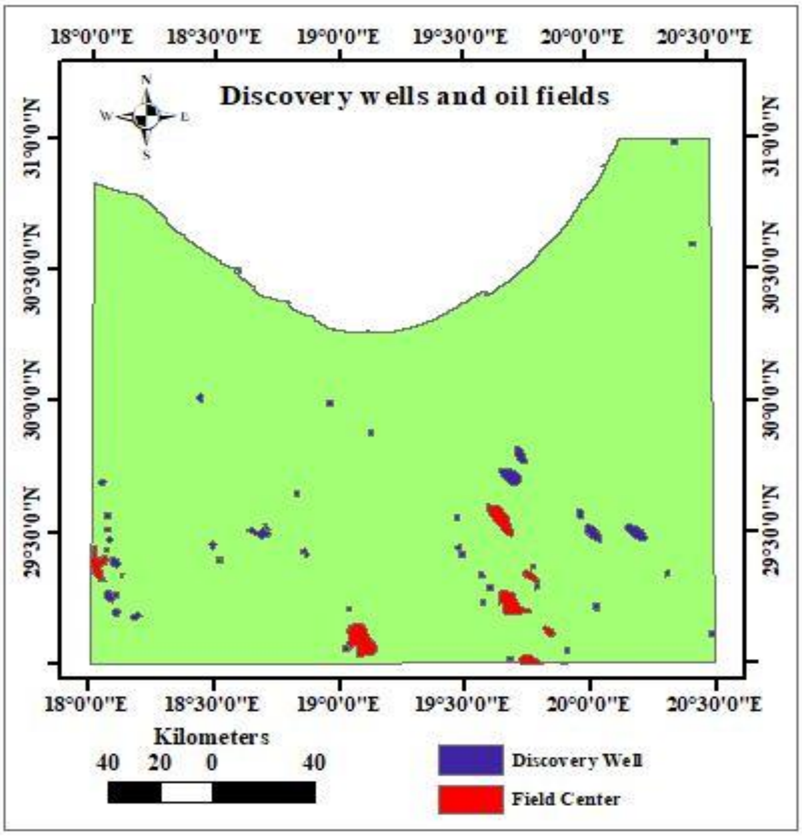


Figure 4.23 Location of discovery wells and oil field center

4.5 Methodology

The methods used for determining the airport location are the GIS (Esri ArcGIS version 10.5 software), the AHP and ROC, and remote sensing methods.

4.5.1 Geographical Information Systems (GIS)

GIS is a computer-based system that combines the input information with storage and management, modification and analysis, and the output as regards the spatial and attribute data so as to be later applied in the decision-making process [92].

GIS is ideal for preliminary site selection studies because it can manage a huge amount of spatial and non- spatial data from different sources and effectively store, retrieve, analyze and display information [93].

Using this tool is both helpful in choosing the right location in a purposeful manner and with adaptability, not to mention the extensive amount of spatial information that can be easily and quickly processed.

A final benefit of GIS is simply its straightforward presentations of the sites finalized for airport construction [94]. GIS gathers the information associated with physical or geographical space and converts it into a form that a computer can recognize for later modifications with the ultimate goal to design work processes, generate evaluations for decision-making, and/or create more cost-effective service-provisions [95].

Raster and vector are two very different, but common, data formats used to store geospatial data. Raster-based data divides the spatial area into grids of the same size. To each grid a different category value is given, representing different geo-referenced attributes. Vector-based data utilizes lines, polygons, and points, providing every one of them a different category value to represent different spatial attributes in the existing world [96].

Vector data employ X and Y coordinates to identify the locations of lines, points, and areas (polygons) that coincide to map features such as trails, parcels, and fire hydrants. For this reason, vector data tend to identify centers and boundaries of features.

Differently, raster data employs a format comprising of a matrix of square areas that show the location of each item or feature. These squares, also known as pixels, cells, and grids, which usually share an equal size in which this size defines the detail that can be preserved in the dataset. Since raster data represent square regions, it is more about the inside sections rather than exteriors as is the case with vector data.

Vector data are ideal for obtaining and maintaining spatial information, whereas raster data serve best to obtain, storing, and analyzing data such as soil properties, temperature, and elevation, etc. that differ from position to another. Additionally, this type of format is mostly employed to save images provided from air or space [97]. GIS has three fundamental capabilities; the first one is maintenance of data, the second is manipulation of databases to extract necessary information, and the last is the employment of gathered information in the decision-making process [98].

4.5.1.1 Processing of Input Data

Input data entails the determination and collection of data intended for a certain purpose, and it has stages as acquisition, reformatting, geo-referencing, compiling, and documenting.

The input feature transforms data from unprocessed to a kind applicable in GIS. In this respect, the information necessary in case of any site selection initiative comes in various forms as either analog maps, charts, tables, and already available and digitized sets, aerial images, maps, satellite photography, surveys, etc. GIS is preferred for its adept combination many forms of data within a single applicable format, as well as for its applicability for not just map production, but for combination and spatial assessment of numerous kinds of data related to the inhabitants, hydrology, land features, weather patterns, land cover, transportation network, and the urban utilities and infrastructures [98], [99].

4.5.1.1.1 Digitizing

Digitization codifies analogous content – such as printed maps or charts – into a digital form using specific charts and the mouse apparatus to move around the cursor and follow and register the points, lines, and polygons required.

It is effective mainly once there are a few maps of maps containing minor geographical information to be used later. however, the disadvantage with this method of data input is the most maps are created for the aim of showing data to the user and do not always describe the precise of the objects' spatial location [92].

4.5.1.1.2 Scanning

Scanning devices can also transform analogous material into digital raster format – common with GIS utilities for map and image data input. Such data depends on the quality of the scanning device and the scanned map. Different from digitizing, the user does not have much control regarding the kind of information depicted by the scanner. The scanning method is generally selected when extensive data content needs to be captured. For instance, maps containing many thousand polygons or with huge features of irregular shapes are preferred maps to scan. In this respect, the degree of clarity and resolution plays a key role in the scanning process [92].

4.5.1.1.3 Data Manipulation and Analysis

GIS varies from other tools in the sense that it can carry out multiple assessments of spatial and attribute data, which are transformed and evaluated to obtain data intended for a certain use. There is a very wide range of analytical operations ready for GIS operators, and several classifications of those operations have been proposed [100].

In general, there are two categories of GIS operations – fundamental (or basic) and advanced functions– with separation in accordance to their applicability in numerous spatial analysis, including spatial multicriteria decision analysis. The fundamental functions are considered to be helpful for a wide range of applications. They are more common than the other category, in other words, the fundamental functions are available in a wide set of GIS systems for various data framework. It involves reclassification, scalar and overlay operations, measurement, and neighborhood/connectivity processes.

The advanced GIS functions provide the abilities of mathematical and statistical manipulation of data relied on theoretical models [92].

4.5.1.1.4 Reclassification

Reclassification and classification operations transform the attribute data associated with a single map layer [101]. They involve the grouping of objects into classes according to the new values assigned to the objects of the input data as well as certain locational and non-locational attribute values. Classification implies the recognition of pattern and organization in the data being considered for a particular analysis [92].

4.5.2 Multi-Criteria Decision Making (MCDM)

To arrive at the right decision in actual settings may often prove to be a challenge given the many facets to be considered. Against this backdrop, the MCDM approach allows for such conclusions to be obtained even in the presence of multiple and contrasting criteria [102]. The combination of GIS and MCDM effectiveness is of critical virtual in spatial multicriteria analysis.

GISs can be more practical to account for spatial attributes and their assessments by facilitating access to data and its saving, reuse, manipulation, and evaluation with the ultimate goal of arriving at sound decisions. However, GIS systems have restricted ability as far as the evaluation of the value structure is involved.

The MCDM techniques provide the tools for assembling the data and the decision maker's choices into unidimensional value or usefulness of alternative decisions. MCDM methods are prepared to assist the decision-maker under some conditions. They supply the rules of achieving complex trade-offs on multiple assessment criteria while considering the decision maker's choices into consideration [92]. GIS-based MCDA provides a combination of powerful tools and methods converting non-spatial and spatial data into information in the decision maker's rule [103].

MCDM methods were utilized to derive the selected criteria weights. after that, these weights were applied on the input layers (criteria maps) in GIS. AHP and ROC methods were two examples of MCDM methods used to derive the weights of criteria maps.

4.5.2.1 Analytic Hierarchy Process (AHP)

In this dissertation, both AHP and GIS are combined to help select the best airport location within the area under investigation in Libya.

AHP is a basic and efficient approach for decision-making and among the popular methods of MCDM. Between the years 2000 to 2014, almost 32.57 % (393 papers) of MCDM-related studies made use of AHP from amongst the 9 other alternatives that exist within that study [104].

AHP can be benefited in assessing items with both tangible and intangible operational criteria, and to obtain relative preferences on absolute scales (unchangeable features) from discrete and continuous paired comparisons in multilevel hierarchical formats. These comparisons could be resulted from real measurements or from an essential scale that shows the relative strength of preferences and attitudes [105].

In particular, AHP is mostly focused on departure from consistency and calculating this departure while maintaining reliance both inside and among the sets of elements within its own structure. The method is the widely used of other MCDM alternatives – as stated earlier - [106] particularly for planning and [107] resource allocation [108], [109] as well as resolving disagreements.

AHP is composed of three stages: determining the priority of aims, criteria, and alternatives; pairwise comparison of criteria; and, lastly, combining the outcomes with those of pairwise comparison to obtain the relative priority to be employed in the hierarchy structure [110].

The process begins by forming a hierarchy (see Figure 4.24) as a way to define the issue, comprising a general objective on top, a series of choices for every objective, and finally a set of criteria or features that relate the options and objectives together. In many scenarios, such criteria are narrowed down further to form sub-criteria at different stages and depending on the issue and its requisites. When it is completed, users employ the AHP model to determine precedence or priorities for every node.

At this stage, all elements related to the issue at hand are compared in pairs as regards the likely effect they can have on a particular attribute held jointly with others. Such a pairwise comparison is given values in the reciprocal matrix format by applying the scales of the relative importance, as proposed by Saaty and depicted in Table 4.1[111].

Saaty stated that the consistency of comparison between various criteria, a nine-point scale [105] can represent the degree of such relative significance existing between two criteria.

Table 4.1 represents the indicated 9-point scale, in which 9 represents absolute preference, 7 very strong importance, 5 as strong importance, etc. until 1 to stand for identical importance. Such an approach makes free assessment possible to determine the degree of significance of each factor – in this way, simplifying the decision-making approach [112]. Pair-wise comparisons of different criteria are arranged as a square matrix, whose diagonal factor is 1.

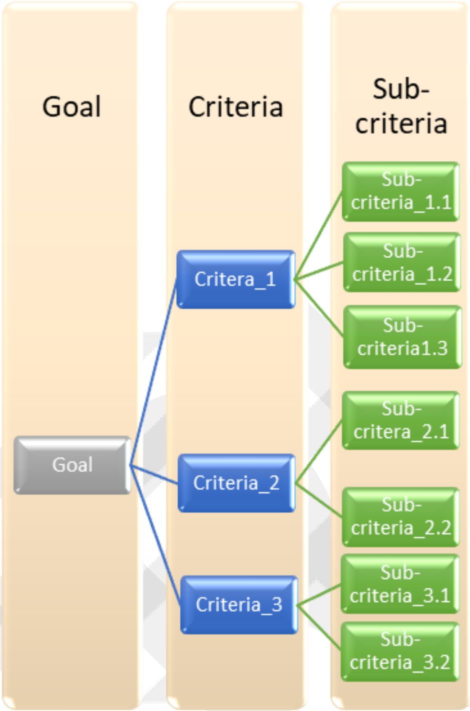


Figure 4.24 Hierarchy structure

Table 4.1 The comparison scale in AHP method

Value of a_{ij}	**Interpretation**
1	Objective *i* and *j* are of equal importance.
3	Objective *i* is moderate importance than objective *j*.
5	Objective *i* is strong importance than objective *j*.
7	Objective *i* is very strong importance than objective *j*.
9	Objective *i* is extreme importance than objective *j*.
2,4,6,8	Medium values

The main eigenvalue along with the related normalized right eigenvector of the comparison matrix offers the relative importance of the compared criteria. Additionally, the elements of the normalized eigenvector are assigned weights concerning the criteria and rated considering the alternatives [113]. During the elicitation process a positive reciprocal matrix can be generated where $(i,j)^{th}$ element a_{ij} will be replaced using a figure relative as determined in Table 4.1 based upon the conditions below:

a_{ij} is the pairwise comparison value and $a_{ij} > 0$ expressing the degree of preference of x_i to x_j.

x_i is the alternative *i*

x_j is the alternative *j*

a_{ij} if x_i dominates x_j

$\frac{1}{a_{ij}}$ if x_j dominates x_i

1 if x_i and x_j do not dominate over one another

With A_{nxn} as an ordinary pair-wise comparison matrix of n alternatives that stand for the intensities of the expert's preference between individual pairs of alternatives A_i versus A_j, for all $i, j =$ (1,2, ……, n).

$$A = [a_{ij}] = \begin{pmatrix} 1 & a_{12} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \dots & 1 \end{pmatrix}$$

From reciprocal matrix A, the weight of criteria can be computed using the arithmetic mean method. Upon determining a normalized matrix (B), its factors can be identified in the manner below:

$$B = [b_{ij}], b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{4.1}$$

Weight of elements calculated i.e. eigenvector $w = [w_i]$ form the normalized matrix

B is performed by calculating the arithmetic mean for each row of the matrix according to the formula:

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{n} \tag{4.2}$$

When matrix A is perfectly consistent then results in a normalized matrix C in which all the columns are identical as the following:

$$C = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix}$$

It, then, follows that the original comparison matrix A can be determined from C by dividing the elements of column i by w_i We thus have:

$$A = \begin{bmatrix} 1 & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots & \frac{w_2}{w_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & 1 \end{bmatrix}$$

The resulting ratio comparisons are depicted in

$$\begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \cdots . \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \cdots . \\ w_n \end{bmatrix}$$

To gain the term $n \, X \, w$, the matrix requires multiplication by w on its right side. considering w as the column vector of the relative weights $w_i, i = 1,2, \ldots., n$

A is consistent if: $A_w = n_w$

In the likelihood of inconsistent A, the relative weight w_i can be averaged based on that of n elements of row i in the normalized matrix C.

