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Analysis of Least Cost Path by Using Geographic Information Systems Network and Multi Criteria Techniques

تحليل اقصر مسار باستخدام نظم المعلومات الجغرافية

وتقنية الشبكة والمعايير المتعددة

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ملخص

أنواع المواصلات المختلفة هذه الأيام لديها مشاكل وصعوبات عديدة تؤثر سلبا على تنقل المواطنين و حركتهم اليومية مما ينعكس مباشرة على حركة الإنتاج والاقتصاد وكذلك التعليم التي تلعب دور أساسي في عملية التنمية وازدهار وتطور الحضارات، مدينة الخرطوم ليست بمنأى عن مشكلات الازدحام والاختناقات في الطرقات وذلك للهجرة المواطنين من جميع الولايات إليها بسبب توفر الخدمات الحيوية الأساسية جامعات ،مستشفيات.....الخ، مما أدى إلى انفجار في عدد السكان وزيادة كبيرة في عدد المركبات والتي أسهمت في ارتفاع عدد الحوادث المرورية وتضاعف نسبة التلوث في الهواء بسب تصاعد غازات وأبخرة المركبات جميع هذه العوامل ساهمت في ضياع كثير من الوقت في المواصلات.

التقنيات والوسائل الحديثة يمكن أن تستخدم لإيجاد الحلول الناجعة لمشاكل الازدحام في المواصلات والطرق لأنها تعطى صناع القرار الحلول والنتائج المنطقية وذلك لتجنب عيوب الطرق التقليدية،الهدف من هذه الدراسة معرفة إمكانيات الوسائل الحديثة في عملية التخطيط لإيجاد انسب مسار من حيث المسافة واختزال تكلفة الإنشاء باستخدام تحليل شبكة نظم المعلومات الجغرافية **(GIS)** وأنظمة التحليل المتعددة **(MCA)** وقد أنشأت شبكة الطرق لحساب زمن الوصول للخدمات الحيوية مدارس، مستشفيات ، مراكز صحية ، متنزهات .....الخ ، ضمن عوامل معينة ،كما وضحت الخطوات العملية التي اتبعت في اختيار أفضل مسار بواسطة نظم المعلومات الجغرافية لمدينة الخرطوم بإدخال محطات ربط حيوية يمر عبرها المسار الذي يعتبر حلقة وصل بينها وهى :المناطق التعليمية والاقتصادية والصحية والترفيهية ومحطات المواصلات حيث أعطيت كل منها أوزان تمثل أهمية العامل فمثلا الأماكن التعليمية أعطيت أولوية على المناطق الترفيهية وكذلك المناطق الصحية أعطيت أفضلية على المناطق الاقتصادية ....الخ.

تم تحديد نقطتي البداية والنهاية للمسار عشوائيا وباستخدام تقنيات نظم المعلومات الجغرافية تم إنشاء المسار،هذه الدراسة توصلت أن التقنيات والوسائل الحديثة كنظم المعلومات الجغرافية (GIS) وأنظمة التحليل المتعددة (MCA) يمكن أن تستخدم لإيجاد أفضل مسار بين نقطتين من حيث المسافة واختزال تكلفة الإنشاء ولقد أمدت المخططين وصناع القرار بوسائل وطرق سهلة الاستخدام في عملية التخطيط لإيجاد انسب مسار.

Abstract

The transportation problem has direct impact in human life towards the progress. With the rapid vehicle volume growth on roads, people spend much time to arrive to their work, school and health centers. As a result, transportation-related problems are getting worse. In Khartoum city the increase in traffic volume results in growing costs in terms of rapidly increasing congestion levels with associated environmental pollution and with a risk of accidents and time wasted during travel. The use of modern technological tools like Geographic Information Systems (GIS) for determining suitable location of optimum routes involves managing a variety of data sets from different sources and at different scales. The aim of this research is to illustrate how GIS, network and multi criteria Analysis (MCA) can be utilized in road planning. Network used to determine travel time. This study outline a detailed process by which MCA can be applied to establish parameters for analysis by GIS. The research shows the steps followed in ArcGIS to determine the most viable route for Khartoum a given parameters: educational, financial, hospitals, business and governmental institutions as well as places of entertainment were identified as being extremely important destination points of service for the path and thus established as parameters. Numerous destination points of service were highlighted and categorized under one of the main groups. Each main group given a value and weighted against other groups to establish an order of priority. A path between two points was obtained. The start and destination point were selected randomly without any pre-knowledge of the area. The thesis has succeeded in showing that it is possible to determine path between two points using Geographic information systems, Network and Multi-criteria analysis in Khartoum city. This study provide a useful tool to decision maker and planner in planning least cost path .

