"Identification of Suitable Sites for Solar Energy Harvesting Plants in Northern Borders Region of KSA, Using GIS-Based on Multi-Criteria Modeling"

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Abstract:
Solar energy is the cleanest and most abundant renewable energy source. Solar technologies may generate electricity, desalinate seawater, and heat water. In 2017, renewable power accounted for 70% of net additions to global power generating capacity, with an estimated 178 GW added globally. Saudi Arabia has one of the greatest solar radiation rates in the world, 2200 kWh/m2/y. To meet demand, Saudi Arabia proposes producing clean, cost-effective solar energy using contemporary technologies. 41 GW gradually till 2032.

The study collected data from government agencies and open sources, determined the study's criteria, created a geodatabase, and considered the unification of technical, economic, and environmental criteria to determine the best sites for solar energy projects in the Northern Borders Region. GIS was utilized in this study to select sites using multi-criteria analysis (MCA). Criteria were weighted by importance using the Analytical Hierarchy Process (AHP). The weight consistency ratio was evaluated for reliability, and the results were significant. The appropriateness index was calculated from weighted criteria and limitations.

With 58696 sq. km, the study found that more than 50% of the Northern Borders Region is suitable for solar energy projects. Most eligible locations with a rate over 80% are 8499.5 sq. km from the Northern Borders Region. The results also show that the centre and west of the Northern Borders Region, particularly Arar and Turaif, are the most suited places. The Turaif governorate has the greatest appropriateness rating above 90%. It is the largest suitable portion of the research area at 1554.8 sq. km and constitutes 1.4% of the Northern Borders Region.

A report advises that Northern Borders Region decision-makers use its findings when building solar projects. The final suitability model produced using technological, economic, and environmental criteria should be applied to additional regions and scales.

الملخص:

الطاقة الشمسية هي مصدر الطاقة المتجددة الأنظف والأكثر وفرة. وتعمل تقنيات الطاقة الشمسية على توليد الكهرباء، وتحلية مياه البحر، وتسخين المياه. وفي عام ٢٠١٧، شكلت الطاقة المتجددة ٧٠% من صافي الإضافات إلى قدرة توليد الطاقة العالمية، مع إضافة ما يقدر بنحو ١٧٨ جيجاوات على مستوى العالم. تتمتع المملكة العربية السعودية بواحد من أعلى معدلات الإشعاع الشمسي في العالم، ٢٢٠٠ كيلووات ساعة/م٢/سنة. ولتلبية الطلب، تقترح المملكة العربية السعودية إنتاج طاقة شمسية نظيفة وفعالة من حيث التكلفة باستخدام التقنيات الحديثة. ٤١ جيجاوات تدريجياً حتى عام ٢٠٣٢.

قامت الدراسة بجمع البيانات من الجهات الحكومية والمصادر المفتوحة، وحددت معايير الدراسة، وإنشاء قاعدة بيانات جغرافية، ونظرت في توحيد المعايير الفنية والاقتصادية والبيئية لتحديد أفضل المواقع لمشاريع الطاقة الشمسية في منطقة الحدود الشمالية. تم استخدام نظم المعلومات الجغرافية في هذه الدراسة لاختيار المواقع باستخدام التحليل متعدد المعايير .(MCA) تم ترجيح (وزن) المعايير حسب الأهمية باستخدام عملية التسلسل الهرمي التحليلي .(AHP) تم تقييم نسبة اتساق الوزن من أجل الدقة والموثوقية، وكانت النتائج ذات أهمية. تم حساب مؤشر الملاءمة من المعايير الموزونة والقيود.

على مساحة قدرها ٥٨٦٩٦ كيلومتراً مربعاً، وجدت الدراسة أن أكثر من ٥٠% من منطقة الحدود الشمالية صالحة ومناسبة لمشاريع الطاقة الشمسية. وأن المواقع المؤهلة بنسبة تزيد عن ٨٠% وتمثل ٨٤٩٩,٥ كيلومتر مربع من منطقة الحدود الشمالية. كما أظهرت النتائج أن وسط وغرب منطقة الحدود الشمالية، وخاصة محافظات عرعر وطريف، هي الأماكن الأكثر ملاءمة. حيث حصلت محافظة طريف على أعلى نسبة ملاءمة تزيد عن ٩٠%. وهي الجزء الأكثر ملاءمة من منطقة الدراسة بمساحة ١٥٥٤,٨ كيلومتر مربع وتشكل ١,٤% من مساحة منطقة الحدود الشمالية.

يوصي التقرير صناع القرار في منطقة الحدود الشمالية أن يضعوا نتائج الدراسة في الاعتبار عند بناء مشاريع الطاقة الشمسية بالمنطقة. وينبغي تطبيق نموذج الملاءمة النهائي الذي تم إنتاجه باستخدام المعايير التكنولوجية والاقتصادية والبيئية على مناطق ومقاييس إضافية.

Chapter-1: Introduction

1.1. Background

The rapid pace of industrial and technological process in the world has led to an increase in demand for energy, and we are faced with an unavoidable fact that fossil fuels will inevitably be implemented, Oil and gas reserves will hardly be available after 40 and 65 years respectively (Mwasha and Iwaro 2010). Renewable power accounted for 70% of net additions to global power generating capacity in 2017, Renewable power generation capacity saw its largest annual increase ever with an estimated 178 GW added globally. New solar photovoltaic generating capacity alone was greater than additions in coal, natural gas, and nuclear power combined.
The Middle East and North Africa (MENA) region has a vast abundance of renewable energy resources. With its strong demographic growth, rapid urbanization and an expanding economy, the MENA region are experiencing a strong growth in demand for energy and electricity. The MENA Renewables Status Report, produced by the International Renewable Energy Agency (IRENA), and the United Arab Emirates, and released in June 2013 as an outcome of the Abu Dhabi International Renewable Energy Conference, provides a status overview of renewable energy markets, industry, policy and investment trends in the region, The most recent data available indicate to massive growth in the renewable energy markets of the Middle East and North Africa (MENA). Regional investment topped US$2.9 billion in 2012, up 40% from 2011 and 650% from 2004. With over 100 projects under development, the region could see a 450% increase in non-hydro renewable energy generating capacity in the next few years (REN21- Renewable Energy Policy Network For the 21st Century).
At the level of the Gulf countries, some Arab Gulf countries have started investing heavily in renewable energy sources, especially solar energy in the last few years (Bhutto et al. 2014, 168). Where Kuwait targets to achieve 15% of its needs by 2020, Oman 10%, And kingdom Of Bahrain 5% of its power needs (Darwish and Shaaban 2016). The Kingdom of Saudi Arabia is characterized by abundant solar energy sources, where Saudi Arabia is one of the highest rates of solar radiation in the world. Saudi Arabia aims to develop modern technologies, clean and cost-effective solar energy to meet the high demand, especially in the summer months by proposing production A total of 41 GW gradually until the year 2032. On this basis, Saudi Arabia is planning to introduce renewable energy as part of the Kingdom's energy mix, in order to reduce the demand for exportable fossil fuels. Solar energy will be a key technology, due to the high of direct normal irradiance (DNI) resource of an average 2200 kWh/m2/y (Alawaji 2001). Studies on solar energy include two types: photovoltaic power and concentrated solar power. Photovoltaic power (PV) are the projects involved in this research. Photovoltaic cells consist of solar panels that allow direct sunlight to be converted into electrical energy. These panels can be collected in fields directly connected to the national grid using a solar-powered, AC-compatible reflector. Saudi Arabia is seeking to build enough photovoltaic capacity to produce 16 GW by 2032. The most important benefits of photovoltaic cells are their simplicity, flexibility in construction, accuracy and low operating expenses (K.A.CARE-King Abdullah City for Atomic and Renewable Energy). The interest in solar energy began in Saudi Arabia early four decades ago when a French team operated a navigation system at Medina airport based on photovoltaic power. The most important steps were taken in 1994, when Saudi Arabia launched the (Energy Saudi Atlas) project In cooperation with the Energy Research Institute of King Abdul Aziz City for Science and Technology and the American National Institute of Energy Research, to conduct accurate measurements of solar radiation in the lands of Saudi Arabia (Hepbasli and Alsuhaibani 2011, 5021). Energy consumption has risen dramatically in Saudi Arabia over the past decade more than doubled between 2003 and 2012 (Fattouh 2013). And Saudi Arabia relies on fossil fuels for 65% and gas for 27% for its electricity and desalination needs. Despite Saudi Arabia's huge fossil fuel reserves, Saudi Arabia is looking ahead with ambitious plans to reach 50% of Saudi Arabia's 2032 renewable energy needs (Nizami et al. 2015; Tlili 2015, 859). And aims to reach 41GW of solar power by routing great investments in this field (AlYahya and Irfan 2016, 697). The Kingdom of Saudi Arabia has taken great steps to achieve its ambitious plan at the level of scientific research and provision, availability and sharing of data. The Kingdom established the King Abdullah City for Atomic and Renewable Energy in 2009 and the city launched the Atlas of renewable sources of energy on the Internet, which aims to create a database serving Renewable energy projects for the electricity generation and desalination, and aims to create a situation of scientific and research momentum in the field of renewable energy.
In terms of the techniques and software used in this field, The geographic information system (GIS) is the best framework for collecting, storing, processing and analyzing spatial data and integrating it with non-spatial data, as well as wide possibilities in presenting results, maps and reports. The Multi-Criteria Analysis (MCA) aims to examine the possibility of the availability of several naturals, environmental and economic Criteria in a specific location in order to reach solutions and the best alternatives to support decision makers. The multi-criteria GIS method is used in many fields to determine the most suitable locations such as Land use planning by Zhanga et al. (2015, 2264), and Colantoni et al (2016). Nuclear power plants by Abudeif et al. (2015), Solid

waste treatment plants by Hassaan (2015), Water harvesting by Inamdar et al. (2013), Wind farm development by Hansen (2005, 75 - 87), and forest fires by GIGOVIĆ et al. (2018). At the level of Saudi Arabia, Dawod (2013, 313) applied the multi-criteria GIS method in determining the best locations for the establishment of tourist facilities in Al-Hada city, east of Makkah.
As for the topic of this research, The study targeted to determine the most suitable sites for the harvesting of solar energy using the multi-criteria GIS in the Northern Borders Region in Saudi Arabia, The solar energy projects depend critically on the choice of the site and provide several spatial and environmental criteria at a high proportion in this site. The geographic information system (GIS) using the multi-criteria method is the ideal template for efficiently Implementation of this task to support decision-makers, provide solutions and spatial alternatives.
Janke (2010, 2228) studied the solar and wind power potential of Colorado using both GIS and a multi-criteria membership analysis. The study considered incoming solar radiation, environmental and land use considerations, Castillo et al. (2016, 86) have presented a study to assess the potential of solar power generation in the EU countries using the multi-criteria GIS method. In Spain, Wanderer and Herle (2015, 2- 8) developed a website to study the most suitable solar harvesting sites using multi-criteria analysis (MCA). Also Matejicek (2015) applied the multi-criteria GIS method to determine the most suitable solar harvesting sites in the Czech Republic, Dawod and Mandoer (2016, 450) in studied the optimum sites for solar energy harvesting in Egypt based on multi-criteria GIS.

1.2. Objectives

Objective 1.(Data Preparation And processing)
This objective included several processes, such as data format conversion, clipping, digitizing, and buffering, were expressed in a base geographical coordinate system WGS 1984, then uniform projection system into WGS 1984 UTM Zone 38N.
Objective 2. (Site Suitability Criteria)
This objective included setting suitability criteria such as solar radiation, slope, highways/roads/railways, transmission lines, major cities, valleys, airports, and international boundaries line. With incorporating geographical and technical constraints, such as urban development area and protected /sensitive areas. Also, this objective included setting scales for each criterion and setting weights for each criterion by using the AHP method to get an overall rating for these criteria.
Objective 3. Development of Multi-Criteria Analysis (MCA)
Implement a multi-criteria analysis method to establish an MCA model to help the decision-makers In selecting the most suitable sites for solar energy projects. In this Objective, the scores have determined for all categories for the suitability levels and the processes algorithm of MCA model was designed.

Objective 4. (The final suitability model for solar harvesting sites)
All suitability models for criteria are collected in a single final suitability model that includes all the criteria according to the weights that were designed in the MCA model And presenting results in final suitability maps.

1.3. Aim

This study intends to select suitable solar harvesting sites in Northern Borders Region. KSA using GIS-based Multi-Criteria Analysis (MCA), at the level of administrative boundaries of the study area Considering various factor criteria, Analytical Hierarchy Process (AHP) is used here for weight setting. And presenting results in final suitability maps. This study seeks to answer the main question: What are the most suitable sites for solar energy projects in the Northern Borders Region, KSA?