With $\overline{w}$ representing the measured average vector, one derives the following:

$A\overline{w} = \lambda_{max}\,\overline{w}, \lambda_{max} \geq n$

Where more proximity between λ_{max} and n implies a more consistent in comparison matrix A.

Considering that there cannot be full conformity among single decisions, the level of consistency obtained upon pairwise comparison can be calculated based on a consistency rate to determine the full completion of the process.

In this case, we refer to the Consistency Index (CI) for square matrix A as suggested by Saaty [111] so as to verify if the measure of the judgments provided is consistent.

In the reverse case that the CI does not yield a valid threshold, the responses to the comparisons made require a re-assessment. In this sense, CI is determined by:

$$CI = (\lambda_{max} - n)/(n-1) \tag{4.3}$$

Here, CI represents the consistency index, λ_{max} the principal matrix eigenvalue, whose order is n.

The CI is comparable to the one related to a random matrix, RI (see Table 4.2), with the ratio, CI/ RI representing the consistency ratio (CR). If CR < 10 %, then the pairwise comparison matrix (PCM) is acceptable and the value of the weights is valid.

Table 4.2 Random inconsistency indices RI ([111], [114])

N	**RI**	***N***	**RI**	***N***	**RI**
1	0	6	1.24	11	1.51
2	0	7	1.32	12	1.48
3	0.58	8	1.41	13	1.56
4	0.9	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

Should the CI not achieve a threshold level, in that case, certain pairwise figures require a re-arrangement, after which the cycle is followed a number of times up to the point that an ideal value of CR < 0.10 can be obtained. In general, for the matrix to be compatible, CR less than or equal to 0.1 should be retained.

A homogeneity correlated with elements within each cluster, fewer elements, and more awareness of the issue improves the very specific and ultimate index of consistency [115]. The rating of each alternative is obtained by aggregating the result of multiplying the weight of criterion by the contribution of the alternative, concerning that criterion [116].

4.5.2.2 Rank Order Centroid (ROC)

Among different weighting strategies recommended in the decision- making, rank-based strategies that change a criterion ranking order into algebraic weights have been asserted as a great practical choice between ease of usage and quality of the choice result [117]. The relative weights of criteria depend on the hypothesis that a universal weight– rank practical correlation exists between the rank of criteria and the average values of the weight.

Such transformation relies on various formulas. Rank ordering the significance of criteria may be easier than describing other inaccurate weights like bounded weights.[118].

According to Barron and Barret [18], the weights obtained in this way are likely to be more accurate compared to those by decision-makers-individuals who can easily and reassuringly disregard the minor changes in basically classifying the significance of each criterion, in particular should the outcomes appear close to that regarded acceptable by them.

Due to this consideration, some techniques have been devised to make ranking more possible for the so-called ‘surrogate’ weights to estimate the actual values of the weights; one is ROC [116].

The ROC weight method provides an approximation of the weights to reduce the maximum error of every weight by differentiating the centroid of all potential weights preserving the rank order of objective significance. It is more accurate than the other rank base formula and its based analysis is highly simple and efficient and supplies suitable implementation tools [18].

Barron and Barrett [18], in essence, came to the understanding that weights obtained in this way prove to be highly consistent. Next, only aware of the rank order related to the actual weight and without any other data whatsoever, we may say that the obtained weights are evenly distributed along the simplex of rank order [119].

$$w_i = \frac{1}{n}\sum_{j=i}^{n}\frac{1}{j}, i = 1, 2, \ldots., n \tag{4.4}$$

The purpose of the ROC weights approach is to determine one group of weights to stand for all likely, acceptable, and reliable combinations regarding the identified linear inequality limitations on the weights,

$$k = \left\{w{:}\, w_1 \geq w_2 \geq \cdots w_n, \sum_{i=1}^{n} w_i = 1, \quad w_i \geq 0, i = 1, \ldots\ldots\ldots, n\right\} \tag{4.5}$$

The k boundaries can be obtained using

$$ext^i = \left(\frac{1}{i}, \frac{1}{i}, \ldots \frac{1}{i}, 0, \ldots., 0\right), i = 1, \ldots.., n$$

In which ext^i is the i^{th} extreme point with *i* positive elements and n – *i* zeros.

Edwards and Barron [120] offered a simple equation to determine a centroid in k through the approximation of coordinates related to the boundaries:

$$w_1^{ROC} = \frac{1 + \frac{1}{2} + \frac{1}{3} + \cdots. + \frac{1}{n}}{n}, w_2^{ROC} = \frac{0 + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{n}}{n}, \quad w_n^{ROC} = \frac{0 + 0 + 0 + \cdots.. + \frac{1}{n}}{n}$$

Here, w_1^{ROC} represents the most significant feature, W_2^{ROC} the second most significant feature, etc.[121]. Also, *i* represents the i^{th}rank order while n represents the option number.

ROC is advantageous owing to steepness and non-linear processing of the weights, which can show a lot of agreement as regards the decision-makers' views [117].

Barron and Barrett [18] contrasted the functioning of four approaches in this respect, namely rank reciprocal (RR), equal weights (EW), rank- sum (RS), and ROC with the help of computer simulation to arbitrarily produce data. At this point, quality is determined in three ways: based on 'hit rate', 'average value loss', and 'average proportion of maximum value range achieved'. ROC, in this sense, is found to work better than all others concerning many conditions and, on every scale.

The precision of ROC has also been verified over other rank-based methods by the work of Ahn and Park [122] and within separate modeling scenarios [117]. In addition, those weights generated by the maximum entropy approach prove to be just as efficient in operations as those of ROC under certain conditions – all conducted and confirmed in theory and in practice [121].

Lee [123] considered the ROC method practical and more efficient for determining the weights of the criteria because of its simplicity and ease-of-use compared to AHP and fuzzy logic method.

Studies by Alfares and Duffuaa [124] were aimed to evaluate the effectiveness of five known approaches to transform many criteria ranks to weights for MCDM; these were RS, RR, ROC, geometric weights (GW), and variable-slope linear (VSL) weights. Comparisons were conducted in accordance to weight estimation accuracy based on various numbers of criteria and DM choices. Here, different alternatives are introduced in accordance to probability distributions of arbitrarily created criteria weights as uniform, normal, and exponential distributions. Again, the modeling outcomes all point to ROC as ideal for exponential weights determination.

According to [18], the ROC weights method is more accurate than the other rank base formula and its based analysis is highly simple and efficient and supplies suitable implementation tools; hence, our adoption of this approach in the present study.

CHAPTER 5

RESULT AND DISCUSSION

5.1 Introduction

The methodology uses the GIS software to evaluate the study zone, based on certain evaluation criteria for the analysis of airport site suitability. These criteria were selected according to the local features of the study zone, applicable rules, regulations, literature review of previous researches, experts' opinion, and availability of the data including maps, documents, etc., and it was classified into five main categories; namely, environmental considerations, topographical conditions, climatic factors, infrastructure facilities, and operational conditions. Each main criterion includes sub-criteria and each sub-criterion is classified as well. Thus, the total number of the applied criteria is 23 as follows:

Distance from residential regions (noise and pollution), land cover, precipitation (mm/day), temperature (C°), clearness index, wind speed (m/sec), atmospheric pressure (KPa), relative humidity, elevation above sea level (m), the slope of the land (%), soil characteristics, distance from faults, distance from water streams, proximity to roads, proximity to water resources, proximity to power lines, proximity to communications stations, land use, distance from wetland and wildlife, distance from oil wells and fields, distance from refineries and industrial factories, distance from lines of oil and gas and proximity to cities centers.

5.2 Manipulation of The Data Collected and Its Resources

All the input data utilized in this research were derived and prepared from a wide diversity of sources that differ in resolution or scale by scanning, geocoding, rectifying, and digitizing the relevant information, as shown in table 5.1.

Table 5.1 Criteria used, sources, format and scale/resolution factor

Factor	**Source**	**Format**	**Resolution or scale**	**Utilized to create layer**
Slope, elevations, water streams	United States geological Survey (USGS) Satellite Imagery [79] earthexplorer.usgs.gov	Digital	30 m x 30 m	Slope (%), elevation (m), distance from water stream
Roads, power lines poles, water resources, communication stations	Open Street Map Satellite Imagery [67] www.openstreetmap.org	Digital	Shapefiles	Proximity to roads, proximity to power lines poles, proximity to water resources, proximity to communication stations.
Precipitation, temperature, wind, atmospheric pressure, humidity, clearness index	National Aeronautics and Space Administration Satellite Imagery [85] power.larc.nasa.gov	Digital	Drawn by author. Data from 22 locations inside the area of study were entered into GIS software to implement interpolation between the point locations using the tool Kriging.	The appropriate degree of temperature (C^o), the suitable wind speed (m/sec), the value of atmospheric pressure (KPa), the less value of relative humidity, the higher clearness index.

“Table 5.1 (cont’d)”

Factor	**Source**	**Format**	**Resolution or scale**	**Utilized to create layer**
Oil and gas lines, oil fields and oil wells, refineries.	Petroleum geology of Libya [125]	Digital	Drawn by author	Distance from lines of oil and gas, distance from oil wells and discovery fields, distance from refineries and industrial factories
Land cover	Food and Agriculture Organization (FAO) Satellite Imagery Lby_ gc _ adg [126]	Digital	Shapefiles downloaded, then prepared by the author	Selecting the appropriate land
Faults	Atlas Libya map 1:5000000 A field guidebook to the geology of Sirte Basin, Libya [127]	Hardcopy	Drawn by author	Distance from faults
Soil characteristics	Atlas Libya map 1:5000000 Geo-Network satellite images [81].	Hardcopy and shapefiles	Drawn by author	Select the suitable type of soil
Land use	Openstreetmap.org [128]	Digital	1:2500	Select the appropriate land
Wetland and wildlife	Openstreetmap.org [128]	Digital	1:2500	Distance from wetland and wildlife

All those data were geo-referenced within the GIS environment using the Transverse Mercator projection system (LGD 2006 _ Libya _ TM _ Zone _ 10 and Datum D _ Libyan _ Geodetic _ Datum _ 2006). Afterward, numerous stages were followed in GIS to obtain the final required layers (such as extract, proximity, buffer, overlay, convert, and clip) and, finally, converting those vectors map (shapefiles) to a raster format.

5.3 Criteria and Sub-Criteria Standardization and Reclassifying

Scores from the different input layers' attributes can only be compared if the measurement units are the same. Through the standardization process, the dimension units are made uniform, and the scores lose their dimension along with their measurement unit [129]. The following stages were carried out to standardization and reclassifying of input layers:

1) Rasterize the input maps format: all types of vector maps (polygon, line, and point) were rasterized by the Path Distance function. Nonetheless, polygon-type maps were rasterized using the direct command for polygons.

2) Reclassification The raster maps were categorized with the reclassify tool taking into account the specified categories as shown in Table 5.2. The information collected from the literature review, experts' opinions, and particular specifications about the safe distances and buffering zones to an airport site were used to determine the reclassifying task by assigning rating value from 1 to 9 (from the least to the most suitability) as highlighted in Table 5.2.