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List of abbreviations	
AHP	Analytical Hierarchy Process
ESRI	Environmental Systems Research Institute
GIS	Geographic information systems
MCA	Multi-Criteria Analysis
UTM	Universal Transverse Mercator
WGS	World geodetic system

Chapter one

Introduction

1.1 General Overview

Nowadays developing countries face a great challenge in their progress towards modern life. Urban transport has always been viewed as a major factor influencing the quality of life. Khartoum, has the highest level of economic activities. Due to an increase in population, as a result of migration from rural areas, traffic congestion and accidents have become a common scene in Khartoum (Fadlalla, 2010).

Traffic congestion along with the problems that stem from it, combine to form, arguably, the greatest dilemma facing city planners. Decreasing this congestion and mitigating related problems is a major priority as the megalopolises of developed nations reach their limits and the metropolises of the developing world burgeon. The establishment of an urban path in one of its many forms has long been a means to mitigate if not solve the traffic problems.

However, the construction of urban path is not without its own difficulties.

Minimizing the altering of existing infrastructure; avoiding the razing of residential areas; the impact on the natural environment while ensuring adequate and quality service to the public are only a few of the many issues to be considered when planning a route.

In this research where the importance of Geographical Information Systems GIS becomes apparent. GIS were integrated with multi citeria analysis which can overcome the dilemmas involved with planning a railway route. With it, a planner can input any number of parameters to be considered under analysis leading to the most optimal route.

The aim of this study uses GIS, and MCA as an effective tools to create and apply network analysis for Khartoum. It provides a helpful application for finding the optimum least cost path , while using Khartoum, the capital city of Sudan as a case study.
This proposed path transport has the potential to provide several advantages, namely the fact that: path service is cost efficient; the infrastructure utilizes less space; it transports a large number of passengers; its environmental impact is comparatively less; and also can be easily adapted to future needs

1.2 Problem Statement:

In the last five years Khartoum has faced a huge problem in urban transport, especially at rush hour times in the morning and evening, due to a lack of modern infrastructure which can facilitate the flow of high traffic volume.
The economic losses are monumental, in terms of wasted time, which can hardly be imagined: thousands upon thousands of employees, students and workers are forced to sit idle, in many cases for hours, in the morning traffic congestion, as well as in the evening.
The transportation problems that exist in Khartoum stem from the fact that the city's population and land area has increased exponentially over the last twenty years, while funding for new infrastructure and repairing of existing infrastructure has not kept pace with this growth. This combined with the fact that urban planners have not possessed sufficient experience in the field, thus resulting short-sighted planning.
This thesis aim to identify the optimum route which links all major vital utilities, through the application of GIS. The application of GIS will enable planners to overcome the obstacles of the current infrastructure by determining the most feasible path between two points.

1.3 The Objective

The main objective of this research is to introduce the capability of MCA and GIS to facilitate network analysis for planning in Khartoum with emphasis on the location of least cost path between two points. The individual objectives are to:

- Determine the travel time based on network analysis.
- Find an optimum location for transportation path using GIS and multi-criteria analysis.
- Identify least cost path between two points.

1.3 Thesis Outline

The thesis comprises five Chapters

Chapter one provides a broad background on the concept of route site selection to solve a variety of problems, including traffic congestion and air pollution. In addition, this chapter includes a discussion of the purpose and scope of the research, Chapter two starts with literature review to numerous studies similar to this thesis and gives a general overview on the application of geographic information systems and multi-criteria analysis. This is aimed at describing the basic principles and concept associated with MCA and GIS.

Chapter three is an essential chapter starts with an overview of the study area and offers a detailed which process of analysis used to identify the optimum path, while taking into account the many factors affecting the selection of a route in Khartoum through the application of geographic information system (GIS) , In chapter four the results of the study presented. It was found that there are essentially two route ways based on the data collected. This chapter also includes a mapped layout of the location of the two paths, followed by a description of the advantages and disadvantages of each of the two paths

Chapter five concludes the research findings. Recommendations for future work are also provided in this chapter for consideration by prospective researchers in the near future.