1.4. Area of focus

The Northern Borders Region is a land with a rich history. It is known for prominent historical sites. Nature reserves and beautiful suburbs fill this region. Northern Borders Region has been the north gate of the Arabian Peninsula since antiquity; hence hold significant historical and geographical importance to the Kingdom. It should be noted here that the common name of the region is (Al Hudud Ash Shamaliya), Which has been used in some old topographic maps and spoken by the citizens , But the official name is (Northern Borders Region), which is used in national institutions, government transactions, new topographic maps, dealing with multinational companies. And we used it in this study. As Map 1.1 shown below the Northern Borders Region is located in the north of Saudi Arabia between latitude degrees 28-32 north and longitude degrees 38- 46 east. The Northern Borders Region is approximately 110989.2 sq km, equivalent to 5.1 % of the total area of the Kingdom of Saudi Arabia (Northern Borders Municipality). Northern Borders Region has a population of

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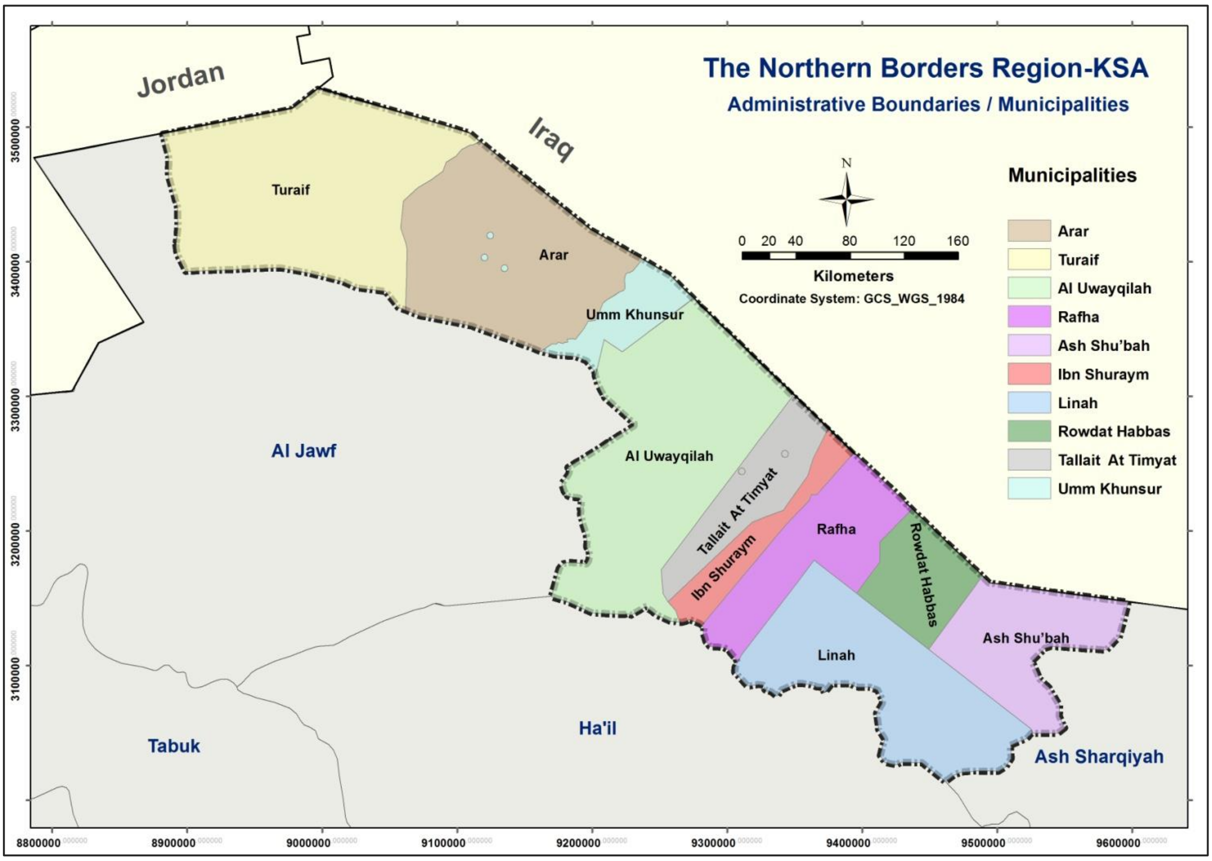
321880 inhabitants, the lowest in Saudi Arabia, with a population of 1.18 % of the total population according to the general census of population and housing in 2010 (GaStat-General Authority For Statistics).

Map 1.1: The administrative division of Northern Borders Region



As Table 1.1 shown below, the Northern Borders Region includes 10 municipalities, the main governorates are Arar, Rafha, Turaif, and Al Uwayqilah. The administrative capital of the region is Arar city, The largest governorates are Turaif with an area of 23093.58 sq km, representing 20.8% of the total area of the study area, and the smallest area is the municipality of Umm Khunsur with an area of 3346.14 sq km, representing 3% of the total area. The topography of the area is characterized by a semi-homogeneous nature. The area consists of a high plateau, 900 meters above mean sea level, extending between Arar and Turaif. The extension extends towards Rafha and Ash Shu'bah with a very low slope, up to 500 meters above mean sea level, and in general, the area is almost devoid of the apparent disparity in elevations (Northern Borders Municipality), See Map 1 in Appendix. the area study covered by many dry and seasonal valleys, such as Wadi Arar, Wadi Badanah, Wadi Al Khirr, Wadi Abu Ar Rubat, and Wadi Aba Al Qur. The climatic characteristics of the region, the temperature is sometimes less than 0 C, and the climate of the northern border is a very hot continental climate in summer and very cold in winter, The average temperature for summer months is 33 ° C, and for winter months is 11 ° C. The rates of rainfall increases from the north-west by 60 mm to the south-east in the Ash Shu'bah by 100 mm, sometimes there are some snow formations on the plateau (PME, The General Authority of Meteorology & Environmental Protection).

Table 1.1: The municipalities of Northern Borders Region

Administrative Division/Municipality	Area/sq km	Proportion /Total Area
Arar	16946.98	15.27 %
Turaif	23093.58	20.81 %
Rafha	8318.88	7.50 %
Al Uwayqilah	21669.30	19.52 %

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Linah	14730.68	13.27 %
Ash Shu'bah	8514.01	7.67 %
Tallait At Timyat	5742.83	5.17 %
Rowdat Habbas	5028.87	4.53 %
Ibn Shuraym	3597.96	3.24 %
Umm Khunsur	3346.14	3.02 %
SUM	110989.23	100

It should be noted that Northern Borders Region is located in the northernmost of Saudi Arabia, an international border area with the Republic of Iraq and the Hashemite Kingdom of Jordan, bordered by the north of the Republic of Iraq with a length of approximately 849 km, and to the south of the regions of Al-Jawf and Hail length of 1000 km. It is bordered to the east by the eastern part of the West by the Hashemite Kingdom of Jordan with an international border of approximately 183.6 km. Also The Trans-Arabian Pipeline (TAPLINE) penetrates the region, an old oil pipeline that is currently not being used but is maintained by Saudi Arabia as one of the world's largest oil pipeline system in the last century, extending from the Arabian Gulf to Sidon port in Lebanon and passing through the northern region parallel to the highway. In this study, we will consider The TAPLINE and international boundaries as local spatial constraints because it is not good to the establishment of solar projects or any major national projects on the international border for legislative, strategic and security reasons. In addition to the legislative restrictions associated with the buffer 500 M of the TAPLINE, which prohibits building or developing projects Inside this buffer (Northern Borders Municipality). But the TAPLINE constraint will be combined with the criteria of distance from roads and railways because it is within the excluded area of the highway buffer. The Northern Borders Region is already a promising area of development projects in the field of industry and mining and is a fertile area for renewable energy projects. Where began work on the establishment of the Wa'ad Al Shamaal Industrial City in 2014. It is an integrated mining city located northeast of Turaif governorate, which seeks to develop the economy, localize technology and exploit natural resources. The city has all the ingredients of industry and sustainable development, and the volume of investments is expected to reach 5.6 billion USD for the Ma'aden Wa'ad Al Shamal Phosphate Co. Project, which is the major focus for the establishment of Wa'ad Al-Shamal City for Mining Industries on an area of 440 sq km (MODON-Saudi Authority for Industrial Cities and Technology Zones).

Chapter-2: Methodology

2.1. Data

This study was based on several sources for obtaining preliminary data from relevant government agencies and other free sources available to researchers, using GIS to generate geodatabases required for study, most of the layers of the study area needed are clipped from the digital map and Digital Elevation Model (DEM), And a few layers are got from digitizing on topographic maps and satellite images. Necessary parts are digitized into shapefiles. The differently formatted vector data are converted into shapefiles and georeferenced. Due the data is from different sources according to the nature of the study, the georeferences will be unified as well as the resolutions of all the datasets in the process of conversion, As for the raster datasets, the resolutions were unified in the reclassification stage. Some layers have different scales, and this has caused the problem of non-matching and has been processed using satellite imagery and digitization. Finally, The georeferences has been unified into :
geographical coordinate system, WGS 1984
projected into WGS 1984 UTM Zone 38N
And Raster datasets cell size (resolution) has been unified into 90 M
Table 2.1 below shows summarizes of the details datasets, their purpose and sources:

Table 2.1: The summary of details for datasets

Data	File Extension	Type	Final Projection	Resolution	Data Source
Solar radiation	TIFF	Grid	WGS_1984_UTM_Zone_38N	30.0 arc-sec	Solar resource data © 2016 Solargis : https://solargis.com Data : DNI (direct normal irradiation) Format :Raster Dataset (ESRI ASCII grid), Resolution: 30.0 arc-sec
Elevation (DEM)	TIFF	Grid	WGS_1984_UTM_Zone_38N	90 M	Free Global DEM Data Sources CGIAR - Consortium for Spatial Information (CGIAR-CSI) http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp Space Shuttle Radar Topography Mission (SRTM) ,
Satellite images	TIFF	Grid	WGS_1984_UTM_Zone_38N	30 M	Municipality of Northern Borders Region.KSA
Highways, Roads	Shp	Polyline	WGS_1984_UTM_Zone_38N	1: 50 000	Basemap from Municipality of Northern Borders Region.KSA
Railways	Shp	Polyline	WGS_1984_UTM_Zone_38N	1: 50 000	Digitized from topographic map
Transmission lines	Shp	Polyline	WGS_1984_UTM_Zone_38N	1: 50 000	Saudi Electricity Company
Administrative boundaries	Shp	Polygon	WGS_1984_UTM_Zone_38N	1: 50 000	Digitized from topographic map
city sites	Shp	Point	WGS_1984_UTM_Zone_38N	1: 50 000	Digitized from topographic map
Airports	Shp	Point	WGS_1984_UTM_Zone_38N	1: 50 000	Digitized from topographic map
Protected areas	Shp	Polygon	WGS_1984_UTM_Zone_38N	1: 50 000	Basemap from Municipality of Northern Borders Region.KSA
International boundaries line	Shp	Polyline	WGS_1984_UTM_Zone_38N	1: 50 000	Digitized from topographic map

2.2. Software

The software employed here are ArcGIS 10.5, Erdas Image 2015, and Google Earth only used to verify some data. Almost all the maps derived from the raw data were in Shapefile vector format. However, raster data are needed to execute the MCA model, Shapefile format files are thus converted to raster format. ArcMap 10.5 is applied throughout the whole process. AHP with Microsoft Excel is specifically used for the weight setting of factor criteria. ArcCatalog from ArcGIS 10.5 package was used to manage data. Microsoft Word, Excel was used for editing, creating tables and graphs.

2.3. Method

2.3.1 GIS as a framework for site selection

A geographical information system (GIS) enables the user to collect, store, visualize and analyze spatial data and interpret relationships and trends. "A GIS has considerable capabilities for data analysis and scientific modeling, in addition to the usual data input, storage, retrieval, and output functions " (Lakhoua 2011, 45). The most important use of the GIS system at the moment is as a decision support system in multi-criteria decision analysis methods (MCA), through the coupling of GIS and MCA software. The GIS approaches used in the site selection usually are network analysis, spatial analysis, proximity analysis, MCA with AHP, FAHP or ROM, etc. In this study, we have used GIS-based MCA with AHP.

2.3.2. The methodology of preparing the databases

Figure 2.1 shows that the data processing methodology included several procedures, provision of raw data from multiple sources and processing of data through editing, digitizing and conversion as well as data management and standardization of georeferenced.

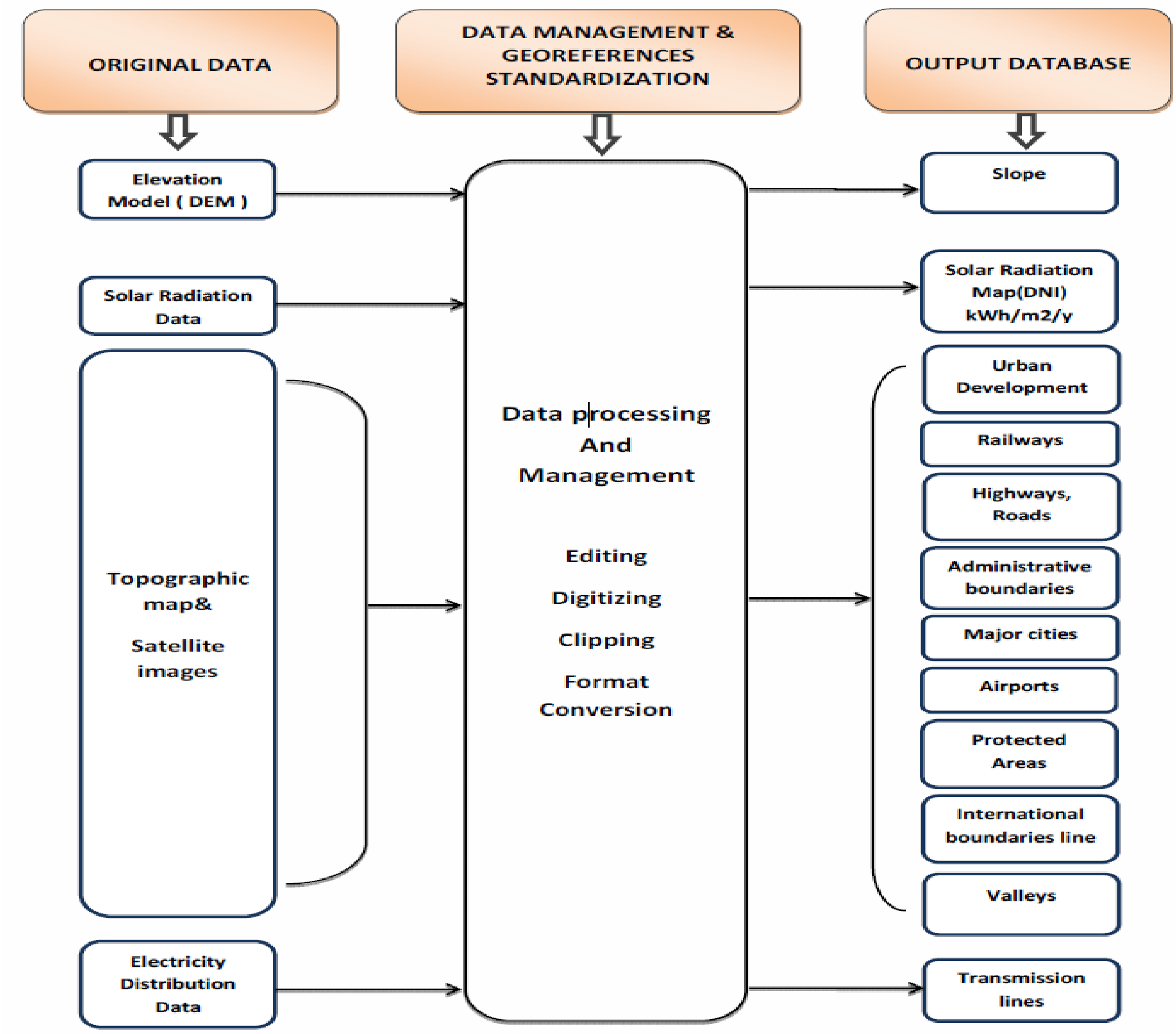


Figure 2.1: The methodology diagram of preparing data

2.3.3. Analytical Hierarchy Process (AHP)

Not all the criteria will have the same importance. Therefore, the AHP process Aims to derive the relative priorities (weights) for the criteria (Mu and Rojas 2017).
Analytic Hierarchy Process (AHP) is one of Multi-Criteria decision-making method that was originally developed by Prof. Thomas L. Saaty (1980, 1-11). It is a method to derive ratio scales from paired comparisons, Table 2.2 below shows the AHP scales for paired comparisons by Saaty et al. (1991). The input can be obtained from actual measurements such as price, weight etc., or from subjective opinions such as satisfaction feelings and preference, and the opinions of experts and specialists. The weights for the decision-making criteria are derived from the pairwise comparisons of the relative importance between every two criteria (the sum of the weights equals to 1).