Table 5.2 Reclassification of input layers

Main criteria	Sub-criteria	Reclassification	Score	Source
Environment considerations	Noise and pollution (distance from residential regions)	< 18000 m	1	[29], [72], [130]
		18000 m – 25000 m	9	
		25000 m – 40000 m	7	
		> 40000 m	3	
	Land cover	Bare area	9	[131]
		Consolidated bare area	8	
		Non-consolidated bare area	6	
		Herbaceous sparse vegetation	4	
		Sparse grassland	3	
		Natural and semi natural vegetation	3	
		Salt hardpans	2	
		Closed to open shrubland	1	
		Artificial surfaces and associated areas	1	
		Water bodies	1	
Climatic factors	Precipitation (mm/day)	0.522 – 0.799	9	[80]
		0.799 – 0.977	8	
		0.977 – 1.21	7	
	Temperature (C°)	27.7 – 33.3	9	[80]
		33.4 – 36.8	8	
	Clearness index	0.081 – 0.185	7	[72]
		0.185 – 0.263	8	
		0.263 – 0.31	9	
	Wind speed (m/s)	3.8 – 4.02	9	[72], [86], [87]
		4.03 – 4.22	8	
		4.23 – 4.56	7	
	Atmospheric pressure (KPa)	98.75 – 99.98	7	[80]
		99.98 – 100.84	8	
		100.84 – 101.54	9	
	Relative humidity %	42.48 – 50.78	9	[80]
		50.78 – 58.26	8	
		58.26 – 68.77	7	

“Table 5.2 (cont’d)”

Main criteria	Sub-criteria	Reclassification	Score	Source
Topographical	Elevation (m)	< 0	1	[80]
		0 - 131	9	
		131 - 227	8	
		> 227	7	
	Slopes (%)	< 1.15	9	[80]
		1.15 – 1.622	8	
		1.622 – 3.55	7	
		3.55 – 8.55	5	
		> 8.55	3	
	Soil properties	Dry soil	9	[72]
		Shallow soil over compact rocks	7	
		Desert soil	6	
		Sedimentary soil	6	
		Shallow soil over incoherent rock material	5	
		Sand dunes with moving sands	3	
		Salt soil	2	
	Distance from faults	< 1000 m	1	[132]
		> 1000 m	9	
	Distance from water streams	< 300 m	1	[133]
		> 300 m	9	
Infrastructure	Proximity to major roads	< 100 m	1	[39], [72]
		100 m – 5000 m	9	
		5000 m – 10000m	8	
		10000 m – 25000 m	5	
		> 25000m	3	
	Proximity to water resources	< 3000 m	9	[72]
		3000 m – 6000 m	7	
		6000 m – 9000 m	5	
		> 9000 m	2	
	Proximity to power lines	< 3000 m	9	[72]
		3000 m – 6000 m	7	
		6000 m – 12000 m	5	
		> 12000 m	2	
	Proximity to communications stations	< 5000 m	9	[72]
		5000 m – 10000 m	7	
		10000 m – 15000 m	5	
		> 15000 m	3	

“Table 5.2 (cont’d)”

Main criteria	Sub-criteria	Reclassification	Score	Source
Operational conditions	Land use	Bare land Industrial Agricultural Sebka Residential Water tank	9 3 3 2 2 1	[72], [73]
	Distance from wetland and wildlife	< 8000 m > 8000 m	1 9	[72], [134]
	Distance from Oil wells and fields	< 8000 m > 8000 m	1 9	[90]
	Distance from Refineries	< 8000 m > 8000 m	1 9	[72], [7]
	Distance from Lines of oil and gas	< 500 m > 500 m	1 9	[72], [135]
	Proximity to cities centers	< 10000 m 10000 m – 20000 m 20000 m – 30000 m 30000 m – 40000 m > 40000	9 8 7 5 3	[72]

All the vector layers which were converted to raster layers and reclassified for the input to the weighted overlay which finally gave the suitability map. Reclassify tool in Spatial Analyst of ArcGIS standardizes the values of all criteria for comparison as depicted in Figure 5.1.

5.4 Analysis

After the preparation of all required criteria layers, two methods AHP and ROC were implemented to assign the suitable criteria weights.

These weights of criteria have been based totally on previous studies, and experts' opinions. Two groups of experts were formed to give their opinions. The first group for the AHP method and the other group for the ROC method. Each group consisting of ten experts of university professors, aviation engineers, planning engineers, geologists, and experienced individuals in the field of environmental management. Questionnaires were prepared and sent to each group of experts for determining the rank and level of importance for all selected criteria.

5.4.1 Determination of Weights Using the AHP Method

It is obvious that the task of assessing the factor weights is primarily based on the understanding of the factor features and the characteristic of the study zone, in addition to the expert's experience associated with the weight assessment process. However, an effort has been made to improve the weight assigning process as objectively as possible by using techniques such as AHP [16]. Collecting the assessments of experts and apply the arithmetic mean method to obtain the relative importance for every criterion.

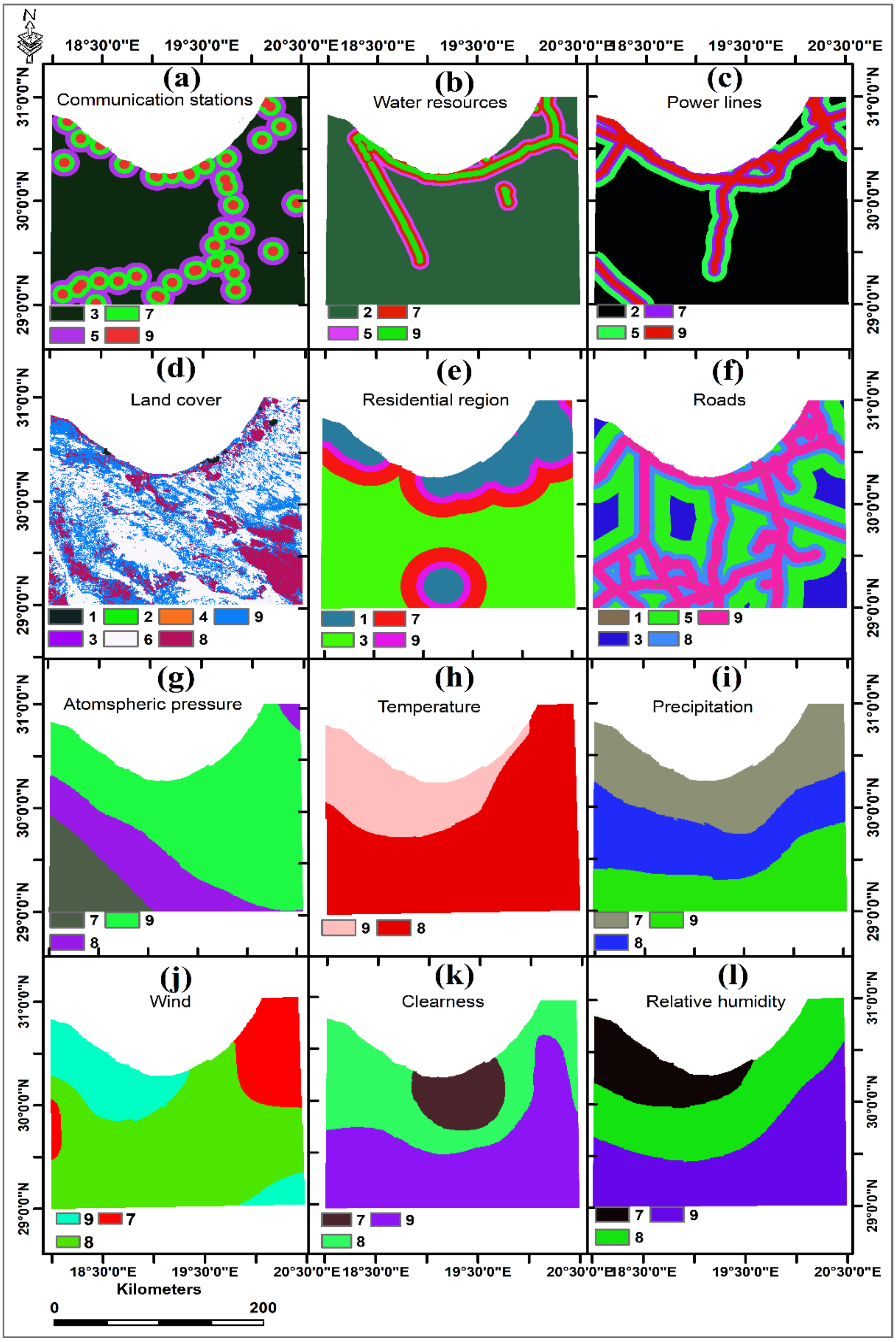
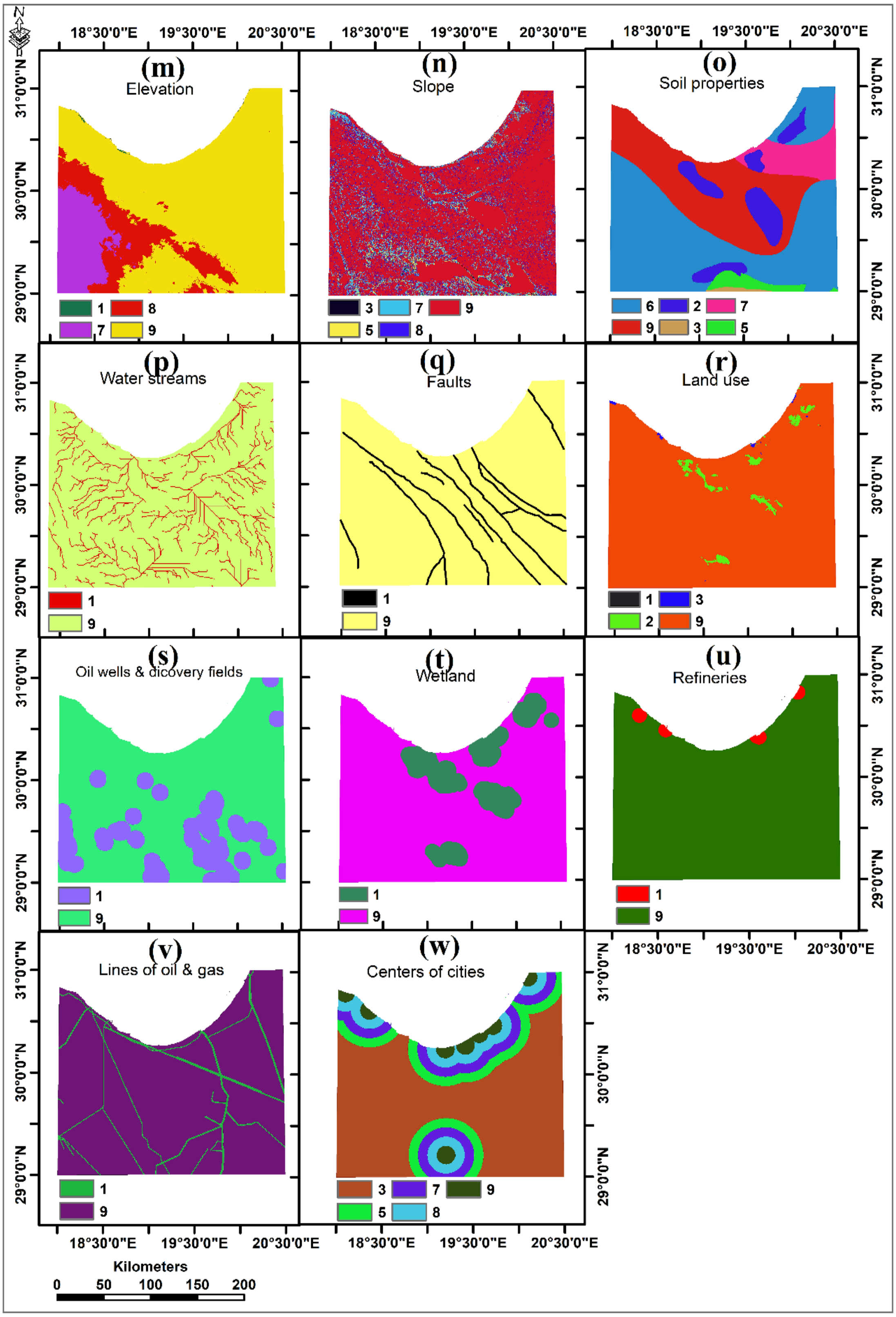


Figure 5.1 Classes determined for (a) Communication stations; (b) Water resources; (c) Power lines; (d) Land cover; (e) Residential region; (f) Roads; (g) Atmospheric pressure; (h) Temperature; (i) precipitation; (j) Wind; (k) clearness; (l) Relative humidity.



Cont. Figure 5.1 Classes determined for (m) Elevation; (n) Slope; (o) Soil properties; (p) Water streams; (q) Faults; (r) Land use; (s) Oil wells and discovery fields; (t) Wetlands; (u) Refineries; (v) Lines of oil and gas; (w) Centers of cities.

Breaking down the issue into a hierarchy of sub-problems that can be more effortlessly understood and subjectively assessed as shown in figure 5.2 and the subjective assessments are changed over into numerical values that are classed on a numerical scale [113].