CHAPTER TWO
Theoretical background

2.1 Literature Review

The application of MCA and GIS in planning purpose is not restricted only to road path planning, pipelines, power transmission line etc. The review of literature in this thesis helps to describe some of the published literature and journal in the application of Geographic information systems and multi-criteria analysis for planning purposes.

One study carried out a research to determine the optimal site for a municipal waste landfill in the union territory of Pondicherry in India, which comprises of four interspersed geographical entities Pondicherry, Karaikal, Mahe and Yanam with an area of 492 km^2 (Sarkar, et al 2007). It used data from the topo-sheets of Pondicherry as the base map. The water bodies, road network and elevation maps were prepared based on the survey of Indian map by digitization. Other data like geology, soil, fault line, water supply source and ground water maps were obtained from other land department. The land use map over the area of study was obtained from the Indian remote sensing satellite. Two approaches were been used in determining the suitable site for a municipal solid waste landfill which include multi-level screening process to screen all environmental factors and secondly, using GIS constraint mapping to eliminate the environmentally unsuitable sites. The factors and constraints were weighted using the Analytical Hierarchy Process (AHP) to derive the relative important weight of each criterion and a pair-wise comparison was conducted among the criterion. In conclusion of their research, seventeen potential sites were located that are suitable for setting a municipal solid waste

landfill. Among the seventeen potential sites, further screening was carried out and three most suitable sites were selected based on their area availability.
Other study was carried out to determine the least-cost reservoir pipeline path to the Langkawi Island, in Malaysia using GIS. It shows how GIS can evaluate the suitable alternatives and visualize the results. The least-cost path was aimed at a major town Kuah and a new tourist area Temoyong. This was influenced by the land-use, terrain, and geological and environmental factors (Yusof et al, 2006). In actualizing the aim of the study created a friction surface which helped to define the cost associated with moving through different land use/cover types around the area of study based on the analysis of the level of difficulty of the pipeline construction across physical features like land-use/cover, inland forest, rubber, mangrove, mixed horticulture, paddy and grass. The least cost path was based on the selected reservoir and targeted areas from Ulu Melaka reservoir to Kuah town and from Limborg reservoir site to Temoyong on the potential forest resort areas.
The first step carried out was to select the start point, which was Ulu Melaka site and the destination, which was Kuah site. The cost distance analysis in the analysis need a friction surface that indicates relative cost of moving through each cells from the start to the destination point. In actualizing this, used the cost friction in IDRISI to create a friction surface. As a check on the influence of decision maker's choice on MCA, changed the friction surface by changing the weights of paddy fields from 5 to 100 and that of rubber from 500 to 5. They used the cost and pathway function of IDRISI to calculate the least-cost path (Yusof et al, 2006).

A study on a selected area in Trabzon situated at the black sea region of Turkey was carried out by Yildirim et al, in 2006 in order to determine the least-cost path for a pipeline between Macka County and Bulak village. The least cost path analysis was carried out in order to determine the difference in the present distance between the two points and the result obtained using least-cost path analysis.

This study used topo-maps, geological and road maps to get the route, and used other maps, fieldwork, and remote sensing techniques. The data layers used in the analysis include slope, geology, land-use, landslide, soil, stream, road, administrative boundaries and tourism. Spatial analysis in ArcGIS 9.0 was used to create source, generate a thematic cost map, perform cost weighted distance, create direction dataset and perform shortest path with distance and direction datasets.

The weighting rate scheme was used to add weights to landslides, land-use, elevations and geology in order of importance with landslide been the first. In conclusion of their study, it was realized that new pipeline route path determined using the least-cost method was 36 km as against the original pipeline length which was 38 km. Further concluded that the choice of preferences by the decision makers might have a significant effect on the result but the result obtained using the least-cost method to determine the best pipeline route is more accurate and less time consuming unlike the traditional method (Yildirim et al, 2006)

2.2 Geographic Information System (GIS)

Geographic Information System defined as a computer based information system used to digitally convert analog to digital application and keep track not only of events, things or activities but also the point where these activities occur (Longley et al, 2002).It helps to represent and analyze the geographic features present on the earth surface and the events including non-spatial attributes linked to the geography under study that are taking place on it (Longley et al, 2002, Bernharden, 2002) Since the mid 1970's, specialized computer systems have been developed to process geographical information in many different ways, the GIS includes not only hardware's and software's but it also include special devices used to input maps and to create map product together with communication systems needed to link various elements.