Table 2.2: The AHP scales for paired comparisons, Source: Adapted from Saaty (1987).

Intensity of importance	Description
1	Equal importance
3	Moderate importance
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocals	Values for inverse comparison

2.3.4. Multi-Criteria Analysis (MCA)

Multi-criteria analysis (MCA) describes any structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives. In MCA, desirable objectives are specified and corresponding attributes or indicators are identified. The actual measurement of indicators need not be in monetary terms but are often based on the quantitative analysis (through scoring, ranking, and weighting) of a wide range of qualitative impact categories and criteria (Hamalainen and Karjalainen 1992, 172). MCA tools are tools that support comparison of e.g. different policy options on the basis of a set of criteria. They are very effective in supporting the assessment of and decision making on complex sustainability issues because they can integrate a diversity of criteria in a multidimensional guise and they can be adapted to a large variety of contexts.
A large number of MCA methods exist to rank, compare and select the most suitable policy options according to the chosen criteria. The method to choose to apply MCA depends on the decision rule preferred and the type of data available (Starr and Zeleny 1977, 5-29). GIS with MCA can be thought of as a process that transforms, combines geographical data and value judgments based on the suitability analysis process to determine the appropriateness of a given area (land resource) for a specific use, i.e. agriculture, forestry, business, urban development to obtain information for decision making, Figure 2.2 shows The Multi-Criteria Analysis (MCA) structure by Eastman et al. (1995, 539).
Methods of Multi-Criteria Analysis Steps :

- Set the goal/define the problem
- Determine the criteria (factors/constraints)
- Standardize the factors/criterion scores
- Determine the weight of each factor
- Aggregate the criteria
- Validate the results

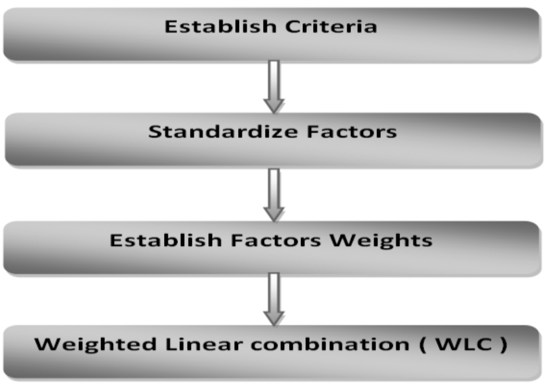


Figure 2.2: The Multi-Criteria Analysis (MCA) structure by Eastman et al. (1995, 539).

Chapter-3: Processes and Results

3.1. Data processing

Through several processes, such as data format conversion, clipping, digitizing, and buffering, the main criteria are extracted from the raw data. There are totally eight-factor criteria (solar radiation, slop, highways/roads/railways, transmission lines, cities, valleys, airports, international boundaries line), Plus two constraints (Urban development area, Protected /sensitive areas). Data processing steps included the extracting of a raster layer for each of the criteria required for this study, Then classification of the values of the criteria into classes and then reclassification to points (from 1 to10) to facilitate the presentation and analysis, Figure 3.1 below shows the structure of data processing.

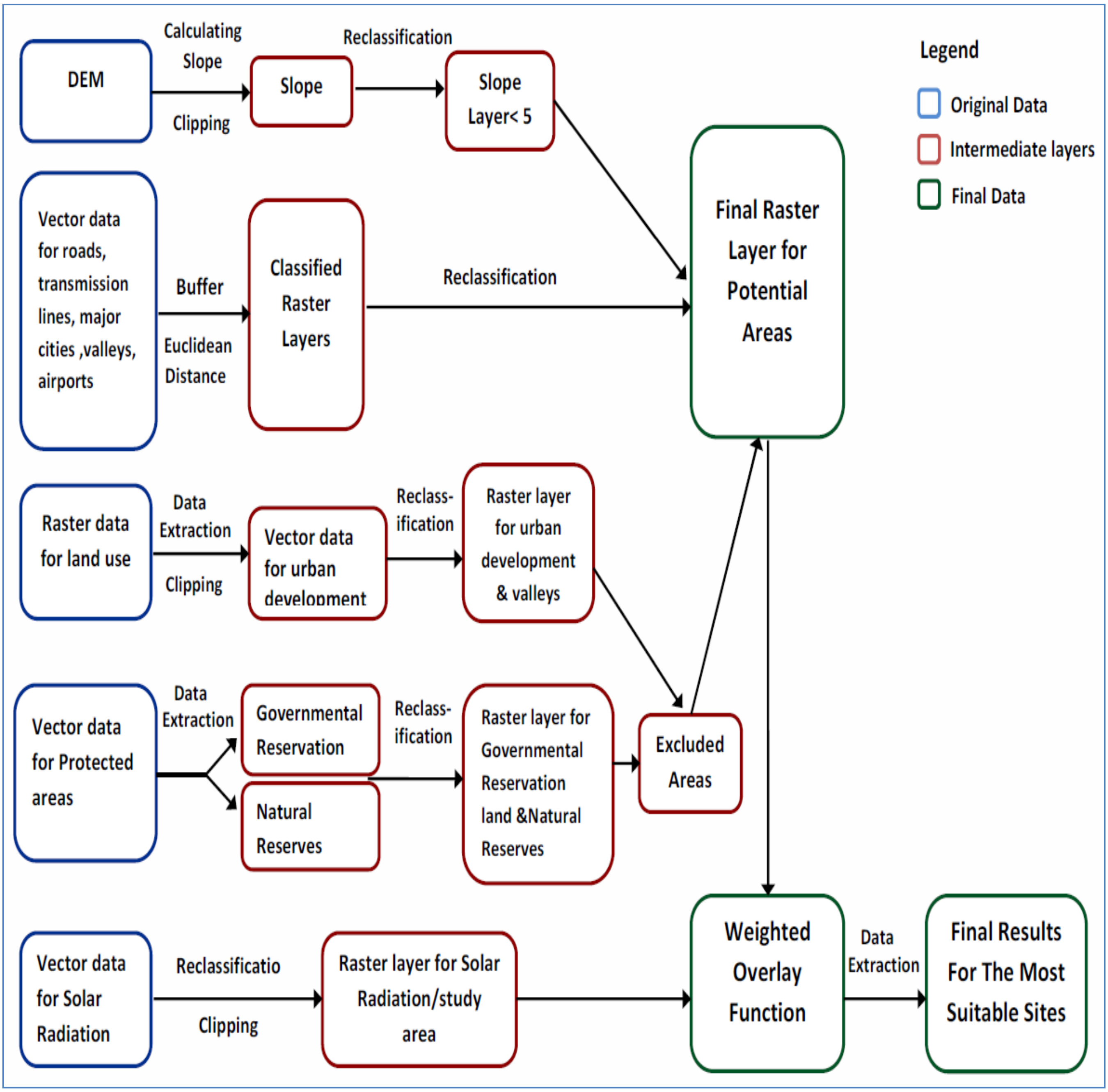
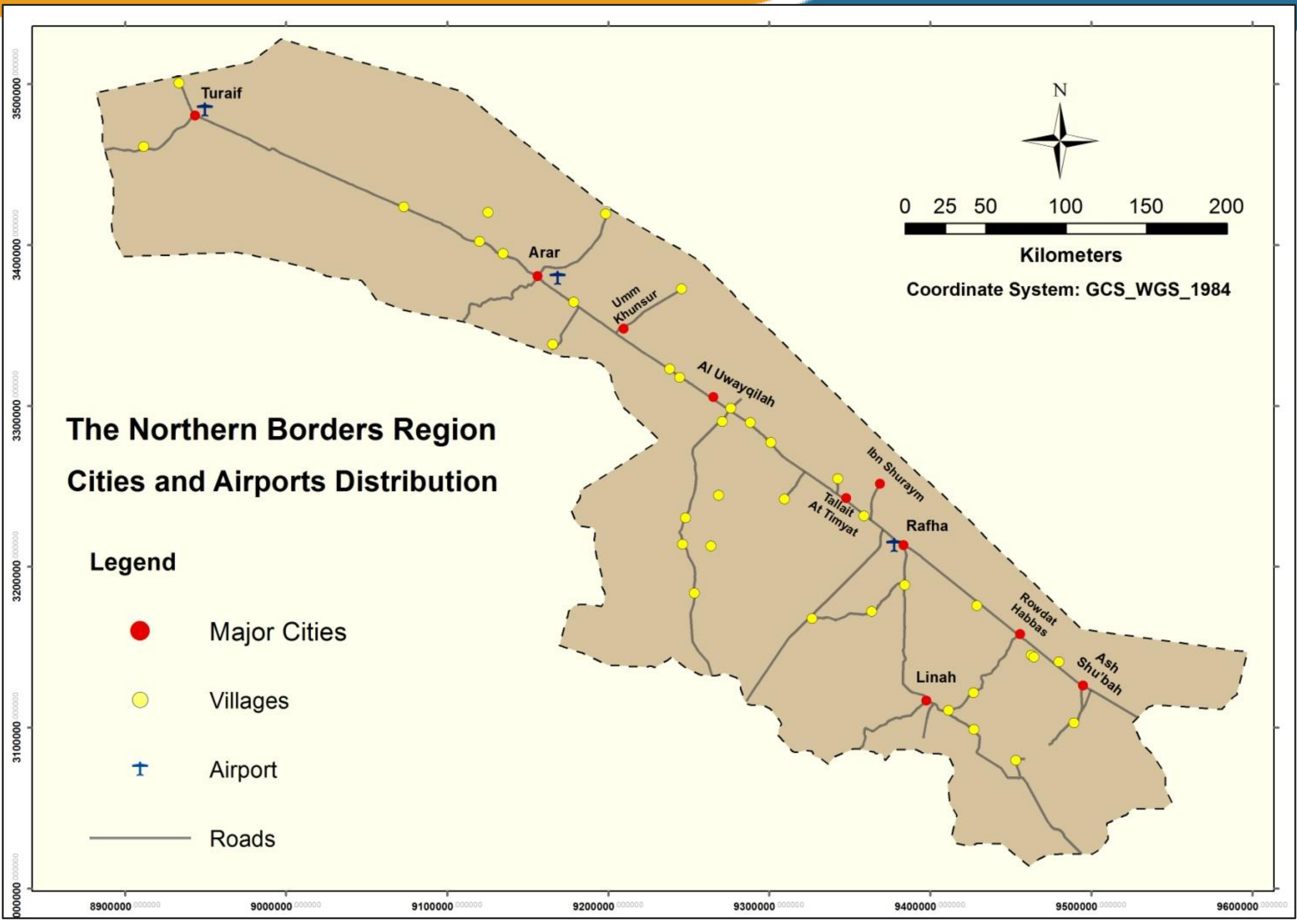


Figure 3.1: The Structure of data processing



Map 3.1: Cities and airports distribution in study area

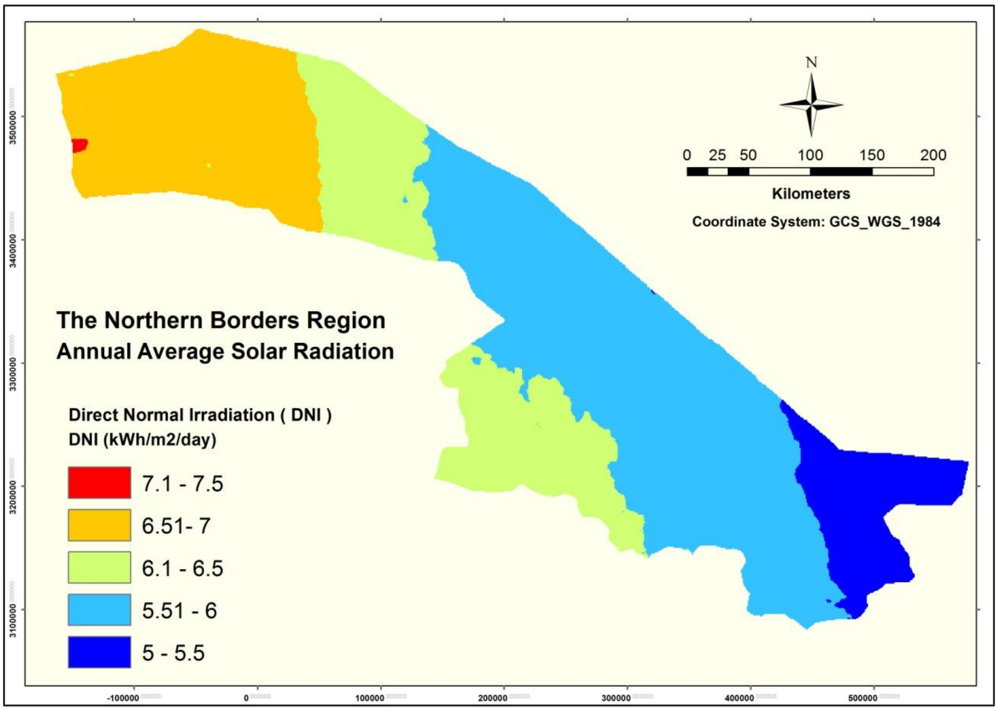
3.2. Setting the multi-criteria

In this context, many studies and literature related to the selecting the suitable sites for the harvesting solar and the methodology for determining criteria have been examined (Watson and Hudson 2015, 20; Recanatesi et al. 2014, 6447). From this basis eight criteria have been selected, They were included in three groups (technical, economic and environmental factor), These criteria are solar radiation, slop, highways/roads/railways, transmission lines, cities ,valleys, airports and international boundaries line, with two constraints (Urban development area, Protected areas), Map 3.1 shows the cities and airports distribution in the study area. Note that the criterion of international borders line was not selected in previous studies but was included as a local normalization with the study area, Because the study area is located on international borders with the countries of Iraq and Jordan.