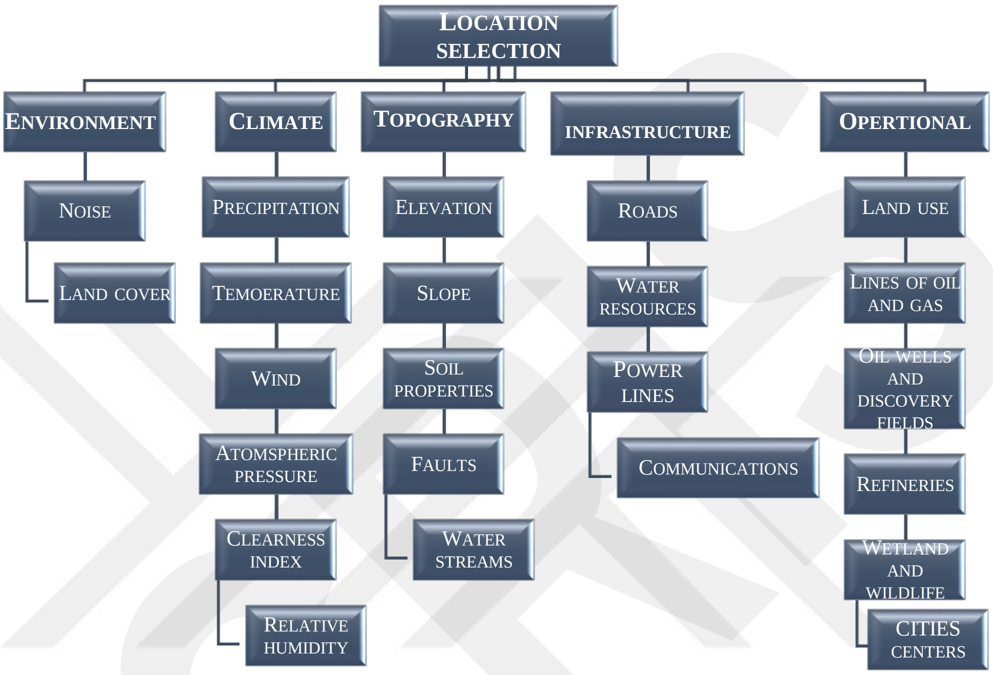


Figure 5.2. The hierarchy diagram of criteria

A series of pairwise comparison matrices (PCM) are formed and the experts are asked to evaluate the relative importance to the criteria for each pairwise comparison matrix by using the nine points of scale as indicated in Table 4.

Starting PCM for the main five criteria as indicated in Table 5.3a

Table 5.3a Comparison matrix of the main criteria

	Environment	Climate	Topography	Infrastructure	Operation
Environment	1	2	1	2	1
Climate	1/2	1	1/2	1/2	1
Topography	1	2	1	1/2	1
Infrastructure	1/2	2	2	1	1
Operation	1	1	1	1	1

$$A=\begin{bmatrix}1 & 2 & 1 & 2 & 1\\ 1/2 & 1 & 1/2 & 1/2 & 1\\ 1 & 2 & 1 & 1/2 & 1\\ 1/2 & 2 & 2 & 1 & 1\\ 1 & 1 & 1 & 1 & 1\end{bmatrix}$$

The reciprocal matrix A implies that criteria weight is obtainable using certain techniques like arithmetic mean. Upon determining a normalized matrix (B), its factors can be identified in the manner below:

$$B=\left[b_{ij}\right], b_{ij}\ =\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad (5.1)$$

$$B=\begin{bmatrix}0.25 & 0.25 & 0.182 & 0.4 & 0.2\\ 0.125 & 0.125 & 0.091 & 0.1 & 0.2\\ 0.25 & 0.25 & 0.182 & 0.1 & 0.2\\ 0.125 & 0.25 & 0.364 & 0.2 & 0.2\\ 0.25 & 0.125 & 0.182 & 0.2 & 0.2\end{bmatrix}$$

The calculation of the weights i.e. eigenvector $w=[w_i]$ form the normalized matrix B is performed by calculating the arithmetic mean for each row of the matrix according to the formula

$$w_{i=}\frac{\sum_{j=1}^{n} b_{ij}}{n} \qquad (5.2)$$

$$Weights\ of\ criteria=\begin{bmatrix}\frac{0.25+0.25+0.182+0.4+0.2}{5}=0.256\\ \frac{0.125+0.125+0.091+0.1+0.2}{5}=0.128\\ \frac{0.25+0.25+0.182+0.1+0.2}{5}=0.196\\ \frac{0.125+0.25+0.364+0.2+0.2}{5}=0.227\\ \frac{0.25+0.125+0.182+0.2+0.2}{5}=0.191\end{bmatrix}$$

The calculated weights of main criteria are arranged in Table 5.3b

Table 5.3b Comparison matrix and significance weight of the main criteria

	Environment	Climate	Topography	Infrastructure	Operation	**Weights**
Environment	1	2	1	2	1	**0.256**
Climate	1/2	1	1/2	1/2	1	**0.128**
Topography	1	2	1	1/2	1	**0.196**
Infrastructure	1/2	2	2	1	1	**0.227**
Operation	1	1	1	1	1	**0.191**

Since the value of pairwise comparison relies on subjective judgment and could cause arbitrary results with bias, so an inspection is required. CR is employed for checking the consistency of the pairwise comparison matrix according to the approach of AHP [136].

Calculation of λ_{max}

$$AxW = \begin{bmatrix} 1 & 2 & 1 & 2 & 1 \\ 1/2 & 1 & 1/2 & 1/2 & 1 \\ 1 & 2 & 1 & 1/2 & 1 \\ 1/2 & 2 & 2 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} 0.256 \\ 0.128 \\ 0.196 \\ 0.227 \\ 0.191 \end{bmatrix} = \begin{bmatrix} 1.356 \\ 0.659 \\ 1.014 \\ 1.196 \\ 1 \end{bmatrix}$$

$$\lambda_{\max} = \left({}^{1}/_{5}\right)\left[\left(\frac{1.356}{0.256}\right) + \left(\frac{0.659}{0.128}\right) + \left(\frac{1.014}{0.196}\right) + \left(\frac{1.196}{0.227}\right) + \left(\frac{1}{0.191}\right)\right] = 5.216$$

$$CI = \frac{5.216 - 5}{5 - 1} = 0.054$$

From Table 4.2 RI = 1.12 for n = 5

$$CR = \frac{CI}{RI} = \frac{0.054}{1.12} = 0.048 < 0.1$$

The PCM is acceptable and the value of the weights is valid.

Applying the same steps for the sub-criteria

Table 5.4 Comparison matrix and weights of the environment sub-criteria

	Noise and pollution	Land cover	**Weights**
Noise and pollution	1	2	**0.67**
Land cover	0.5	1	**0.33**

$\lambda_{max} = 2, CI = 0, CR = 0$

Table 5.5 Comparison matrix and weights of the climate sub-criteria

	Precipitation	Temperature	Clearness index	wind speed	Atmospheric pressure	Relative humidity	**Weights**
precipitation	1	1	0.5	0.5	1	0.5	**0.111**
Temperature	1	1	0.5	0.5	1	0.5	**0.111**
Clearness index	2	2	1	1	2	1	**0.222**
wind speed	2	2	1	1	2	1	**0.222**
Atmospheric pressure	1	1	0.5	0.5	1	0.5	**0.111**
Relative humidity	2	2	1	1	2	1	**0.222**

$\lambda_{max} = 6, CI = 0, CR = 0$

Table 5.6 Comparison matrix and weights of the topography sub-criteria

	Elevation	Slopes	Soil characters	Geological layers	Water stream	**Weights**
Elevation	1	0.5	0.5	0.5	1	**0.120**
Slopes	2	1	1	0.5	0.5	**0.175**
Soil characters	2	1	1	1	3	**0.264**
Faults	2	2	1	1	3	**0.294**
Water stream	1	2	0.34	0.34	1	**0.147**

$\lambda_{max} = 5.328, \quad CI = 0.082, \quad RI = 1.12, \quad CR = 0.07 < 0.1$

Table 5.7 Comparison matrix and weights of the infrastructure sub-criteria

	Roads	Water	Electricity	Communications	**Weights**
Roads	1	0.5	0.5	1	**0.17**
Water	2	1	1	2	**0.33**
Electricity	2	1	1	2	**0.33**
Communications	1	0.5	0.5	1	**0.17**

$\lambda_{max} = 4, CI = 0, CR = 0$

Table 5.8 Comparison matrix and weights of the operational conditions sub-criteria

	Land use	Distance from Wetland	Distance from Oil wells and fields	Distance from Refineries	Distance from Lines of oil and gas	Population	**Weights**
Land use	1	1	2	1	2	0.5	**0.180**
Distance from lakes	1	1	2	1	2	1	**0.198**
Distance from Oil wells and fields	0.5	0.5	1	0.5	1	0.5	**0.099**
Distance from Refineries	1	1	2	1	2	1	**0.198**
Distance from lines of oil and gas	0.5	0.5	1	0.5	1	0.5	**0.099**
Population	2	1	2	1	2	1	**0.226**

$\lambda_{max} = 6.054,\ CI = 0.011,\ RI = 1.24,\ CR = 0.008\ < 0.1$

Tables – 5.3 to 5.8 - shows the calculated CR value and the weights of criteria for every comparison matrix. Table 5.9 is summarizing all values of CR and weights of criteria.

Table 5.9 Weights of criteria using AHP method

Stage 1			**Stage 2**			**Stage 3**
Main criteria	**Weight**	**CR**	**Sub-criteria**	**Weight**	**CR**	**Total weight**
Environment	**0.2564**	**0.048**	Noise and pollution (Distance from residential regions)	**0.67**	**0**	**0.172**
			Land cover	**0.33**		**0.085**
Climate	**0.1282**		Precipitation (mm/day)	**0.11**	**0**	**0.014**
			Temperature C^0	**0.11**		**0.014**
			Clearness index	**0.22**		**0.028**
			Wind speed (m/s)	**0.22**		**0.028**
			Atmospheric pressure (KPa)	**0.11**		**0.014**
			Relative Humidity %	**0.22**		**0.028**
Topography	**0.1964**		Elevation of land above sea level (m)	**0.12**	**0.073**	**0.024**
			Slopes of land %	**0.175**		**0.034**
			Soil Properties	**0.264**		**0.052**
			Distance from faults	**0.294**		**0.058**
			Distance from water streams	**0.147**		**0.029**
Infrastructure	**0.2277**		Proximity to roads	**0.167**	**0**	**0.038**
			Proximity to water resources	**0.333**		**0.076**
			Proximity to power lines	**0.33**		**0.076**
			Proximity to communications stations	**0.167**		**0.038**
Operational	**0.1914**		Land use	**0.179**	**0.008**	**0.034**
			Distance from wetland and wildlife	**0.198**		**0.038**
			Distance from oil wells and discovery fields	**0.099**		**0.019**
			Distance from Refineries	**0.198**		**0.038**
			Distance from Lines of oil and gas	**0.099**		**0.019**
			Proximity to cities centers	**0.226**		**0.043**
			Total Weight			**1.00**

According to the obtained results of the main criteria weights, the environmental and infrastructure criteria were the most important, while the climate and operational criteria were the least important criteria. And for the sub-criteria, the pollution and noise factor were the most important, while the atmospheric pressure factor was the least important.

5.4.1.1Implementation of ArcGIS Modeler Based – AHP

Generating and performing the suitability model is carried out by using ArcMap GIS 10.5 modeler and adding all the re-classified maps of criteria and overlaying all criteria weights. The final output map, which is generated after overlaying the weighted (AHP) factor layers of the study zone, was divided into six classes - 4 to 9 - of suitability indices including average suitability (area = 0.0293% of total area) , average-to-good suitability (10.66%), good suitability (67.02%), very good suitability (20.17%), excellent suitability (1.84%), and perfect suitability (0.027%) as shown in (Figure 5.3).

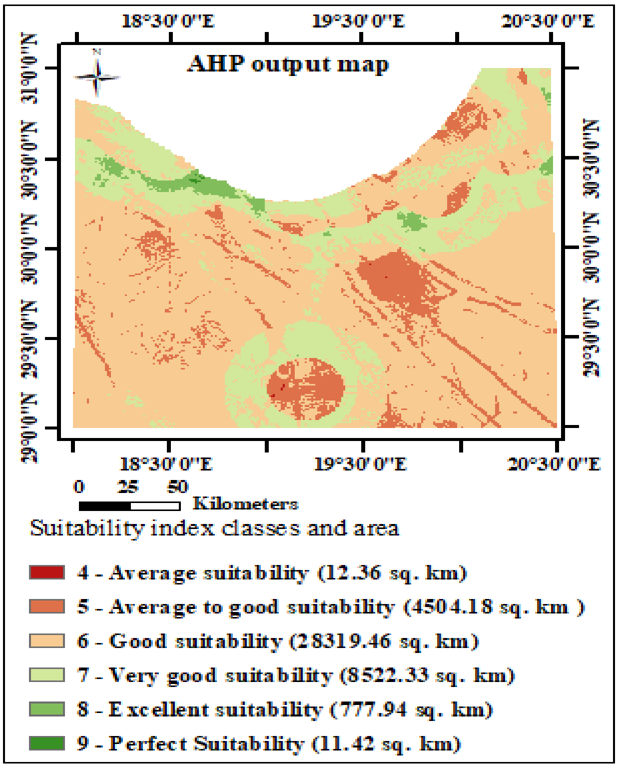


Figure 5.3 Output map of applying AHP method

5.4.2 Determination of Weights Using ROC Method

The ROC weight approach gives an approximation of the weights to scale back the utmost error of each weight by identifying the centroid of all potential weights keeping the order of objective significance.