A GIS makes it possible to link or integrate information that is difficult to associate through any other means and can use combinations of mapped variables to build and analyze new variables (Bernharden, 2002) ,and it also have a wild range of applications which include researchers incorporation of map making process of traditional cartographers into GIS technology for the automated production of maps, resource management ,scientific investigations, asset management, environmental impact assessment ,urban planning, sales, marketing and logistic,….etc. (Aronoff, 1993).

2.2.1 Data management, manipulation and analysis using GIS

Data management component comprises of functions needed to store and retrieve data from the database. The methods used to implement these functions affect how efficiently the systems perform all operations with the data (Aronoff, 1993).

Data manipulation and analysis using GIS helps to determine the information that can be generated by the geographic information system. Every geographic information system has a distinguishing features and their ability to manipulate and integrate spatial and attribute data (Aronoff, 1993).

In the management of data and analysis using geographic information systems, the components of the geographic information (GI) include all available functions of the GIS that are needed to store and retrieve data from the database. The manipulation and analysis of data in a geographic information system is not automatically achieved.

The users are required to be involved in the specification of the necessary functions and performance levels of the systems (Aronoff, 1993).

Different GIS(s) have their ability and functions to manipulate and analyze data depending on the functions available in the geographic information systems.

Some of the possible functions of a (GIS) include measurement functions, which enable the calculation of associated points, lines, areas and volume classification and rectification which helps to transform the attribute data associated with a single map layer and involves the grouping of objects into classes according the new values entered by the user in specification of the different classes needed, other function of the GIS for manipulating and analyzing data include scalar operation, overlay operations, connectivity operations, visualization of data, etc (Malczewski, 1999).

2.2.2 Data input and output

Data input and output cannot be automatically carried out by the Geographic information systems on its own without the user specification. The function of the input component of the GIS is to convert the inputted data from their existing form to another form that can be used by the geographic information systems.

The data used as input and output could be printed (hardcopy) or digital. The printed media could be of paper maps; tables of attribute, photos, etc, while the digital data could be of electronic files of maps and associate attribute data, air photos and even satellite imagery (Aronoff, 1993).

The data input procedures could be an easy and straight forward process or a complex one. A runoff mentioned that the process of data input could be a daunting task if the existing form of data differs greatly from the one used in a GIS or the data amount is huge and sometimes the conversion process itself is daunting.

Data input can influence the result that is expected at the output of the geographic information systems as such the data input should be taken into deep account as possible errors in the data input could cost organization more and more money to fix and suit it with the need of the organization. The various method of data entry should be evaluate in terms of the processing to be done, the accuracy standards to be met and the form of output to be produced (Aronoff, 1993).

The data output in geographic information systems is a result in charts, maps, table of value or text in hard copy or soft copy, maps that have been derived from the inputted data and the information produced are then to be printed or displayed as output of GIS. The output or reporting functions of geographic information systems vary more in quality, accuracy and ease of use than in the capabilities available (Aronoff, 1993). There are a variety of output devices, which includes display monitors, pen plotters, electronic plotters, laser printers, etc. The output functions are determined by the users need in two formats, which is the display and transfer formats. The display output format presents the information to be the GIS user in some form while the transfer formats transfer the information into another computer based system for further processing and analysis (Malczewski,1999).

2.2.3 Data storage

When working with GIS data, it is necessary to understand how various forms of GIS data are stored in their native format. This understanding is critical in order to be successful in moving GIS datasets around. For example, an ESRI shape file is just one file but a grouping of multiple files that work together to create a more efficient method of storing spatial and tabular data, yet keeping the association.

The manner in which a digital map is stored in a record is determined by a format, a set of instructions specifying how the data are arranged in fields. Different software's often organize data to ensure effective use. Most GIS data are arranged in layers much like convectional map-making and the individual data layers are stored in individual data files. GIS data can be stored in vector data format, raster data, attribute data, etc (Bernharden, 2002). The storage components of a GIS include those functions that are needed in the (GIS) to store and retrieve data from its database (Malczewski, 1999).The efficiency of the data performance with the system is determined by the way and method used for the data performance, and the way and methods for the data storage. (Malczewski,1999) suggested that it is advisable that there is an understanding of the elements of computer storage which will enable a GIS user to design optimum storage for different types of data.