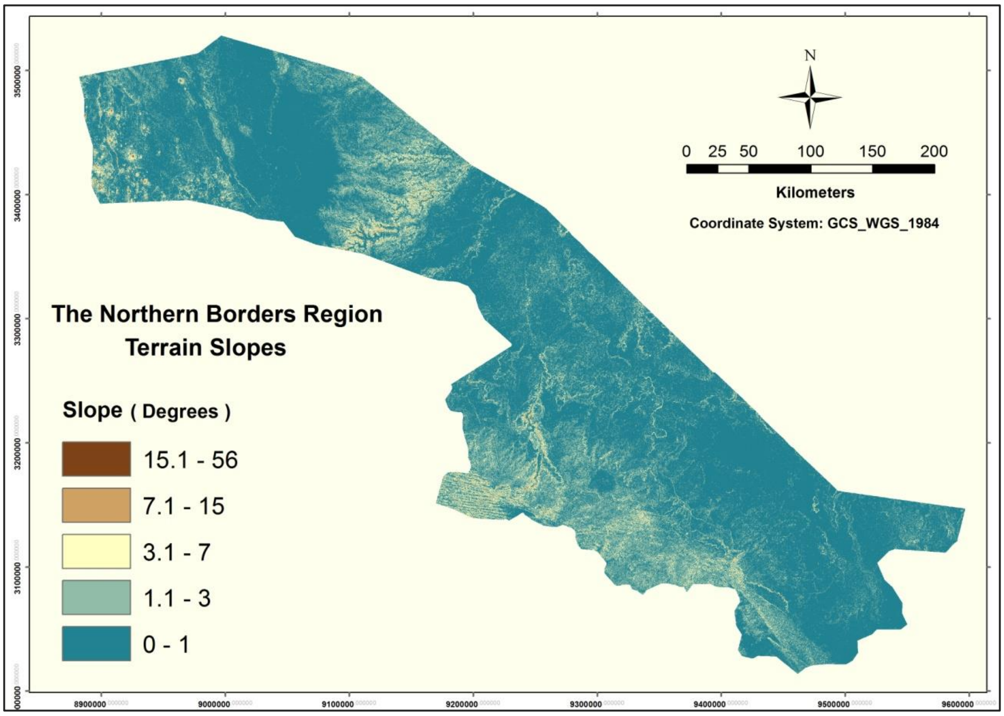
3.2.1. Factor criteria

The value of solar radiation is the basic criteria in the collection of energy for any area targeted for solar projects, Map 3.2 shows that the amount of solar radiation in the study area ranges from 5.2 to 7.09, It is a good rate that makes all study area within suitable or most suitable sites for according this factor. in this study was determined the solar radiation rate by more than > 4.5 (kWh/m2/day) is suitable.
And comes second the rate of slopes, for this study the slope output measurement was set to degrees elevation, Less than 5 degrees were identified is suitable as shown in Table 3.1. For installations of equipment of solar energy projects the slope can be a very important economic and technical factor, the higher the gradient, the more investment is required to flatten the ground (Suri and Hofierka 2004, 175). The Map 3.3 indicates that the surface slope rates in most of the study area by more than 90% of the area of the study area ranges from 0 to 5 degrees, which is equivalent to the rate of suitability assigned to the slope factor in this study. Also distance from the transmission lines is a factor Technically and economically important the greater the distance, the greater the amount of energy lost during the transfer of energy and thus increase the cost of energy transmission (Dawod and Mandoer 2016, 450), Map 3.4 shows the roads network, The proximity of the road network in this study was determined by more than 5 km to be suitable. The distance of 0 - 500 m was set as an excluded area

in the study as a road buffer and also to the TAPLINE. In addition to other environmental factors are less important but required such as distance from cities, airports, valleys, airports and international boundaries line (Table 3.1). It should also be noted that the factor may have more than one effect. The technical factor may have an economic and environmental impact, e.g. the distance from the transmission lines is a technical factor, but also has an economic impact.



Map 3.2:The rate of solar radiation for study area



Map 3.3:The rate of slopes for study area

Technical Factors :

- Solar Radiation (C1)
- Slope (C2)
- Distance from transmission lines (C3)

Economic Factors :

- Distance from roads and railways (C4)
- Distance from cities (C5)
- Distance from airports (C6)
- Distance from international boundaries line (C7)

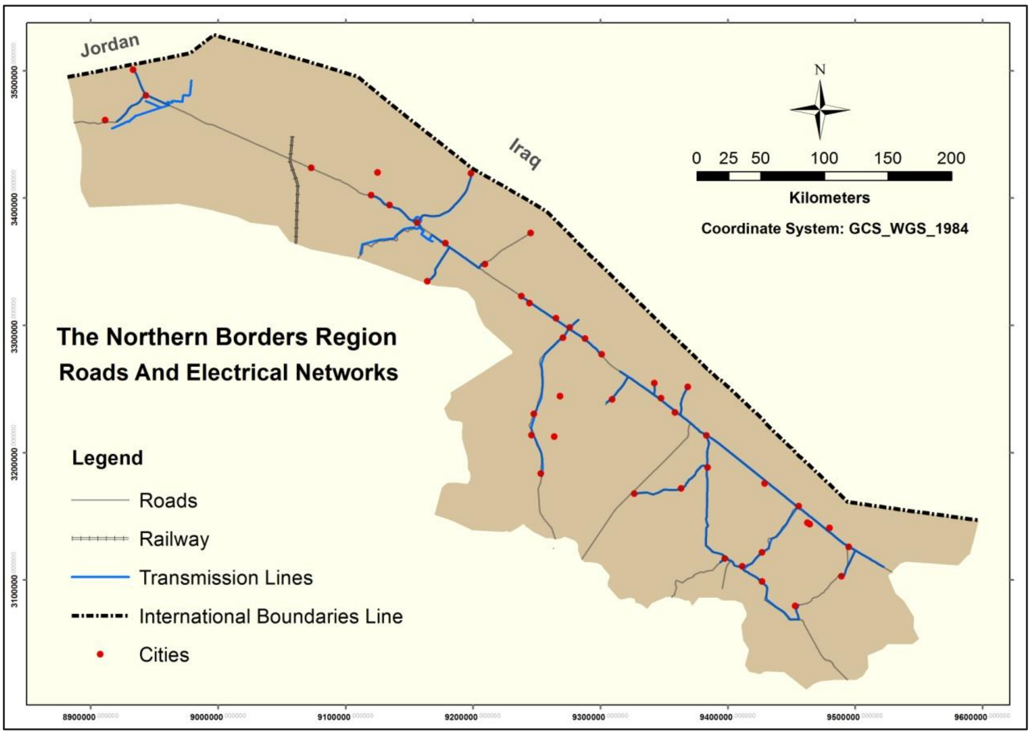
Environmental Factors :

- Distance from valleys (C8)

Environmental Factors category also include the constraints used in the study, Urban development area, Protected areas, Table 3.1 shows all factors criteria setting.

Table 3.1: Factors criteria setting

Categories	**Factor**	**Setting**
Technical	Solar Radiation (C1)	Solar radiation rate (kWh/m2/day) > 4.5 is suitable
	Slope (C2)	Land Slope (degree) < 5 is suitable
	Distance from transmission lines (C3)	The proximity to transmission lines (Km) < 5 is suitable
Economic	Distance from roads and railways (C4)	The proximity to roads (Km) > 5 is suitable
	Distance from cities (C5)	The proximity to cities (Km) > 5 is suitable
	Distance from airports (C6)	The proximity to airports (Km) >3 is suitable
	Distance from international boundaries line (C7)	The proximity to international boundaries line (km) >15 is suitable
Environmental	Distance from valleys (C8)	The proximity to valleys(m) >500 is suitable



Map 3.4: The roads network and electrical grid in study area

3.2. 2. Constraint criteria

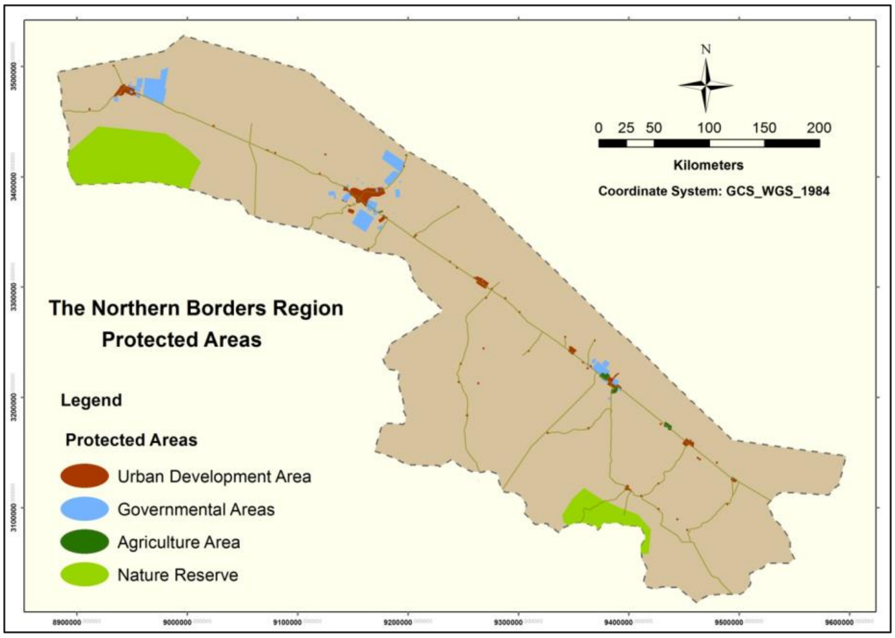
Two constraints have been imposed in the processing multi-criteria s model, Table 3.2 shows the constraint criteria setting. The first is the urban area, which includes residential and investment areas with an area of 949.68 sq km, representing 0.85% of the total area of the study area. The second is protected areas, These include the governmental reservation land, agriculture area, and nature reserves. The area of government reserves is 1487.75 sq km, that representing 1.34% of the total area of the study area. For the agricultural areas, the northern borders region is poor in agriculture. Basically, It is a desert area with little rain and no rivers, where the area of agricultural areas is 98.21 sq km that representing 0.09% of the total area as table 3.3 shown. As for the natural reserves in the northern borders region, there are two natural reserves, the first Huratt Al Harah Reserve with a total area of 14099.3 sq km. The western part of the study area is located and part of it is located within the study area. It covers an area of 5089 sq km. The second natural reserve is Al-Taiseyah Reserve, It is located in the south-east of the study area. The area within the study area is about 1593.05 sq km and has a total area of 3606 sq km. The total area of the two natural reserves within the study area is about 6682.05 sq km and represents about 6.02% of the total area. Therefore, the total area which excluded from the study area is 9217.69 sq km, representing 8.30 % of the total area of the study area, Table 3.3 shows the details of area constraints in the study area, Map 3.5 shows the protected areas map for the study area.

Table 3.2: Constraint criteria setting

Constraint	Description	Setting
Urban development area	Residential and investment areas	Inside =1, outside =2
Protected areas	Governmental reservation land, agricultural areas, and nature reserves.	Inside =1, outside =2

Details of area constraints in the study

Constraint	Area/sq km	Proportion/Total Area
Urban Development Area	949.68	0.85%
Governmental Areas	1487.75	1.34%
Nature Reserve	6682.05	6.02%
Agriculture Area	98.21	0.09%
SUM	9217.69	8.30 %



Map 3.5: The protected areas map for the study area.

3.2.3. Determining criteria weights

Based on the scale for pairwise comparisons by Saaty referred to above, The appropriate scales for each criteria were determined as shown in Table 3.4, And by using the AHP method, the weights are set as shown in Table 3.5, It should be noted here that the intensity of importance of each criterion was based on the previous studies and opinions of experts in the field of solar energy, Table 3.8 shows the final of Weighting value factor criteria computed using AHP.

Table 3.4: Setting scales for criteria

Criteria	Intensity of importance	Description
Solar Radiation-C1	9	Extreme importance
Slope-C2	7	Very strong or demonstrated importance
Distance from transmission lines -C3	5	Strong or essential importance
Distance from roads and railways -C4	3	Moderate importance
Distance from cities -C5	2	Moderate importance
Distance from airports -C6	2	Moderate importance
Distance from international boundaries line -C7	3	Moderate importance
Distance from valleys -C8	3	Moderate importance

Table 3.5: Normalized Criteria Comparison Matrix (AHP)

Criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	Row/SUM	Weights(w)
Solar Radiation-C1	0.392	0.469	0.469	0.341	0.250	0.250	0.341	0.341	2.852	0.3565
Slope-C2	0.131	0.156	0.156	0.205	0.179	0.179	0.205	0.205	1.414	0.17675
Distance from transmission lines -C3	0.131	0.156	0.156	0.205	0.179	0.179	0.205	0.205	1.414	0.17675
Distance from roads and railways -C4	0.078	0.052	0.052	0.068	0.107	0.107	0.068	0.068	0.601	0.075
Distance from cities -C5	0.056	0.031	0.031	0.023	0.036	0.036	0.023	0.023	0.258	0.032
Distance from airports -C6	0.056	0.031	0.031	0.023	0.036	0.036	0.023	0.023	0.258	0.032
Distance from international boundaries line -C7	0.078	0.052	0.052	0.068	0.107	0.107	0.068	0.068	0.601	0.075
Distance from valleys -C8	0.078	0.052	0.052	0.068	0.107	0.107	0.068	0.068	0.601	0.075
SUM	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	8.000	1.000

This matrix of weights can only be used after calculating the consistency ratio (CR), as it evaluates the credibility. The pairwise matrices are considered to be consistent when the CR is less than 0.1 (10%). The pairwise matrices are considered to be inconsistent, and the resultant weight matrix of the criteria is not acceptable when the CR is greater than 0.1 (Saaty 1980, 1-11). We can calculate the consistency ratio (CR) as follow :

Where.. $CR = \frac{CI}{RI}$

Consistency index: $CI = \frac{\lambda_{\max} - n}{n-1}$ Where $\lambda_{\max} = \sum_{i}^{n} CV_{ij}$

Table 3.6: Random in consistency indices for n = 10 by Saaty

n	1	2	3	4	5	6	7	8	9	10
Random inconsistency indices (RI)	**0**	**0**	**0.58**	**0.9**	**1.12**	**1.24**	**1.32**	**1.41**	**1.45**	**1.49**

Random index (RI): constant corresponding to the mean random consistency index value based on n, (Table 3.6-3.7).