Questionnaires were aggregated from all experts regarding the ranks of the criteria, then a meeting was held for all experts to discuss their opinions, finally, a compromise agreement was reached for all opinions.

Applying the method of ROC to calculate the weights for each criterion as shown in Table 5.10.

5.4.2.1Implementation of ArcGIS Modeler Based – ROC

Generating and performing the suitability model is carried out by using ArcMap GIS 10.5 modeler and adding all the re-classified maps of criteria and overlaying all criteria weights. The final output map, which is generated after overlaying the weighted (ROC) factor layers of the study zone was divided into six classes - 4 to 9 - of suitability indices, included average suitability (area = 0.166% of total area), average-to-good suitability (5.88%), good suitability (60.05%), very good suitability (29.75%), excellent suitability (3.8%), and perfect suitability (0.095%) as shown in (Figure 5.4).

Table 5.10 Weights of criteria using ROC method

Criterion	**Rank**	$\boldsymbol{Weight\ (w_i) = \frac{1}{n}\sum_{j=i}^{n}\frac{1}{j}}$
Noise and pollution (Distance from residential regions)	1	w_1 = (1/23) (1/1+1/2+1/3+…. +1/23) = 0.162
Land cover	2	w_2 = (1/23) (1/2+1/3+-------+1/23) = 0.119
Distance from faults	3	0.097
Soil Properties	4	0.083
Land use	5	0.072
Proximity to power lines poles	6	0.063
Proximity to water resources	7	0.056
Proximity to roads	8	0.050
Proximity to cities centers	9	0.044
Distance from wetland and wildlife	10	0.039
Distance from Refineries and industrial factories	11	0.035
Distance from Lines of oil and gas	12	0.031
Distance from Oil wells and discovery fields	13	0.027
Wind speed (m/s)	14	0.024
Clearness index	15	0.021
Slope of land %	16	0.018
Precipitation (mm/day)	17	0.015
Temperature C^{O}	18	0.013
Atmospheric pressure (KPa)	19	0.010
Distance from water streams	20	0.008
Relative humidity %	21	0.006
Elevation of land above sea level (m)	22	0.004
Proximity to communications stations	23	0.002
Total weights		**1.000**

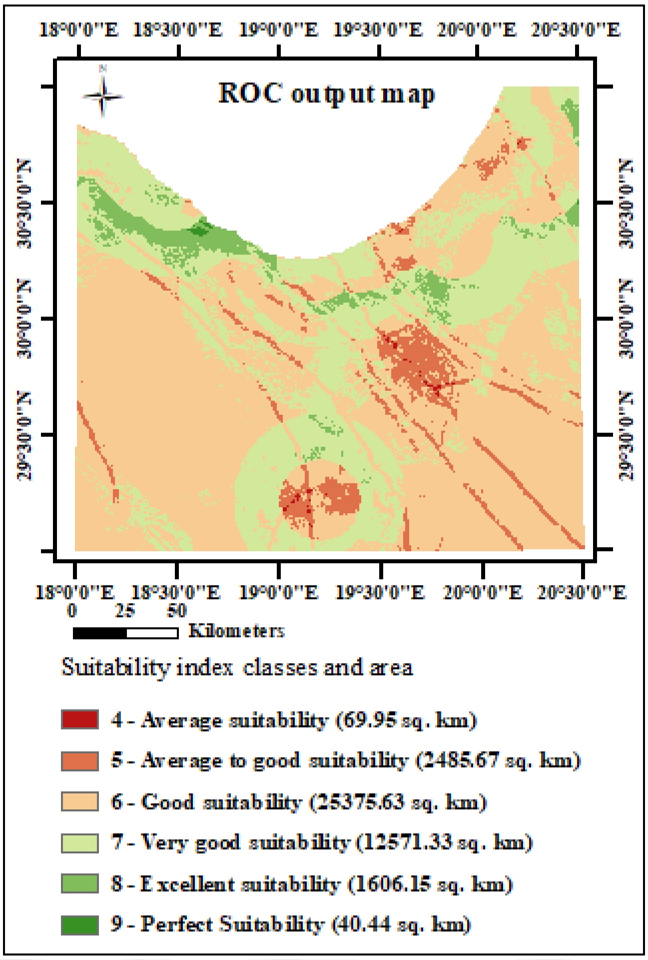
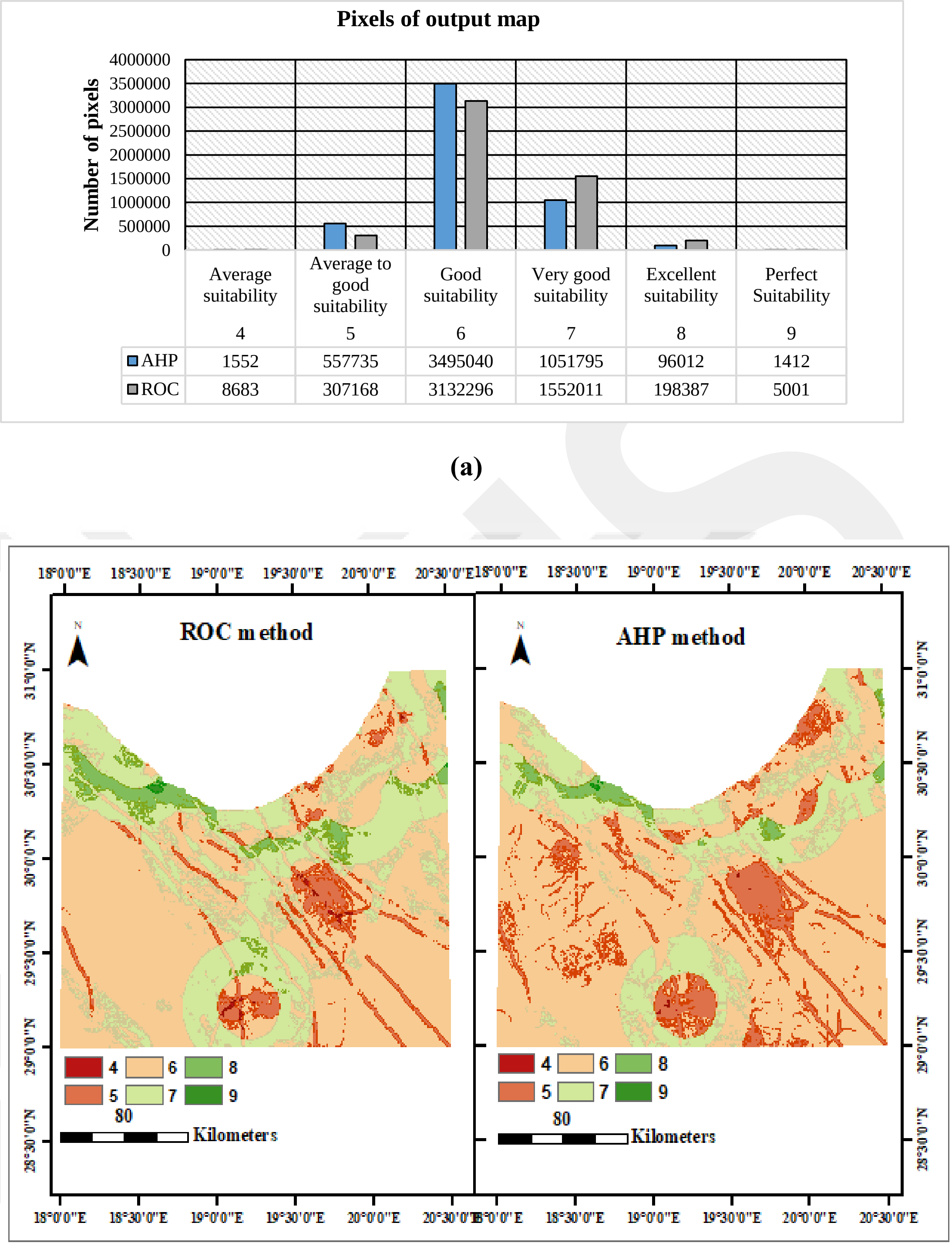


Figure 5.4 Output map of applying ROC method

5.4.3 Comparison of the Results from the AHP and ROC Used

From the obtained result by applying AHP and ROC methods, each output map includes six categories of suitability index categories but, the difference was in pixels units for each as indicated in Figure 5.5a, b.

To know the percentage of matching and non-matching between the output maps, we used the spatial analysis tool “Map Algebra” and applied the command raster calculator to combine the two output maps (the AHP raster map and the ROC raster map).

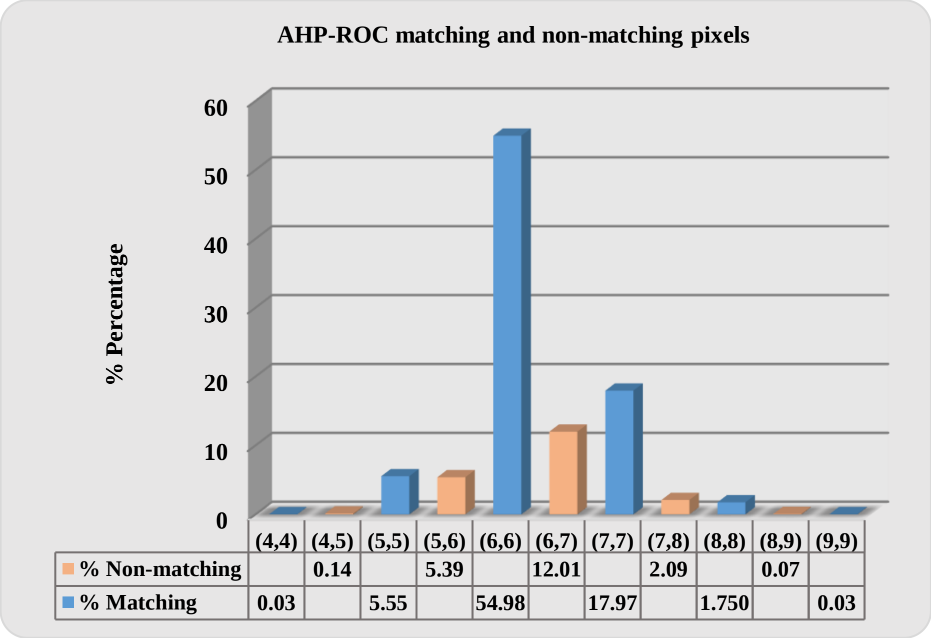


	Average suitability 4	Average to good suitability 5	Good suitability 6	Very good suitability 7	Excellent suitability 8	Perfect Suitability 9
AHP	1552	557735	3495040	1051795	96012	1412
ROC	8683	307168	3132296	1552011	198387	5001

(b)

Figure 5.5 (a) Number of pixels and suitability index resulting from the two output maps. (b) Output map of AHP and ROC.

A final comparison map is, then, obtained including the number of pixels for each suitability index class and the raster categories combined number for AHP and ROC, along with the conformable ratios for each suitability index class used for matching. In this final comparison map, [(4, 4), (5, 5), (6, 6), (7,7), (8,8) and (9, 9)] refer to the pixels of correct classes in both methods, and [(4, 5), (5, 6), (6, 7), (7, 8), (8, 9) and (9, 8)] were considered as acceptable classes. Figure 5.6 indicates the percentage of matching and non-matching classes of suitability index pixel values.



	(4,4)	(4,5)	(5,5)	(5,6)	(6,6)	(6,7)	(7,7)	(7,8)	(8,8)	(8,9)	(9,9)
🟧 **% Non-matching**		**0.14**		**5.39**		**12.01**		**2.09**		**0.07**	
🟦 **% Matching**	**0.03**		**5.55**		**54.98**		**17.97**		**1.750**		**0.03**

Figure 5.6 The percentage of matching and non-matching classes of suitability index pixels values.

Reclassifying the output map of comparison, and later the classes of the identical output number of raster classes, we combined the pixels to arrive at a category of matching zones, and the other classes were combined to produce the category of non-matching areas (acceptance area), as shown in Figure 5.7. The matching pixels in the output map amount to 80.3%, while the non-matching pixels comprise 19.7%. If we summed the matching and non-matching pixels percentages, it can be concluded that the two techniques are compatible with a percentage of 100%.