2.2.4 Visualization using GIS

Maps have traditionally been used to explore the earth. GIS technology has enhanced the efficiency and analytical power of traditional cartography. Through visualization, a GIS can be used to produce images not just map, but drawings ,animations and other cartographic product. These images allow researchers to view their subjects in ways that they never could before. The images often are helpful in conveying the technical concept of a GIS to non-scientist (Bernhardsen, 2002).

2.3 Multi-Criteria Analysis (MCA)

MCA is designed to be an interactive and flexible management tool for geographic analysis and it is well suited for modeling complex sustainability issues. In the context of conflict resolution and policy implementation, MCA decision models are one of the oldest forms of geographical analysis. Their structures consist of an explicit set of objectives decided upon by a decision maker or an expert group for the purpose of determining an optimal solution (Malczewski, 1999). The optimal solutions are recommended through the set of alternatives that satisfy the largest extent of the expert group objectives. MCA is well suited for conflict resolution as many problems incorporate a wide range of highly complex information that otherwise would be overwhelming for manual aggregation or subjective to high levels of human error (Malczewski, 1999).

The main role of the MCA technique is to deal with difficulties that human decision makers have shown to have in handling large amount of complex information in a consistent way (Malczewski, 1999). MCA can be used to identify a single most preferred option, to rank option, to short-list a limited number of options for subsequent detailed appraisal or simply to distinguish acceptable from un-acceptable possibilities. There are many different types of decision, which fit the broad circumstances of MCA, these are influenced by the time taken to undertake the analysis which may vary, the analytical skills of those supporting the decision, etc (Malczewski, 1999).

(Malczewski, 1999) reported that Multi-criteria analysis is well suited to managing and evaluating structural programs in partnership since the opinions of national and supranational members may be expressed jointly without losing any of their specificity or having to make too many concessions regarding their value scales and the analysis is similar to the techniques adopted in the field of organizational development or information systems management.

2.3.1 Key features of MCA

MCA establish preferences between options by reference to an explicit set of objective that is the decision making body as identified and for which it has established measurable criteria to assess the extent to which the objectives may alone provide enough information for decision-makers (Aronoff, 1993). MCA uses models that help to predict how certain aspects of the real world will be have and it helps to describe the relationship among data elements in order to predict how events in the real world will occur. In MCA, quality or result that is obtained is determined by the data and criterion selection by the MCA user (Aronoff, 1993)

2.3.2 The performance matrix

Performance matrix is one of the features of MCA and it usually applies two types of techniques, which includes scoring and weighting. It is a form of a consequence table in which each row describes an option and each column describes the performance of the options against each criterion. In a basic MCA, the performance matrix can act as a final result analysis where the objectives are Met based on the entries in the matrix. This may not be the same for the case of a more sophisticated analytical MCA. In this case, the information is basically converted into consistent numerical values (Malczewki, 1999).

2.3.3 Scoring and weighting

A performance matrix in MCA usually applies two types of techniques for its numerical analysis, which is scoring and weighting. Scoring and weighting in MCA uses mathematical routines which may be written in computer programs and helps in both scoring and weighting to give an overall assessment of each option been assessed for its quality. The use of scoring and weighting in MCA is dependent on the individuals that will be providing the inputs that are required to produce the detailed information that is consistent with the preferences that have been identified by the individual input(Malczewski, 1999).

In the scoring techniques, the expected consequence of each option are assigned a numerical score on the strength of preference scale for each criterion with more preferred option having higher scores and lower option having lower scores(Malczewski, 1999). In the weighting option, numerical weights are assigned to define for each criterion and the relative valuation of a shift between the top and bottom of the chosen scale. Different methods can be used in the application of weights, which include ranking, rating, pair-wise comparison and trade-off analysis (Malczewski, 1999).

2.4 Different types of MCA

There are many different types of MCA. This thesis have looked and given a brief description of some MCA techniques.

2.4.1 Basic AHP procedures

The Analytic Hierarchy Process allows users to assess the relative weight of multiple criteria (or multiple alternatives against a given criterion) in an intuitive manner Its major innovation was the introduction of Pair-wise comparisons which is a method that has been shown by researchers that when quantitative ratings are unavailable, human are still adept at recognizing whether one criterion is more important than another (Malczewski, 1999). In 1980Saaty invented the AHP methodology and he established a consistent way of converting such pair wise comparisons into a set of numbers representing the relative priority of each of the criteria (Malczewski, 1999).