Table 3.7: Calculating the consistency ratio (CR)

Calculating The Consistency Ratio (CR)

Criteria	C1	C1	C3	C4	C5	C6	C7	C8	weighted sum	Weights(w)	λ Max	CI	RI	CR
C1	0.357	0.530	0.530	0.376	0.226	0.226	0.376	0.376	2.995	0.357	8.402	0.057	1.41	0.041
C2	0.119	0.177	0.177	0.225	0.161	0.161	0.225	0.225	1.471	0.177	8.322	0.046	1.41	0.033
C3	0.119	0.177	0.177	0.225	0.161	0.161	0.225	0.225	1.471	0.177	8.322	0.046	1.41	0.033
C4	0.071	0.059	0.059	0.075	0.097	0.097	0.075	0.075	0.608	0.075	8.093	0.013	1.41	0.009
C5	0.051	0.035	0.035	0.025	0.032	0.032	0.025	0.025	0.261	0.032	8.093	0.013	1.41	0.009
C6	0.051	0.035	0.035	0.025	0.032	0.032	0.025	0.025	0.261	0.032	8.093	0.013	1.41	0.009
C7	0.071	0.059	0.059	0.075	0.097	0.097	0.075	0.075	0.608	0.075	8.093	0.013	1.41	0.009
C8	0.071	0.059	0.059	0.075	0.097	0.097	0.075	0.075	0.608	0.075	8.093	0.013	1.41	0.009

Therefore, the consistency ratio (CR) for all weights of the factors calculated in this study is **0.02** which is acceptable as less than **0.10.**

Table 3.8: The weighting value of factors criteria computed using AHP.

Criteria	Weights %
Solar Radiation-C1	36 %
Slope-C2	18 %
Distance from transmission lines -C3	18 %
Distance from roads and railways -C4	8 %
Distance from cities -C5	3 %
Distance from airports -C6	3 %
Distance from international boundaries line -C7	7 %
Distance from valleys -C8	7 %

3.3. Development the model and performing the processes.

CR for all Criteria

n	8	
λmax	8.19	
CI	0.03	
RI	1.41	
CR	0.02	**< 0.10**

3.3.1. Development of the MCA model.

After setting of the factor criteria and constraint criteria separately, and giving the appropriate weights to the factors, as well as checking the consistency rate that gave us the green light regarding the reliability of the weights calculated in the AHP method, Table 3.9 shows summarized of the final criteria and constraint with weights. GIS-based MCA process integrates them together and gets the final result. Figure 3.2 shows the model diagram for MCA processing based on GIS.

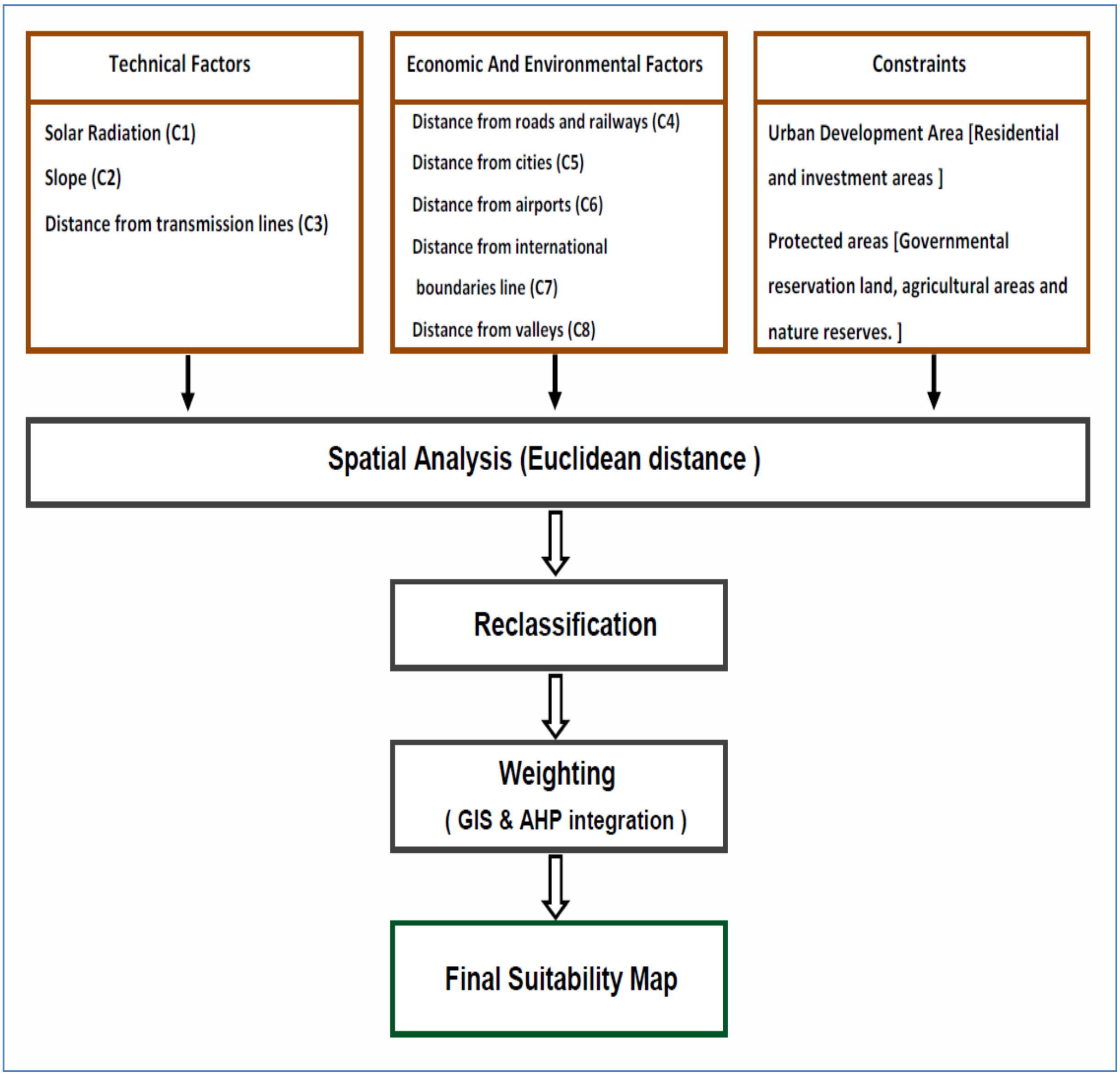


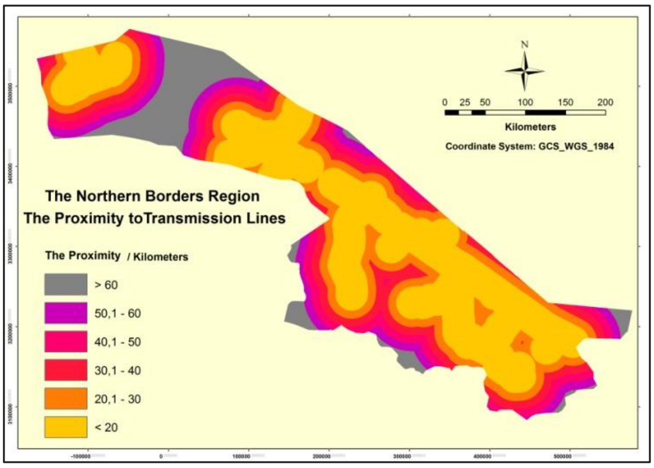
Figure 3 .2: The model diagram for MCA processing

Table 3 .9: The finally criteria and constraint with weights

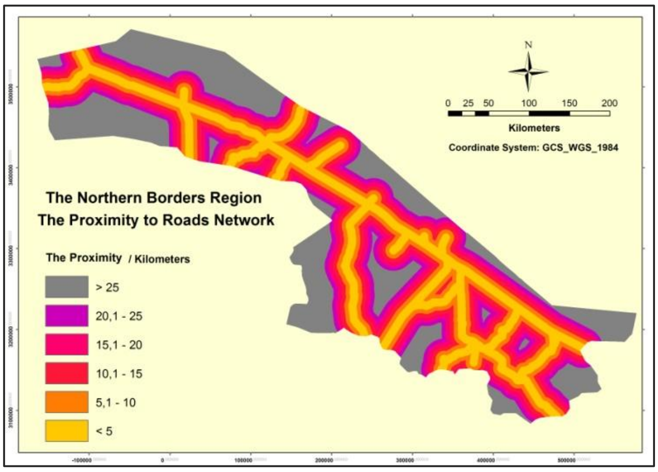
Criteria	Unit	Type	Categories	Suitability Level	Weights	CR
Solar Radiation	kWh/m2/day	Factor	> 6.5 5.51- 6.5 5 - 5.5 < 5	Most suitable Moderate suitable Less suitable NA	0.36	0.041
Slope (degree)	Degree	Factor	0 - 3 3 - 5 5 - 10 > 10	Most suitable Moderate suitable Less suitable NA	0.18	0.033
Distance from transmission lines	kilometer	Factor	0 - 5 5 - 10 10 - 20	Most suitable Moderate suitable Less suitable	0.18	0.033
Distance from roads	kilometer	Factor	0 - 0.5 0.5 - 5 5 - 8 8 - 10	Excluded Less suitable Moderate suitable Most suitable	0.08	0.009
Distance from cities	kilometer	Factor	0 - 2 2 - 5 5 - 8 8 - 10	Excluded Less suitable Moderate suitable Most suitable	0.03	0.009
Distance from airports	kilometer	Factor	> 3 < 3	Suitable Excluded	0.03	0.009
Distance from international boundaries line	kilometer	Factor	> 15 < 15	Suitable Excluded	0.08	0.009
Distance from valleys	Meter	Factor	> 500 < 500	Suitable Excluded	0.08	0.009
Urban development area	—	Constraint	Residential area Investment areas	Excluded Excluded	NA	NA
Protected areas	—	Constraint	Governmental reservation areas Agricultural areas Nature reserves	Excluded Excluded Excluded	NA	NA

3.3.2. Performing the processes.

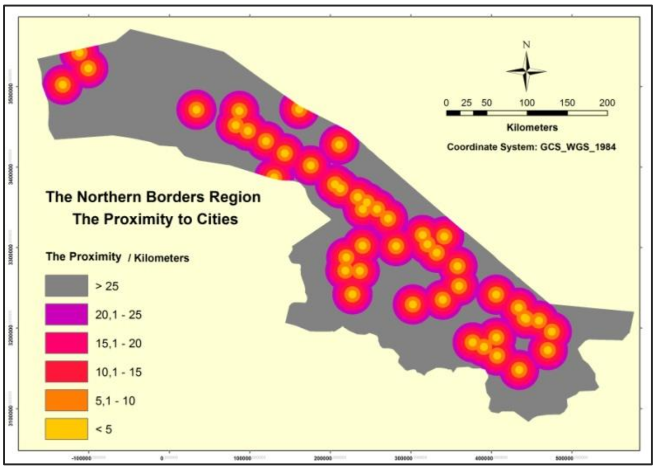
By using the (Euclidean distance) spatial analysis tool was determined the proximity to roads and to determine the distances from transmission lines, cities, airports, valleys and international boundaries line. The Euclidean distance tool measures the distance from each cell to the closest feature of a given type, Map (3.6-3.7-3.8-3.9) shown the proximity to roads network, transmission lines, cities and valleys then the distance ranges were classified according to the factors and constraints of each criterion. In addition to applying the reclassification process to the raster layers using the score rankings of the factors and constraints.



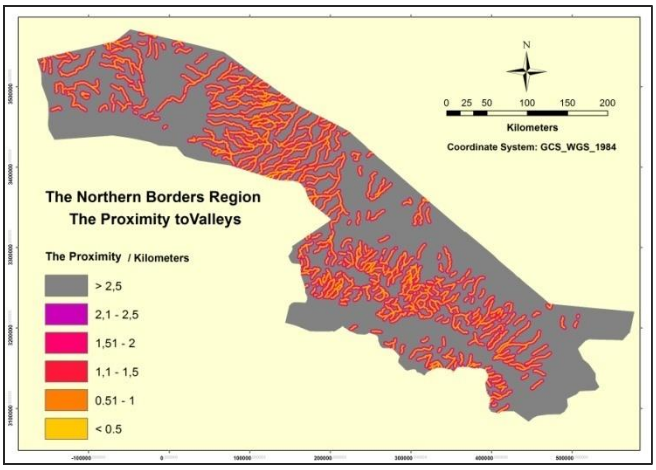
Map 3 .6:The proximity to transmission lines



Map 3 .7: The proximity to roads network



Map 3 .8: The proximity to cities



Map 3 .9: The proximity to valleys

Output raster layers for each individual criteria were generated, that show the suitability areas according to the factors and constraints of each criterion, The factors and constraints were combined with the weights of the parameters used in the study using the weighted overlap tool. This tool with the principle of weighted linear combinations (WLC) is the base to integrate the AHP and GIS. The following expression describes the land suitability index (LSI):

$$S_i = \sum_{i=1}^{n} (W_i \times X_i)$$

Where..

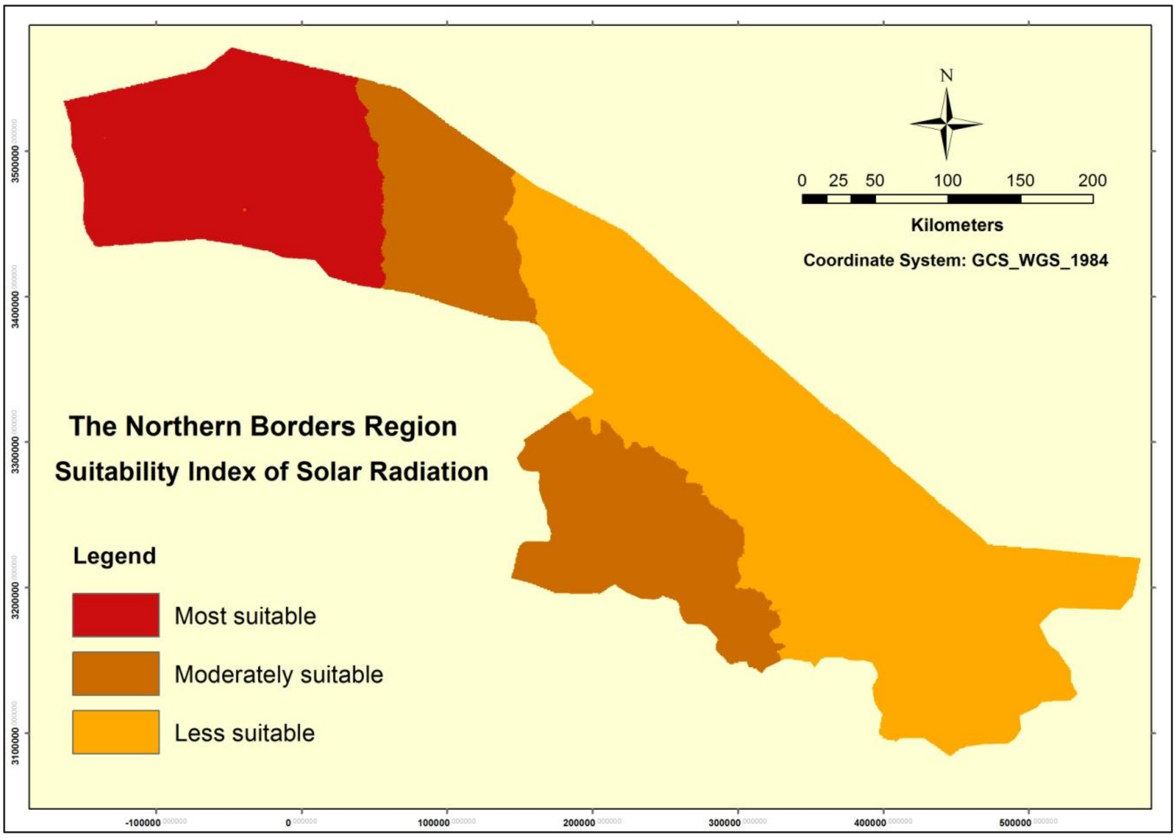
S = The suitability index (LSI)
i = The parameter
n = The number of criteria
Wi = Weighting of parameter i
Xi = The score of parameter i and constraint