One of the conditions for the weighting method to be applicable is that the obtained result should be similar or almost the same as the results of various methods evaluated. If the different methods provide different results, the causes for the variance require being analyzed so that a suitable method should be selected to conform with decision-making [123].

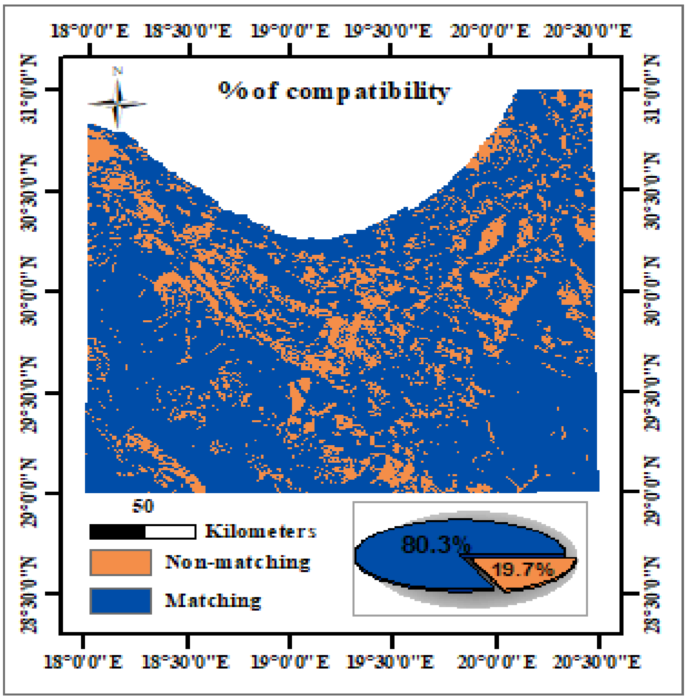


Figure 5.7 The comparison map of ROC and AHP methods and its percentages.

5.4.4 Correlation Coefficient Between the ROC and AHP

To check the correlation between the two methods used for the determination of the criteria weights, correlation coefficients between the ROC and AHP methods were calculated. The correlation coefficient was 0.867, as depicted in Figure 5.8. Consequently, this result indicates a strong relationship between the two different methods evaluated and used in this study. We can say the small differences that occurred between the results of the two used methods were due to the ability of AHP to fine-tune weights more precisely [137]. Also, the results show that the determination of criteria weights by the different teams of experts with the same aim in the decision-making issues will yield almost the same result as long as the experts' evaluation is close together.

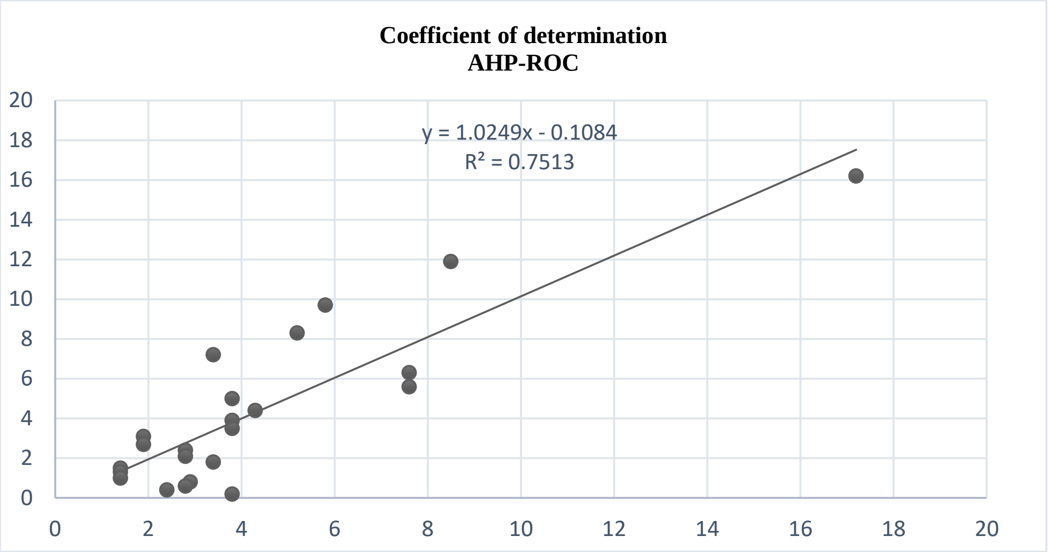


Figure 5.8 AHP-ROC Coefficient of determination

5.4.5 Assessment of Suitability of Candidate Sites

Following the comparison process, three candidate sites were chosen as those meeting the full requirements and located in different locations within the regions of the highest suitability index (i.e., suitability index from 7 to 9). The stated sites were each assigned a letter—A, B, and C—and each covered approximately 50 sq. km (5000 hectares) (see Figure 5.9). In order to determine the best candidate site, a sensitivity analysis was performed.

An overall review of several sensitivity analysis approaches can be found in Saltelli et al. [138] and Campolongo et al. [139]. Numerous analysts have proposed sensitivity analysis approaches that can be applied with particular MCDA strategies. These approaches are utilized to examine the relationship between changes in the weights of criteria and consequent changes within the alternatives rank, that taking after the completion of the decision analysis [140].

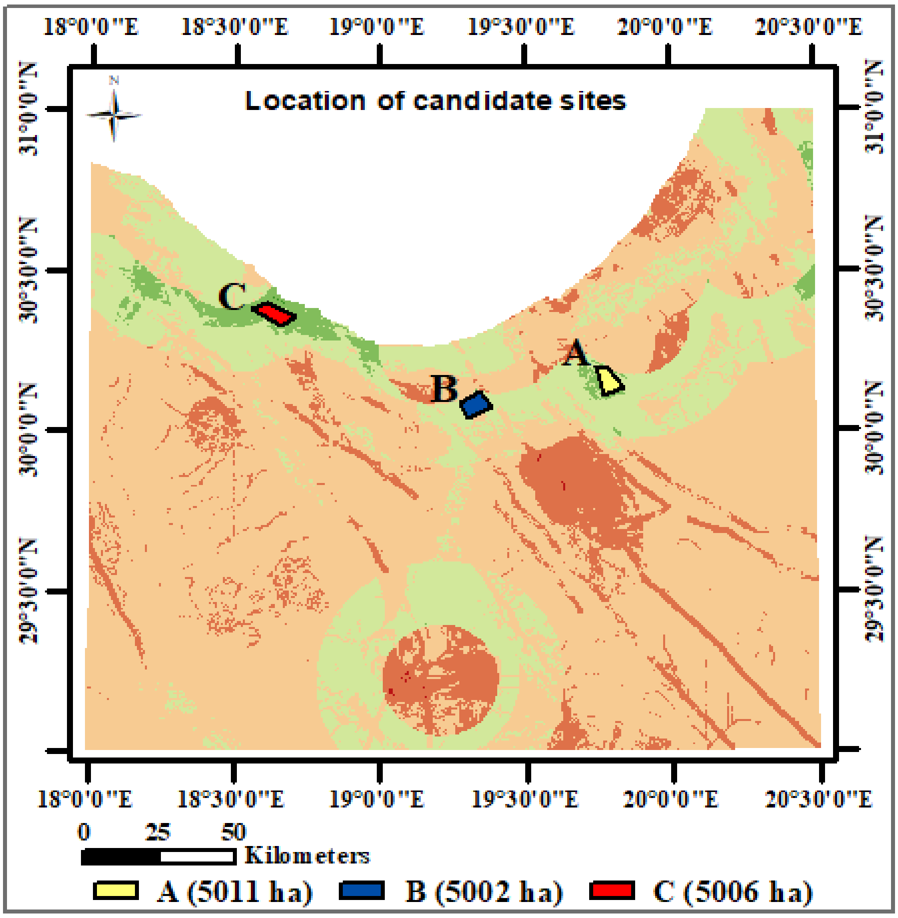


Figure 5.9 Location and area of candidate sites

Chen et al. [141] determined the three most frequently utilized sensitivity analysis methods: specifically, changing the relative significance of criteria, changing the values of criteria, and changing the weights of criteria. Using the method of changes in criteria weights may be more common instead of testing for the changes regarding the criteria values. Dabral et al. [142] considered that there are several basic approaches to evaluating sensitivity analysis, including one at a time (OAT), variance-based methods, and regression analysis. Eldemir et al. [143] considered the sensitivity analysis as a tool that performed to reach a better realization of how the changes in decision criteria factors influence the direct area. Minh et al. [144] conducted a sensitivity analysis to decrease the uncertainty by comparison of the weights of parameters in scenarios, relying on mean values and standard deviation (SD).

In this dissertation (as suggested in Bahrani et al. [145]), the criteria weights related to the environment and infrastructure (input layers) are the highest weights among the rest. To perform the sensitivity analysis of the model, the weights related to these criteria were changed by (± 5%, ± 10%, and ± 15%) to construct six scenarios, with the remaining ones staying as they were initially [145].

The results obtained from the six scenarios show that the range of land suitability index for the intended study zone did not change and stayed within 4 and 9, whereas some changes were visible in the number of pixels in certain locations. To rank the candidate sites A, B, and C, we computed the area of each class of land suitability index in each candidate site for the six scenarios and, then, recorded the changes as shown in Table 5.11.

Accordingly, in scenarios 1, 3, and 5, with increasing the criteria weights, the areas belonging to the suitability index of classes 8 and 9 became better and more increased in site C. On the contrary, in scenarios 2, 4, and 6, with decreasing the criteria weights, those areas which belong to the suitability index of class 8 and 9 became smaller and were deleted from site B.

Comparing the changes that occurred in site A and site C, we noticed that in the latter within all the changes which occurred, scenarios maintained the highest suitability index of class 9, whereas the former (site A) did not have polygons of suitability index 9 except for in one scenario (see Figure 5.10). Finally, site C was selected as the best one among all the candidate sites because it is not affected by the changes in weights of criteria, followed by site A, then site B.

Table 5.11 Areas of candidate sites for six scenarios

Scenarios number	**% change**	**SITE A**				**SITE B**				**SITE C**			
		Suitability index 6	**Suitability index7**	**Suitability index 8**	**Suitability index 9**	**Suitability index 6**	**Suitability index7**	**Suitability index 8**	**Suitability index 9**	**Suitability index 6**	**Suitability index 7**	**Suitability index 8**	**Suitability index 9**
Original	0%	**-**	**330.63**	**4681.18**	**-**	**-**	**4118.76**	**883.80**	**-**	**-**	**-**	**4030.07**	**976.36**
No.1	5%	-	-	5011.79	-	-	2923.08	2079.49	-	-	-	4023.72	982.72
No.2	-5%	-	508.05	4503.81	-	78.39	4802.84	121.33	-	-	-	4245.71	760.72
No.3	10%	-	-	5011.79	-	-	668.89	4333.68	-	-	-	3208.91	1791.35
No.4	-10%	-	1224.80	3787.06	-	335.27	4667.29	0	-	-	-	4545.22	461.21
No.5	15%	-	-	4909.69	102.11	-	274.92	4727.64	-	-	-	2641.70	2358.97
No.6	-15%	-	1563.86	3448.00	-	462.07	4540.50	-	-	-	-	4544.81	461.21
Area of site		TOTAL AREA OF SITE A = 5011.857 ha				TOTAL AREA OF SITE B = 5002.564 ha				TOTAL AREA OF SITE C = 5006.431 ha			