A potential drawback with the AHP method is the rank reversal. Because judgment in AHP is relative by nature, changing the set of alternatives may change the decision scores of all the alternatives. Even when anew very poor alternative is added to a completed model, the alternatives with top scores sometimes reverse their relative ranking (Malczewski, 1999).

2.4.2 Outranking method

The outranking method starts by making comparison of alternatives for each single criterion in order to denote partial binary resolution (Roy, 1996). Outranking is used where the criteria are not all considered commensurable, and therefore no global score can be produced. The analysis is based on multiple comparisons of the type for example, does Measure A outrank Measure B from the point of view of the environment criterion and does Measure A outrank Measure B from the point of view of the employability criterion etc (Roy, 1996). (Roy, 1996) suggest that these questions can be answered yes or no or be qualified, in which case the notions of a weak preference and a threshold criterion are introduced and the analysis makes all possible comparisons and presents a synthesis of the type.

Outranking methods constitute a class of ordinal ranking algorithms for multicriteria decision-making. The outranking method of MCA was developed in France and has achieved a fair degree of application in some continental European countries and it is based on the concept of outranking. Weighting in outrank ingrate measured by the degree to which each criterion influences a final statement of whether or not alternative A is equal or preferred to B. The key feature about outranking is that they allow for two or more alternatives to remain incomparable if there is insufficient argument to support that one alternative outranks the other.

The main concern about outranking is that it is dependent on some rather personal decision of what precisely constitutes outranking and how the threshold

Parameters are set and manipulated by the decision maker (Roy, 1996).

2.4.3 Linear additive method

The linear additive method of MCA shows how option value on the many criteria can be combined into one overall value by multiplying the value core of each criterion by the weights of that criterion and then adding all those weights scores together. The linear additive methods can be operation a lised using any GIS system having overlay properties (Malczewski, 1999).

The use of linear additive method can be applied to both raster and vector GIS environment and there are two strong assumption in the additive method of MCA which is linear and additive of attributes. In the linearity assumptions, the desirability of an additional unit of an attribute is constant for any level of that attribute while in the additively of attributes; there is no interaction effect between the attributes (Malczewski, 1999).

2.4.4 MCA based on fuzzy set

The MCA method of fuzzy set shows the many ways with which fuzziness can be introduced into an existing model of decision-making .There are different types of fuzzy set method among which include the fuzzy additive weighting method which is similar to the linear additive method. Both methods apply the weighted average as the aggregation operator and the difference between this two methods is that the fuzzy additive weighting method operates on the fuzzy data were the entries of the decision matrix and weights are specified in terms of fuzzy numbers(Malczewski, 1999).

Fuzzy sets attempt to capture the idea that our natural language in discussing issues is not precise as options are fairly attractive from a particular point of view or rather expensive. The fuzzy arithmetic then tries to capture these qualified assessments using the idea of a membership function through which an option would belong to the set of options with a given degree of membership lying between 1 and 0 (Malczewski, 1999). Different types of models have applied the principles of fuzzy set among which include the Bellman-Zadeh model. This model of Bellman-Zadeh serves as a point of departure for most subsequent work on decision in fuzzy environment (Malczewski, 1999).

2.5 Advantage of MCA over informal judgment:

The features and application of MCA have helped me distinguish it from the informal method of planning. The informal method of planning employs the use of crude instruments, takes time and resources etc. I present some possible advantages of MCA over informal method of planning.

- MCA is open and explicit. That is MCA is done or shown in an open or direct way so that there is no doubt about what is happening.
- The use of MCA saves time and resources.
- There is a chance of an audit trial because of the use of scores and weight.
- MCA provides a better communication among the decision makers and the entire community.
- Choice and criteria are open to analysis by different stakeholders involved in the planning process and possible changes can be made if found not suitable.
- With the availability of data, MCA can be carried out without direct visitation to the area of study.

With the use of MCA, planners do not go through the rigorous task of continual site visitation and working under bad weathers. The analysis and planning process is carried out using different software and a computer and as such can be done indoors.