Finally, The weights of the criteria are combined with the scores of the factors and constraints to produce a suitability index for each cell of the output map (Eastman et al. 1995, 539). In the re-classification process has been converting values of each raster on a scale from 1 to 10 points where 10 equal the highest suitability index, and 1 equal the lowest suitability index, but 1 has been sated as restrictions for Some factors such as roads and valleys. As for the constraint, criteria has been sated 1 is Inside or excluded and 2 is outside or suitable. Then in the Weighted Overlay function, The factors were assigned scores between 0 and 10, with the setting of restrictions according to re-classification outputs. In the final suitability index map, four categories have been assigned in the following ranking :

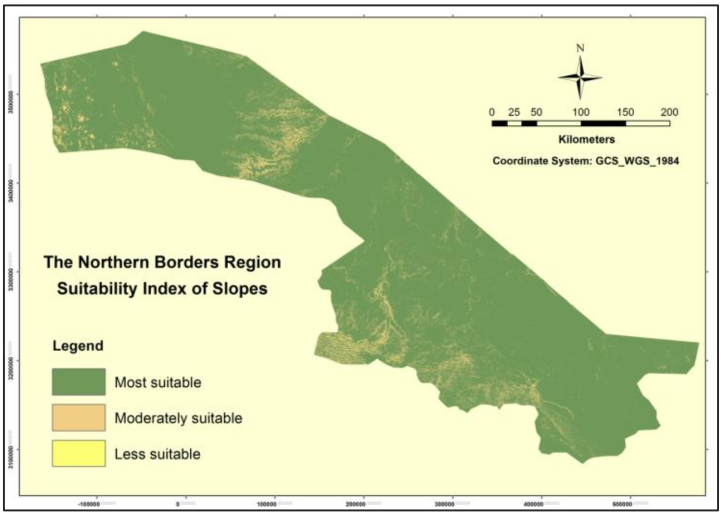
[0] (not suitable)
[1- 5] (less suitable)
[5 – 8] (moderately suitable)
[8 -10] (most suitable).

3.4. Results

Several models have been developed for each criterion, each model representing the spatial suitability of each criterion, Map 3.10 shows the suitability Index model of the solar radiation criteria, The figure indicates the concentration of high solar radiation rates in the west of the Northern Borders Region. And the average solar radiation decreases as we move east. The calculation of the areas by calculating the size and count of pixels indicates that the most suitable areas are 25576.2 sq km, representing 23% of the total area of the study area. While the moderately suitable areas are 28718.6 sq km, representing 26% of the total area of the Northern Borders Region. The least suitable areas are 56400.9 sq km, representing 51% of the total area. In short, according to the solar radiation criteria, nearly half of the area of the Northern Borders Region is suitable for solar projects (See Table 1 in Appendix). Map 3.11 shows the suitability Index model of slope criteria, The figure indicates that most of the Northern Borders Region lands have suitable slope rates for solar energy projects. The most suitable areas are 104244.6 sq km, representing 94% of the total area of the study area, while the less suitable areas represent 0.3% of the total area of the Northern Borders Region.

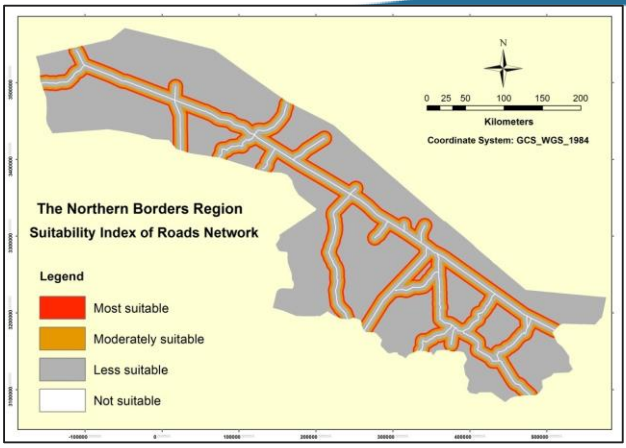


Map 3 .10: The suitability Index of solar radiation



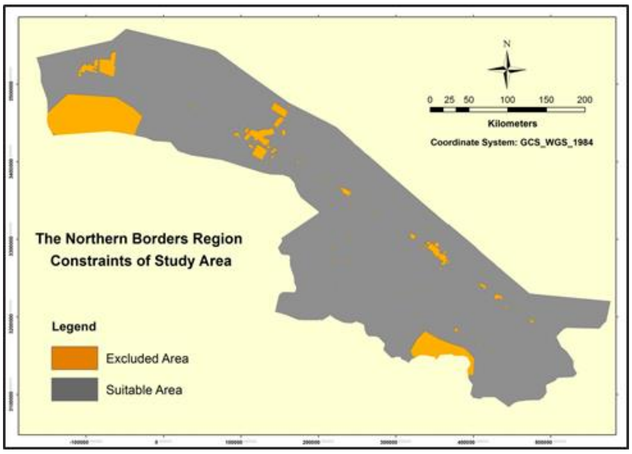
Map 3 .11: The suitability Index of Slopes

Map 3.12 shows the suitability Index model of the roads network criteria, The figure indicates that most of the Northern Borders Region lands are connected by a good roads network which covering most areas of the region and connecting between all cities and villages. It is noted that the areas suitable for the roads network criteria are 20874.5 sq km and represent about 20 % of the total area of the Northern Borders Region. The areas in which the roads are located are excluded and have an area of 2167.7 sq km, representing 2 % of the total area. It should be noted here that the suitability of roads criteria has a start and an end, in the sense that increasing the distance of proximity to the roads is not suitable and the excessive distance away to roads is also not ideal.



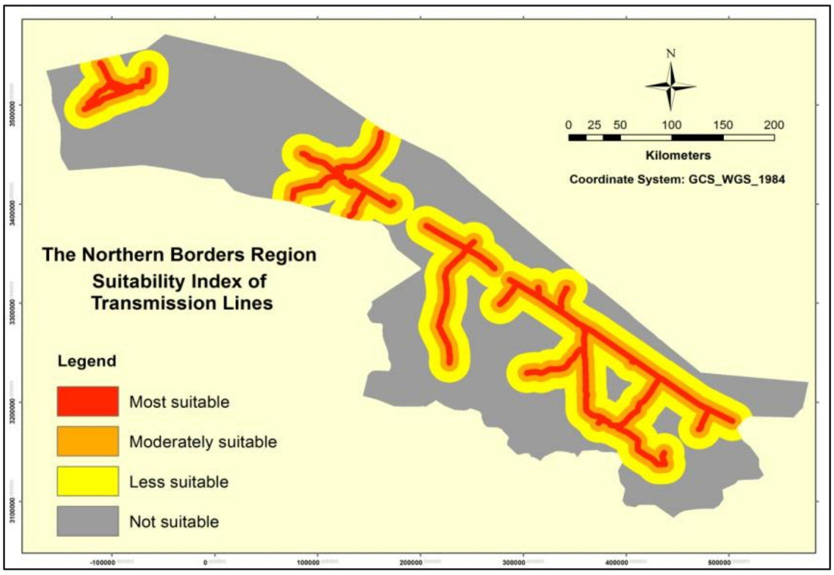
Map 3 .12: The suitability Index of roads

Map 3 .14 shows the excluded areas from the study, which prohibits the establishment of solar projects, including residential areas, investment, government reserves land, agricultural areas, and natural reserves. This area is 9115.8 sq km, represents 8.3 % of the total area of the Northern Borders Region, as well as the areas which considered to be restrictions in other criteria such as sites where roads and valleys are located, and a buffer imposed on international borders. These restrictions have been applied in the final suitability model.



Map 3 .14: The excluded areas

Map 3.13 shows the suitability Index model of the transmission lines criteria, The figure shows that the electricity distribution grid extends well in the Northern Borders Region lands, and note that the suitable areas are not more than five kilometers from the transmission lines, The suitable areas according to the criteria of proximity to the transmission lines is 22899.2 sq km and represents about 21% of the total area of the Northern Borders Region, And the not suitable areas is 63166.2 sq km, represents 57 % of the total area. For details of suitable areas according for criteria Separately, See Table 1 in Appendix.



Map 3 .13: The suitability Index of transmission lines

The results of the final suitability model indicate that more than 50% of the area of the Northern Borders Region is suitable for solar energy projects with an area of 58696 sq km. Map 3.15 shows the final suitability model that the most suitable areas with a suitability index more than 80 % cover an area of 8499.5 sq km from the Northern Borders Region area which are located within the governorates of Arar and some villages within Arar administrative area such as Hazem Al Jalamid and Al Didab, also the Turaif governorate and Al Uwayqilah governorate in some villages within Al Uwayqilah administrative area in the south such as Salmaniya, Zahwha and Al Yadyiah. A small area near the village of Qaysoumat Fihan in Rafha governorate, And some of the villages belonging to the administrative area of Umm Khunsur governorate such as Ibn Said, Ibn Bakr and Al Sulaymaniyah, Table 3.10 shows the summary of results for final suitability model (Figure 3.3). The results indicate that most of the most suitable areas appear in the center and west of the Northern Borders Region, (Map 3.16). As table 3.11 shown below, the western region, especially in Turaif governorate, is characterized by the highest suitability index of more than 90%. It is the highest suitable area of the study area on 1554.8 sq km and represents about 1.4 % of the total area of the Northern Borders Region,(Map 3.17). Also, the final suitability index map shows that the least suitable areas are concentrated in the eastern areas of the Northern Borders Region, especially in the governorates of the Ash Shu'bah, Rowdat Habbas, and Linah, (Map 3.18).
The graph of the governorates most suitable for solar energy projects in the Northern Borders Region is presented in Figure 3.4.

Table 3.10: Summary of results for final suitability model

Ranking	Suitability Level	Area/ sq km	Proportion/Total Area
0	Not suitable	30466	28 %
1-5	Less suitable	21517.7	19.3 %
5-8	Moderately suitable	50197.2	45%
8-10	Most suitable	8499.5	7.7 %

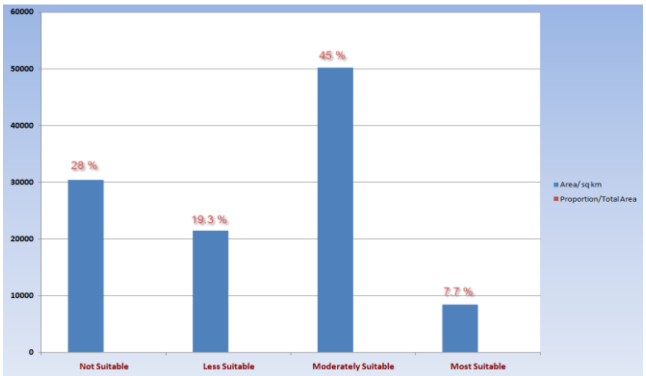
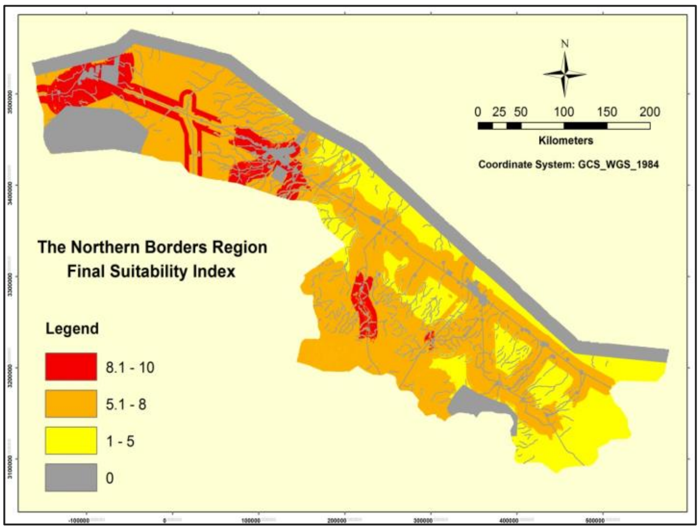
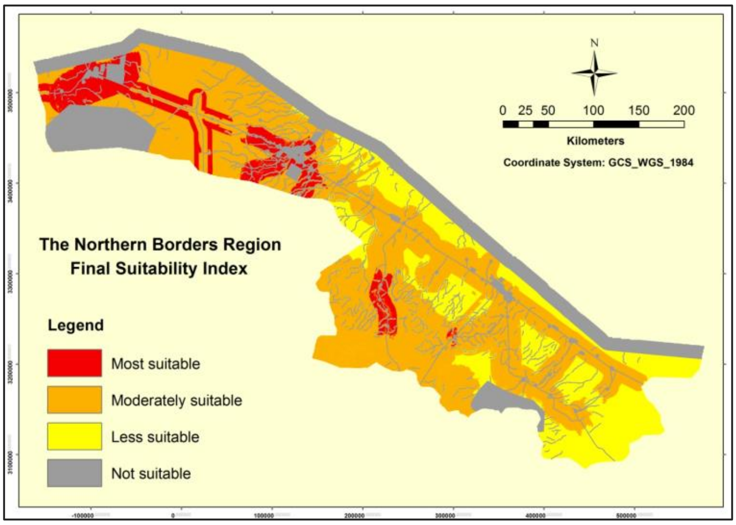