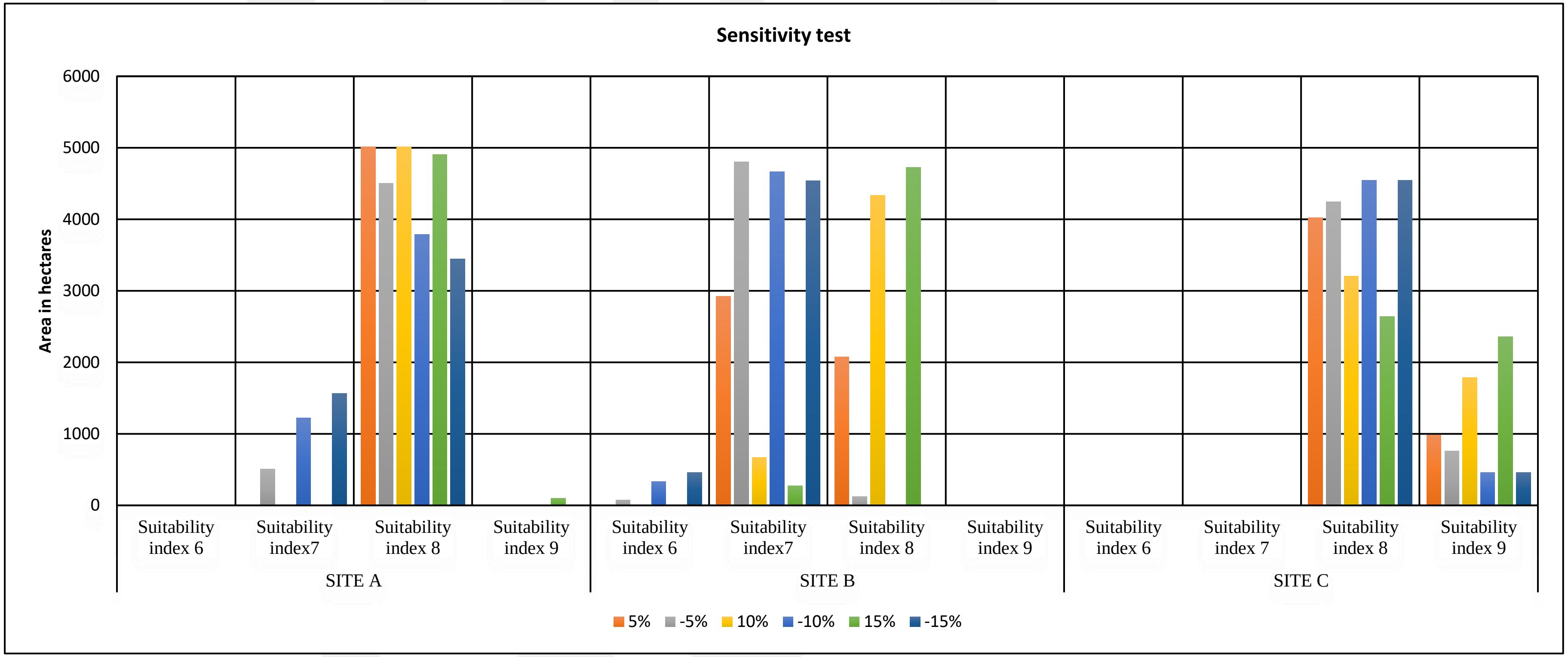


Figure 5.10 Distribution of suitability index resulting from sensitivity test

5.5 Business Continuity

Airports play a crucial role in linking people, promoting trade, sustaining communities and economies, and protecting the national interests of a country. Therefore, any deficiency in the functions of the airport will not only lead to aircraft delays and other enormous disadvantages for airport customers but could also tarnish their domestic reputation or image, even harm the economy and essential operations. All airports across the globe could experience disasters and hazards at any moment and, as such, the very nature of the present study is to reduce avoid the effects of such disasters and risks via selecting the right airport location.

Sometimes the GIS model can't find the location that fulfillment all the required criteria with a class of the highest one. Thus, a business continuity study was done to ensure the selected location will stay well-positioned to recuperate from the business interruption, construction damage, financial effect, and loss of life that a natural disaster or man-made event may cause. Besides, considering the accessibility of the alternative airport, and the ability of staff and stranded passengers to travel to an alternate airport.

5.5.1 Natural Disasters

Oftentimes, threats that occur naturally do not arise from human interference or rely on it; rather, they involve earthquakes, landslide, and volcanic eruptions as well as the meteorological phenomena such as tornadoes, winter storms, floods, lightning strikes, and wildfires. Some of these threats can be predicted before they take place, such as weather-related events, for which there is usually sufficient time for preventive measures. On the other hand, some threats such as earthquakes may be predicted, but it is difficult to pre-estimate the time of occurrence and the extent/scope of their impact [146].

5.5.1.1 Weather Conditions

Extreme weather conditions are occurrences that interfere with ordinary flight schedules, causing airport, airline, and passenger disruptions. Referring to the study zone and the selected location, we noticed that all the collected meteorological data as regards precipitation, temperature, clearness index, wind speed, atmospheric pressure, and relative humidity were satisfied and within the specification limits.

5.5.1.2 Geography

The hydrological study was conducted to determine the water streams and watershed locations as seen in Figure 5.11a. The selected sites A and B were located at the outer edge of the watersheds, whereas site C is completely outside. All the selected sites were far away from water streams and, hence, in safe locations from the proximity of flood plains. In this study, we avoided the areas susceptible to immediate earthquake damage. Also, all the selected sites are far away from volcanoes and faults (see Figure 5.11b). For avoiding hazardous terrain, we selected the areas of almost levelled-ground with a safe slope (see Figure 5.11c). For emergency conditions, we considered the accessibility of the alternative airport, the ability of staff and stranded passengers to travel to an alternate airport. This consideration includes the methods of transportation via the closest highway, the distance to the closest airport in that region, and the communication means with the civil aviation authorities and government (see Figure 5.11d). All the selected sites are considered close to the main infrastructures, such as major roads, water resources, electricity, and communications. And for avoiding any unexpected events, we can build huge water tanks and installing electrical generators and using internet networks while the Loss of communications lines.

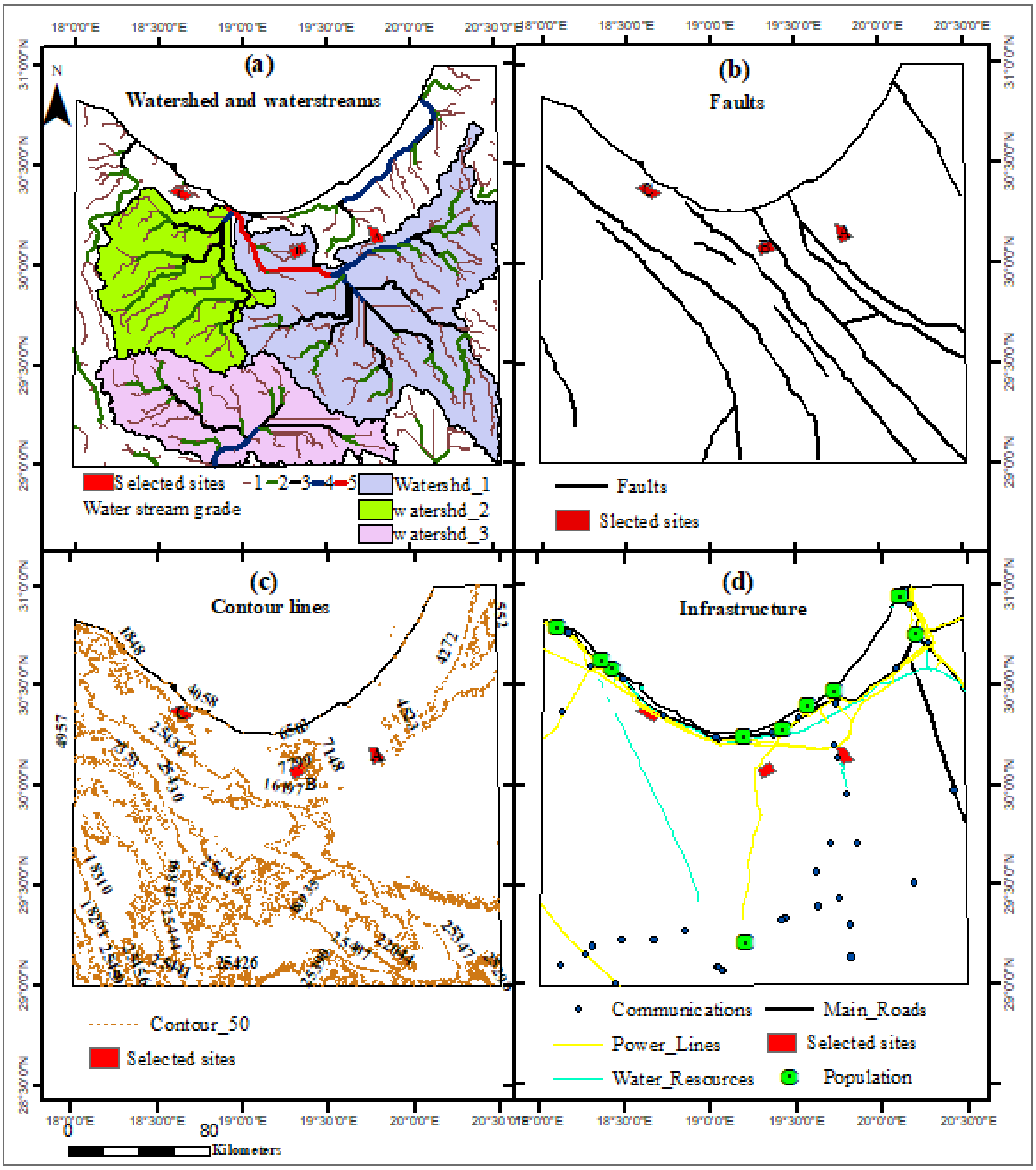


Figure 5.11 Resulted map of business continuity study

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

This dissertation presents the combination of AHP and ROC techniques, integrating GIS, and utilizing the environmental and multi-scientific criteria, which are pursued in the advanced countries, and represents an efficient and proficient technique in the process of selecting an appropriate site for the airport in Libya.

Twenty-three input layers were entered into the process of an overlaying analysis with GIS to solve the issue of airport site determination in the proposed region, with the ArcGIS 10.5 software technique having a high capacity to manipulate a huge volume of data from different sources.

These layers were the distance from residential regions (noise and pollution), land cover, precipitation, temperature, clearness index, wind speed, atmospheric pressure, relative humidity, elevation of land above sea level, the slope of the land (%), soil characteristics, distance from faults, distance from water streams, proximity to roads, proximity to water resources, proximity to power lines, proximity to communications stations, land use, distance from wetland and wildlife, distance from oil wells and fields, distance from refineries and industrial factories, distance from lines of oil and gas and the proximity to city centers.

The weights of criteria were derived from the AHP and ROC methods depending on the local features of the study zone, applicable rules, regulations, literature review of previous researches, and the opinion of experts.

The two output maps which were generated after applying both weighting methods AHP and ROC in the study zone had resulted in the same six classes - 4 to 9 – of suitability indices with a small difference in the areas of suitability indices in each map for each class, which included average suitability, average-to-good suitability, good suitability, very good suitability, excellent suitability, and perfect suitability.

A comparison of the two resulting maps was made, and the proportion of matching pixels was found to be 80.3%, while the proportion of non-matching pixels was 19.7 %. Also, the correlation analysis indicates a positive relationship (R = 0.867) between the AHP and ROC methods. Thus, the ROC method is considered practical and effective.

Three sites were candidates for the airport location among several sites in the places which had the highest suitability index in the final map. Then, a sensitivity analysis was conducted to evaluate the reliability of the used method and the ranking of the candidate sites. The obtained results show that site C perfectly outranked the other candidate sites despite the differences in the decision weights within a range of ±15%. Finally, a business continuity study was applied in this dissertation from the perspective of the location to ensure the avoidance of any potential natural catastrophe.

Validation is an essential part of the site selection operation to determine and confirm the suitability of the specific sites. However, within this research, to evaluate and validate the accuracy of the maps generated, field checks and a satellite image analysis confirmed the proposed sites agree well with the result of the model.

It is expected that this study will serve as a guideline for future studies and applications of airport location and other facilities.

This study will contribute to the future of Libya in the following ways:

- The proposed airport location between two existing airports, the distance between them is more than 600 km, will be very beneficial for the residents of that zone and oil companies’ employees.
- Adding important outcomes that may result in providing better service for the Libyan public.
- It must be taken into consideration that an airport represents an important investment in the infrastructure and that its contribution to communications development can be a significant motivation for regional expansion in that

region.

- Applying an already-known method to a new area and a new scope of work that enhances the importance of using GIS. Furthermore, this study can serve as a pioneer work in future studies to be implemented for Libya.

Future Work

For further future works, the cost factor could be added to the criteria to ensure the closest site concerning the resources of manpower and material of construction.
It has to be asserted that the GIS-based MCDA technique provides a local index of suitability, aiming to identify the best-required locations rather than areas that are inappropriate or restricted, in which additional geotechnical analyses need to be carried out before making the final decision.

The study results indicate the accuracy in the performance of the model applied here for airport site selection in Libya that is very compatible with the actuality in the field. Thus, it could be assigned as a decision-supporting tool for decision-makers and planners. Besides, this approach seems to be very promising in the direction of employing scientific tools to rationalize optimal site selection in major transport projects and other facilities' locations.

As far as the author knows, using GIS to determine the appropriate location of an airport is considered one of a few research types in this field, especially with the use of layers such as climate, among the required criteria.

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APPENDIX

This research study contributes towards the requirements for a PhD degree at
Atilim University in Ankara, Turkey
Research Topic: Combining AHP and ROC with GIS for airport site selection:
A case study in Libya

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Supervisors Assoc. Prof. Dr. Turan Erman Erkan (erman.erkan@atilim.edu.tr)

Dear Sir/Madam,

Completing this questionnaire should require less than 20 minutes. We plan to benefit from your knowledge and experience to determine the weights of criteria which will be used with geographical information system (GIS) for determining the suitable location of an airport in Libya. For this purpose, please fill all the tables in this questionnaire. Two methods will be used for determining the criteria weights, the first one is the analytical hierarchy process (AHP), and the second is rank order centroid (ROC).