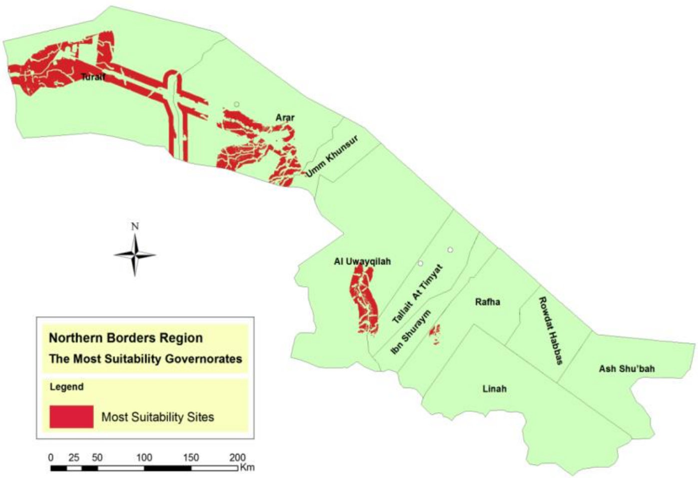
Figure 3 .3: The results of final suitability model

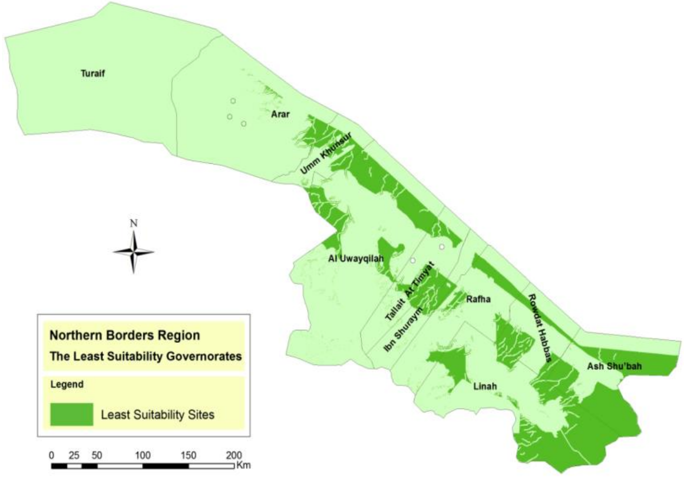


Map 3 .16: The final suitability index - Ranking



Map 3 .15: The final suitability index - Suitability Level





Map 3 .17: The Most Suitability Governorates

Map 3 .18: The Least Suitability Governorates

Table 3.11: Summary of results for most suitability sites in governorates

Governorates	Most Suitable Sites	
	Area/sq km	Proportion
Turaif	4521.5	53.2%
Arar	2811.6	33%
Al Uwayqilah	965.6	11.4%
Rafha	86	1%
Umm Khunsur	67.9	0.8%
Other Governorates	46.9	0.6%
SUM	8499.5	100%

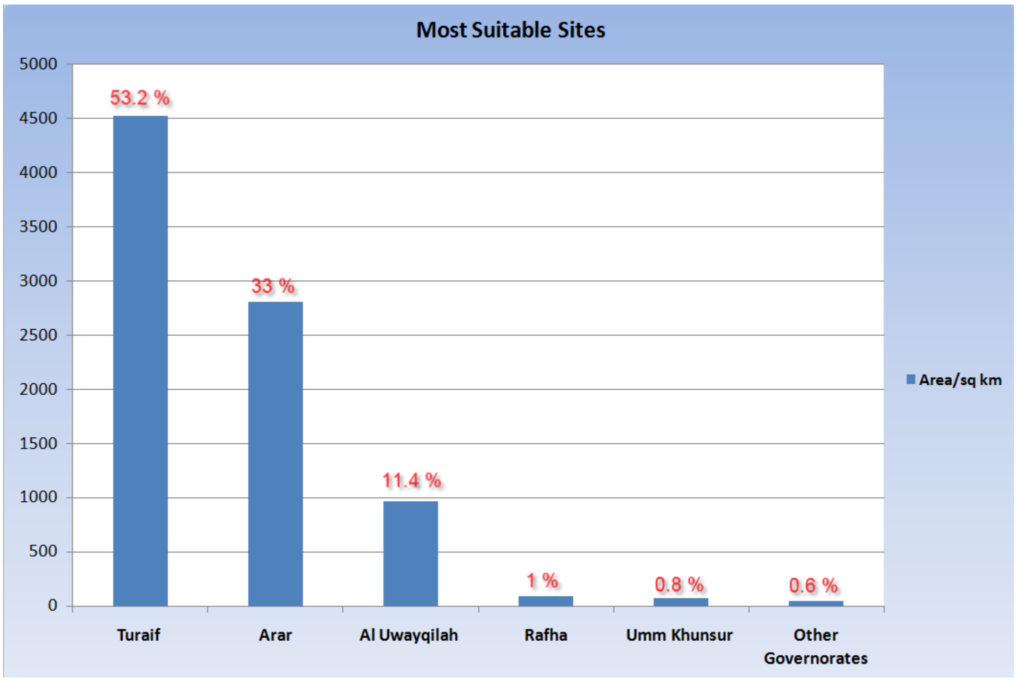


Figure 3 .4: The most suitability sites in governorates

Chapter- 4: Conclusions

4.1. Results Discuss

The study targeted primarily to identify the most suitable sites for the establishment of solar energy projects in the Northern Borders Region, according to several well - known technical, economic and environmental criteria which have been used in previous studies, In this study, we used the GIS approaches in the sites selection based on Multi-criteria analysis (MCA), Weights were given to the criteria according to their importance using the Analytical Hierarchy Process (AHP) methodology. The consistency ratio of the weights was verified to achieve reliability, and the results became significant, So it became important in decision support. The results bring happy news to decision-makers in the field of solar energy, both on the level of land suitable for solar projects in the Northern Borders Region or at the level of geographical location of the most suitability areas, where the results indicated that more than 50% of the area of the Northern Borders Region is suitable land for solar energy projects, with an area of 58696.7 sq km, a large area that allows the production of abundant solar energy to become an added value to the national economy . As for the geographical location of the most suitable and suitable land, the results indicate that the suitable land is distributed fairly well over all the Northern Borders Region governorates that tracked the roads network and electricity grid, But the news most happiness for decision makers is that more than 86% of the most suitable land is located in the governorates of Turaif and Arar is the most governorates in terms of population and economically stronger, which will lead to increased demand for energy, as well as That major industrial and mining projects such as Wa'ad Al-Shamal City for Mining Industries, Will be settled in these governorates. Also, in the near future many complementary industries will be established which will attract people Who are looking for promising economic opportunities. Therefore, the issue of using solar energy in the governorates of Arar and Turaif is urgent and should not be delayed.

We can say that the appropriate slope rates, the high amount of solar radiation, the efficiency of the electricity grid and the network of roads linking cities are well distributed, they have a crucial role in getting great results in terms of the distribution of suitable sites in all governorates of the Northern Borders Region, But unfortunately, however, the dry valleys which are heavily distributed in the Northern Borders Region, have been an obstacle to the continuous expansion of the suitable land, It also excluded areas of land of 7993.5 sq km, are not allowed for the establishment of solar projects.

It should be noted here that excluded areas, such as residential areas, government reserves, agricultural lands and nature reserves, cut off large areas of the study area about 9217.69 2 sq km representing 8.3% of the total area of the Northern Borders Region, Some of these lands, if included in the study area, especially the unused reserved government land, the results will be better.

This study only presented some of the spatial analysis necessary for the Identification of solar harvesting sites. The study did not extend to includes some affecting factors on the amount of solar radiation such as humidity, dust, fog, and pollution.

Generally, The results are promising in the field of solar energy in the Northern Borders Region and there are no barriers to the exploitation of solar energy in the study area, where the results were logical according to the criteria that were carefully developed based on the opinion of experts and specialists and previous studies.

4.2. Recommendations

Based on the results, the study recommends that:

- The results of the study should be taken into consideration by decision makers in the implementation of solar projects in the Northern Borders Region.
- Applying of the final suitability model developed in accordance with technical, economic and environmental criteria in other regions and on other scales.
- Setting the Northern Borders Region on the priorities of the future plans of the Kingdom of Saudi Arabia for solar energy projects. The Northern Borders Region is an economically promising environment and is expected to increase demand for energy.
- Increasing research and studies in the field of solar energy at the level of the region, cities, and buildings.
- Expanding studies to include unused government reserves. The status of landuse for these lands is adjusted according to the results of the study.

- Future research is required to include the factors affecting the choice of sites suitable for solar harvesting and the amount of solar radiation such as humidity, dust, fog, and pollution.
- Facilitating access to data and information related to solar research that supports researchers in this field.
- Raising awareness and knowledge related to the use of renewable energy especially solar energy, both for citizens and investor.

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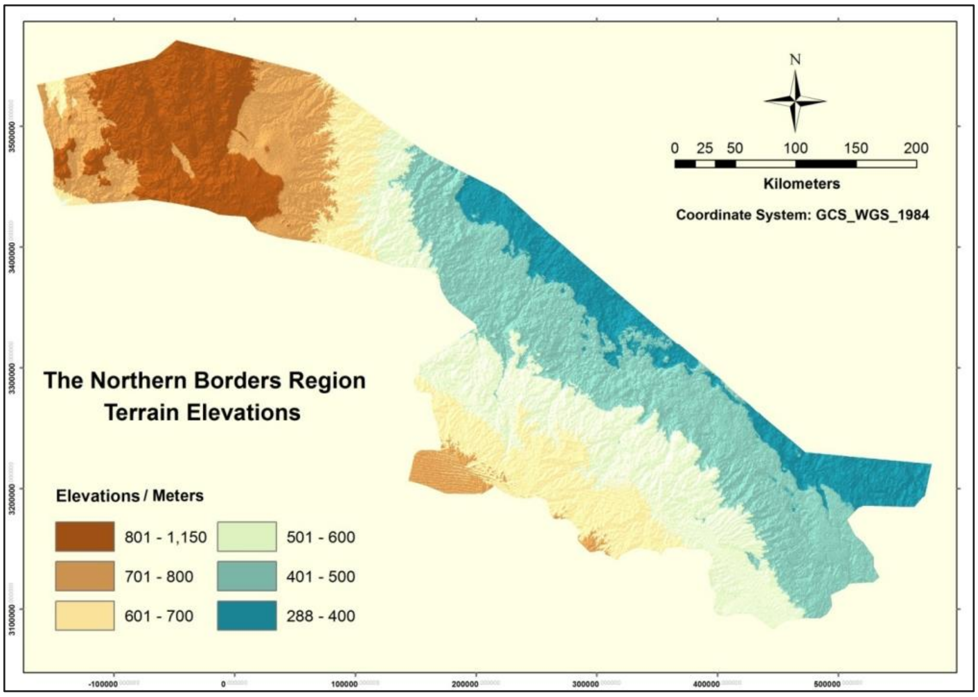
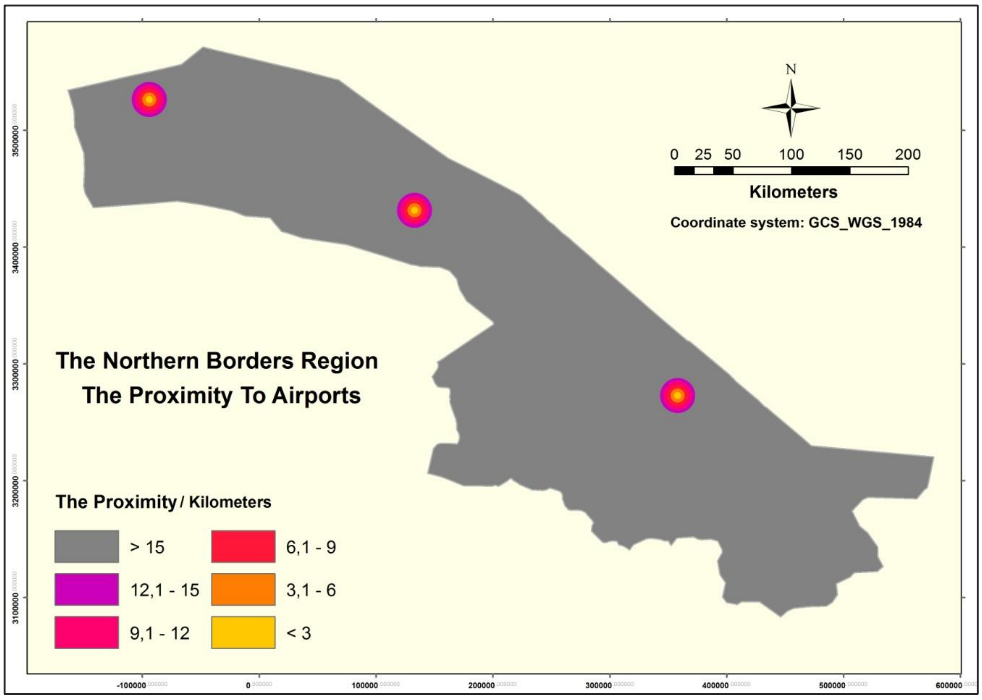
Appendix

The appendix contains three parts. The first part relates to the maps produced during the study. This is the map of elevations which the slope rates and the valleys paths were extracted, as well as some proximity maps and suitability maps to the criteria. The second Part relates to tables of the final suitability data for the criteria separately at the study area, as well as details of the final suitability index at the municipal level separately. The third part concerns the presentation of tables for work procedures with AHP.

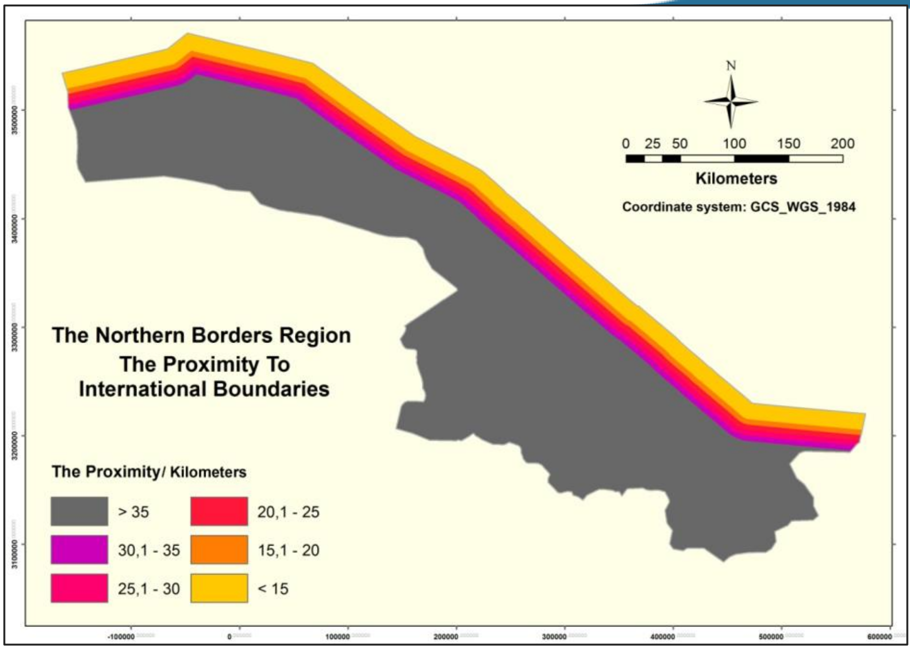
PART I: The Maps of Elevations, Proximity And Suitability Index :



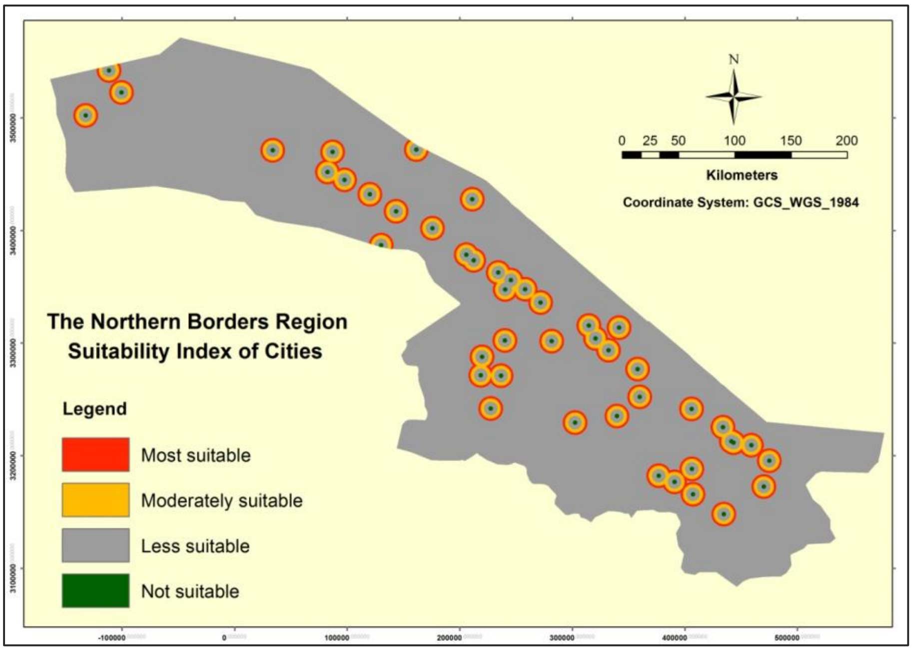
Map 1: The Elevations for The Northern Borders Region



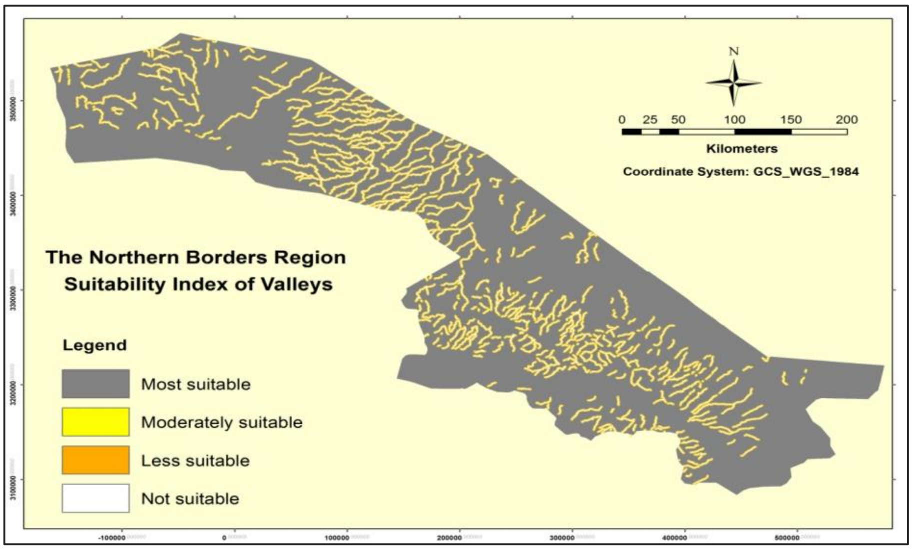
Map 2: The Proximity to Airports



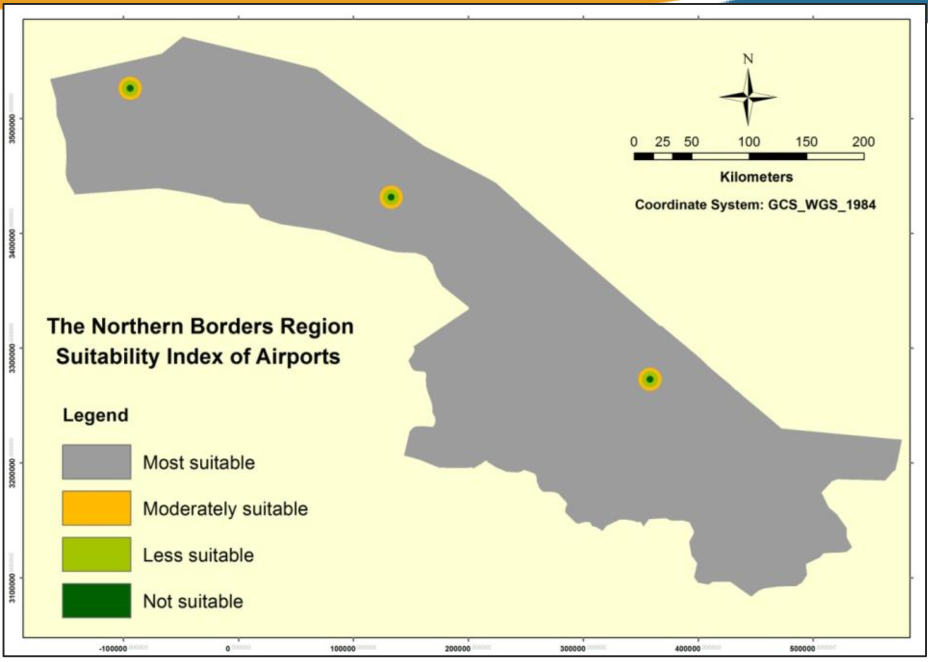
Map 3: The Proximity to International Boundaries



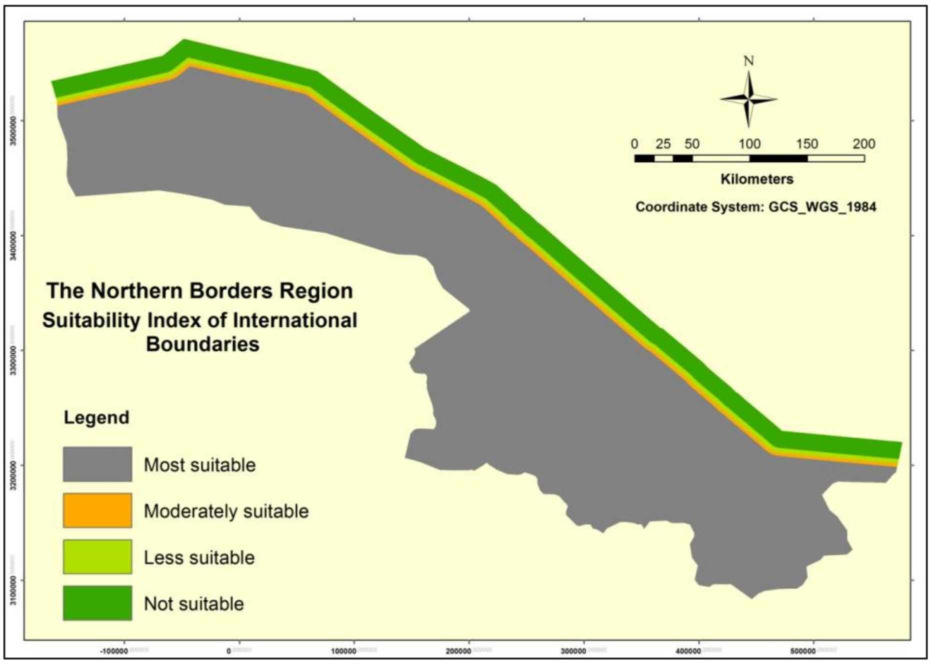
Map 4: The Suitability Index Of Cities



Map 5: The Suitability Index Of Valleys



Map 6: The Suitability Index of Airports



Map 7: The Suitability Index of International Boundaries

PART II: The Final Suitability Index:

Table 1: The Final Suitability Index of The Criteria Separately.

Direct Normal Irradiation (DNI)

Suitability Level	Area/ sq km	Proportion/Total Area
Less suitable	56400.9	51 %
Moderately suitable	28718.6	26 %
Most suitable	25576.2	23 %

Slope

Suitability Level	Area/ sq km	Proportion/Total Area
Less suitable	335.2	0.30 %
Moderately suitable	6426.8	5.7 %
Most suitable	104244.6	94 %

Transmission Lines

Suitability Level	Area/ sq km	Proportion/Total Area
Not suitable	63166.2	56.9 %
Less suitable	24968	22.5 %
Moderately suitable	14803.6	13.3 %
Most suitable	8095.6	7.3 %

Roads

Suitability Level	Area/ sq km	Proportion/Total Area
Not suitable	2167.7	2 %
Less suitable	87991.4	79 %
Moderately suitable	10800.6	10 %
Most suitable	10073.9	9 %

Constraints

Suitability Level	Area/ sq km	Proportion/Total Area
Excluded Area	9115.8	8.3 %
Suitable	87991.4	91.7 %

Table 2: The Final Suitability Index of Municipalities Level Separately.

Municipalities	Suitability Index	Area/sq km	Proportion
Turaif	Not Suitable	10304.2	44.5%
	Less Suitable	0.03	0.001%
	Moderately Suitable	8186	35.5%
	Most Suitable	4521.5	19.5%
Arar	Not Suitable	5334.4	31.4%
	Less Suitable	588.4	3.5%
	Moderately Suitable	8228.3	45.5%
	Most Suitable	2811.6	16.6%
Al Uwayqilah	Not Suitable	3462	16%
	Less Suitable	4900	23%
	Moderately Suitable	12891.8	59.5%
	Most Suitable	965.6	4.5%

Rafha	Not Suitable	2042.4	24.5%
	Less Suitable	1316.28	16%
	Moderately Suitable	4874.2	58.5%
	Most Suitable	86	1%
Linah	Not Suitable	2745.9	18.6%
	Less Suitable	6165.7	42
	Moderately Suitable	5763	39.4%
	Most Suitable	0	0%
Tallait At Timyat	Not Suitable	1152.9	21%
	Less Suitable	1315.7	21%
	Moderately Suitable	3261	57%
	Most Suitable	51	1%
Ibn Shuraym	Not Suitable	736	21%
	Less Suitable	632.8	18%
	Moderately Suitable	2216.3	61%
	Most Suitable	0	0%
Rowdat Habbas	Not Suitable	1579.8	31%
	Less Suitable	1469.3	29%
	Moderately Suitable	1979.77	40%
	Most Suitable	0	0%
Ash Shu'bah	Not Suitable	2003.9	24%
	Less Suitable	4794	56%
	Moderately Suitable	1669.6	20%
	Most Suitable	0	0%
Umm Khunsur	Not Suitable	1106.3	33%
	Less Suitable	1023	31%
	Moderately Suitable	1148.5	34%
	Most Suitable	67.9	2%

PART III : The tables of work procedures with AHP.

Table 3: Criteria Comparison Matrix (AHP)- Step 1

Criteria	C1	C2	C3	C4	C5	C6	C7	C8
Solar Radiation-C1	1.000	3.000	3.000	5.000	7.000	7.000	5.000	5.000
Slope-C2	0.333	1.000	1.000	3.000	5.000	5.000	3.000	3.000
Distance from transmission lines -C3	0.333	1.000	1.000	3.000	5.000	5.000	3.000	3.000
Distance from roads and railways -C4	0.200	0.333	0.333	1.000	3.000	3.000	1.000	1.000
Distance from cities -C5	0.143	0.200	0.200	0.333	1.000	1.000	0.333	0.333
Distance from airports -C6	0.143	0.200	0.200	0.333	1.000	1.000	0.333	0.333
Distance from international boundaries line -C7	0.200	0.333	0.333	1.000	3.000	3.000	1.000	1.000
Distance from valleys -C8	0.200	0.333	0.333	1.000	3.000	3.000	1.000	1.000
SUM	2.552	6.400	6.400	14.667	28.000	28.000	14.667	14.667

Table 4: Criteria Comparison Matrix- Step 2

Criteria	C1	C2	C3	C4	C5	C6	C7	C8
Solar Radiation-C1	0.392	0.469	0.469	0.341	0.250	0.250	0.341	0.341
Slope-C2	0.131	0.156	0.156	0.205	0.179	0.179	0.205	0.205
Distance from transmission lines -C3	0.131	0.156	0.156	0.205	0.179	0.179	0.205	0.205
Distance from roads and railways -C4	0.078	0.052	0.052	0.068	0.107	0.107	0.068	0.068
Distance from cities -C5	0.056	0.031	0.031	0.023	0.036	0.036	0.023	0.023
Distance from airports -C6	0.056	0.031	0.031	0.023	0.036	0.036	0.023	0.023
Distance from international boundaries line -C7	0.078	0.052	0.052	0.068	0.107	0.107	0.068	0.068
Distance from valleys -C8	0.078	0.052	0.052	0.068	0.107	0.107	0.068	0.068
SUM	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 5: Normalized Criteria Comparison Matrix (AHP)- Step 3

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	Row/SUM	Weights(w)
Solar Radiation-C1	0.392	0.469	0.469	0.341	0.250	0.250	0.341	0.341	2.852	0.3565
Slope-C2	0.131	0.156	0.156	0.205	0.179	0.179	0.205	0.205	1.414	0.17675
Distance from transmission lines -C3	0.131	0.156	0.156	0.205	0.179	0.179	0.205	0.205	1.414	0.17675
Distance from roads and railways -C4	0.078	0.052	0.052	0.068	0.107	0.107	0.068	0.068	0.601	0.075
Distance from cities -C5	0.056	0.031	0.031	0.023	0.036	0.036	0.023	0.023	0.258	0.032
Distance from airports -C6	0.056	0.031	0.031	0.023	0.036	0.036	0.023	0.023	0.258	0.032
Distance from international boundaries line -C7	0.078	0.052	0.052	0.068	0.107	0.107	0.068	0.068	0.601	0.075
Distance from valleys -C8	0.078	0.052	0.052	0.068	0.107	0.107	0.068	0.068	0.601	0.075
SUM	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	8.000	1.000