Study zone

This area is located in the northern part of Libya between longitude lines from18˚00' 00" to 20˚30' 00" E and latitude lines from 29˚00' 00" to 31˚00' 00" N, its area about (42254) km^{2}, as depicted in (Figure 1).

Climate conditions

The average climate condition in study zone as the following:

Wind: from 14 km/hr to 17 km/hr

Precipitations: from 0.52 mm/day to 1.21 mm/day

Temperature: from 27 C^{o} to 37 C^{o}

Atmospheric pressure: from 99 KPa to 101.5 KPa

Clearness index: from 0.081 to 0.31

Relative humidity: from 42.48 % to 68.77 %

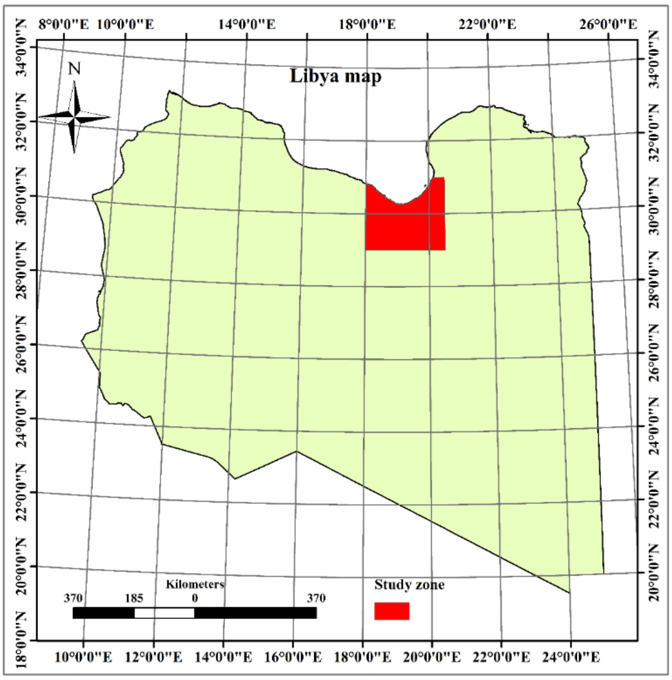

Figure 1. Location of study zone

Infrastructure benefits: (See figure. 2a below)

Faults and petroleum lines and fields: (See figure. 2b below)

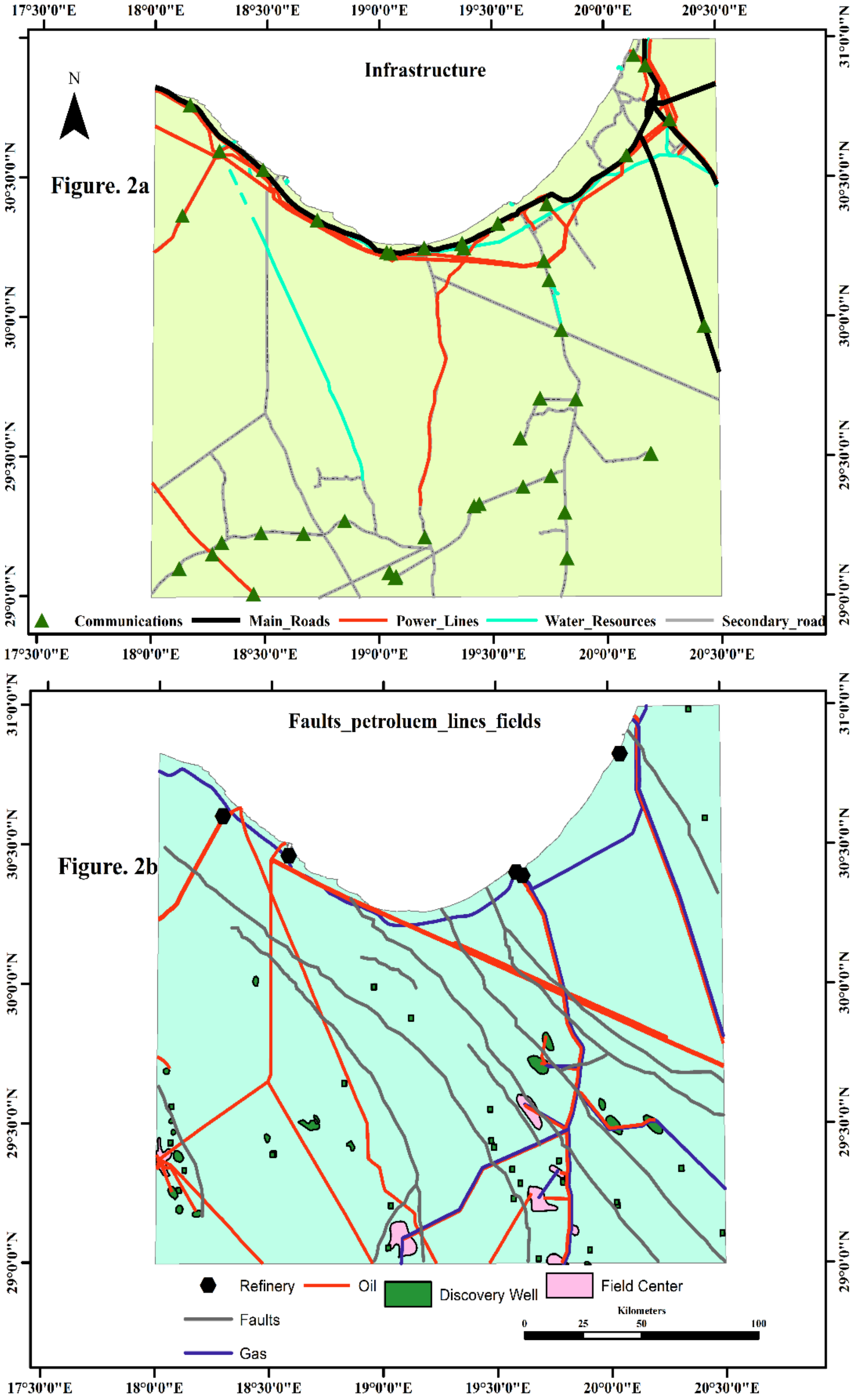

Figure. 2 a-Infrastructure benefits, b- Faults and Petroleum lines and fields

Introduction

The identification of a new airport site is a difficult task that involves the consideration of multiple criteria. Taking into account the specific characteristics of the area that will accommodate the airport project, some of these criteria become higher in priority in relation to other criteria. all the relevant criteria in this research have been based totally on the local features of the study zone, applicable rules, regulations, literature review of previous researches, and availability of the data including maps, documents, etc.

The decision criteria used for selecting airport locations were classified into five main categories; namely, environmental considerations, topographical conditions, climatic factors, infrastructure facilities, and operational conditions. Each main criterion includes sub-criteria and each sub-criterion is classified as well. Thus, the total number of the applied criteria is twenty-three as follows:

Distance from residential regions (noise and pollution), land cover, precipitation (mm/day), temperature (C^o), clearness index, wind speed (m/sec), atmospheric pressure (KPa), relative humidity, elevation above sea level (m), slopes of land (%), soil characteristics, distance from faults, distance from water streams, proximity to roads, proximity to water resources, proximity to power lines, proximity to communications stations, land use, distance from wetland and wildlife, distance from oil wells and fields, distance from refineries and industrial factories, distance from lines of oil and gas and proximity to population centers.

Name and Surname …………………………………………………….

Email …………………………………………………………………….

AHP method

The approach decomposes a complicated decision issue into less complicated ones to structure a hierarchy of decisions. A series of pairwise comparison matrices (PCM) are formed and the experts are asked to evaluate the relative importance to the criteria for each pairwise comparison matrix by using the nine points of scale as indicated in Table below:

Value of a_{ij}	**Interpretation**
1	Objective *i* and *j* are of equal importance.
3	Objective *i* is moderate importance than objective *j*.
5	Objective *i* is strong importance than objective *j*.
7	Objective *i* is very strong importance than objective *j*.
9	Objective *i* is extreme importance than objective *j*.
2,4,6,8	Medium values

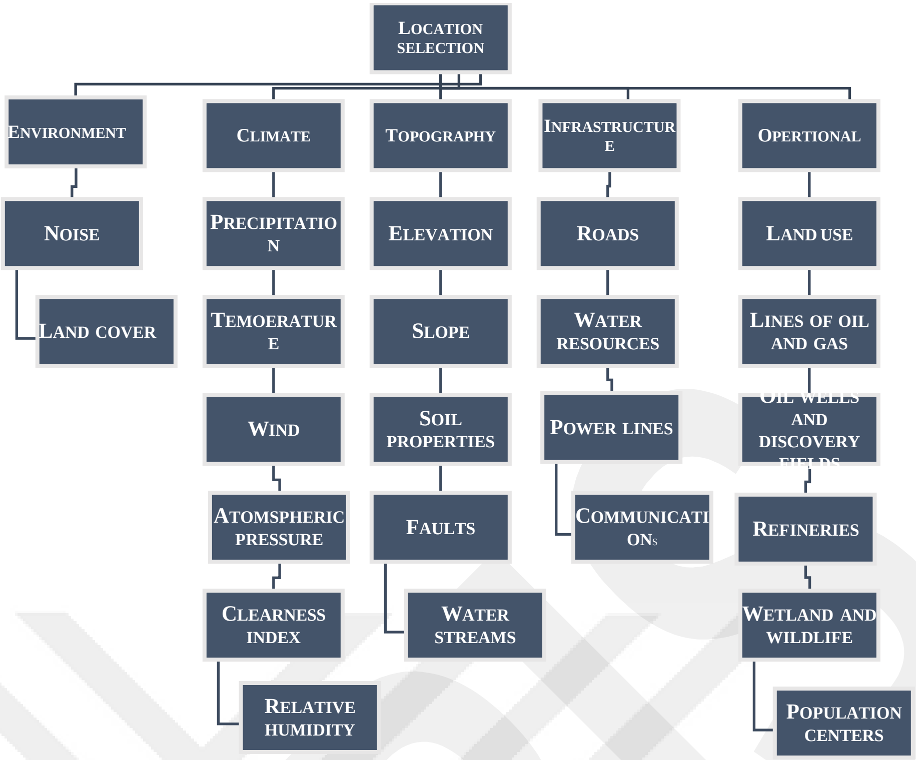

Fig. 3 Hierarchy diagram of criteria and sub-criteria

A) Main criteria

	Environment	Climate	Topography	Infrastructure	Operation condition
Environment	1				
Climate		1			
Topography			1		
Infrastructure				1	
Operation condition					1

B) Sub-criteria of Environment

	Noise and pollution	Land cover
Noise and pollution	1	
Land cover		1

C) Sub-criteria of climate

	Precipitation mm/day	Temperature C^o	Clearness index	wind speed m/s	Atmospheric Pressure kPa	Relative Humidity %
Precipitation mm/day	**1**					
Temperature C^0		**1**				
Clearness index			**1**			
Wind speed m/s				**1**		
Atmospheric Pressure kPa					**1**	
Relative Humidity %						**1**

D) Sub-criteria of topography

	Elevation above sea level	Slope of land	Soil characters	Faults	Water stream
Elevation above sea level	**1**				
Slope of land		**1**			
Soil characters			**1**		
Distance from faults				**1**	
Distance from water stream					**1**

E) Sub-criteria of infrastructure

	Proximity to roads	Proximity to water resources	Proximity to Power lines poles	Proximity to Communications stations
Proximity to roads	1			
Proximity to water resources		1		
Proximity to Power lines poles			1	
Proximity to communications stations				1

F) Sub-criteria of operational conditions

	Land use	Distance from Wetland	Distance from Oil wells and fields	Distance from Refineries	Distance from Lines of oil and gaz	Distance from Population centers
Land use	**1**					
Distance from lakes		**1**				
Distance from Oil wells and fields			**1**			
Distance from Refineries and industrial factories				**1**		
Distance from Lines of oil and gaz					**1**	
Distance from Population centers						**1**

Thank you for your participation. Your assistance is greatly appreciated

Name and Surname ……………………………………………………………

Email ………………………………………………………………………

ROC method

Please rank the following criteria according to its importance (number 1 means the most important and number 23 is the least one)

Criterion	Rank
Noise and pollution	
Distance from faults	
Proximity to Power lines poles	
Proximity to roads	
Distance from Oil wells and discovery fields	
Precipitation (mm/day)	
Atmospheric pressure (Kpa)	
Relative humidity %	
Proximity to communications stations	
Distance from wetland and wildlife	
Elevation above sea level	
Wind speed (m/s)	
Temperature C^o	
Distance from water streams	
Land use	
Proximity to cities centers	
Slope of land %	
Soil properties	
Proximity to water resources	
Distance from Lines of oil and gas	
Distance from Refineries and industrial factories	
Land cover	
Clearness index	

Thank you for your participation. Your assistance is greatly appreciated