CHAPTERTHREE

METHODOLOGY

3.1 Back ground

The previous chapter provided background information relating to the specific research topic, including the criteria used in this thesis, and GIS system as well as the advantages of (MCA) as useful process of planning. This chapter will describe the methodology used to select the optimum path for railway in Khartoum. Figure 3.1 The methodology steps

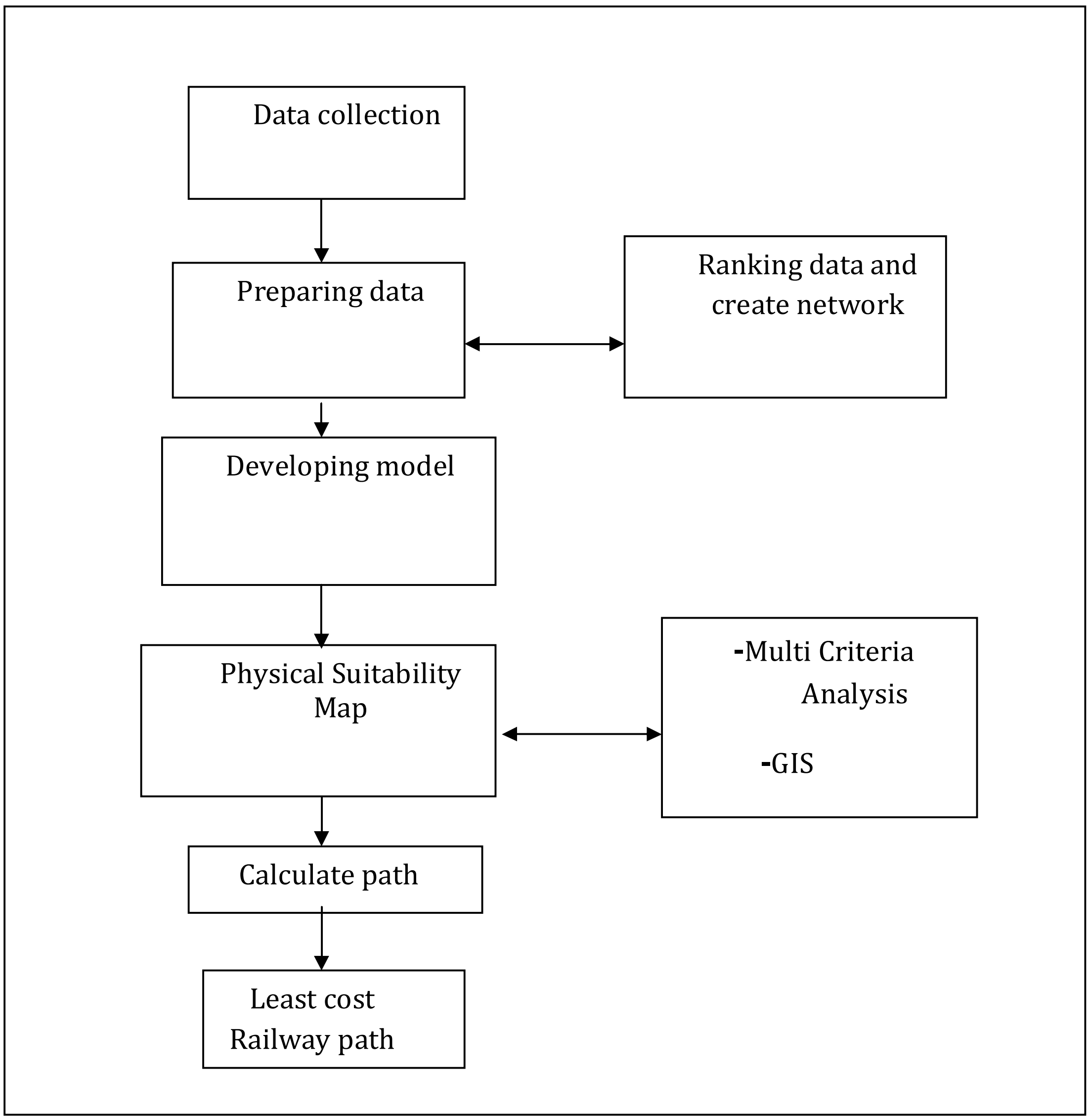


Figure 3.1: Flow Chart of Methodology

3.2 Overview of the Study Area

The city of Khartoum is located at the confluence of the White and Blue Niles which combine to form the River Nile. The locality of Khartoum is 405.6 meters above sea level between the (**32°35′31.977"E** and **15°30'6.842"N**)to (**32°28'19.474"E** and**15°37'13.559"N**),The point where the two Niles meet is known as the "Al-Mogran". The capital Khartoum contains three metropolitan cities, which is includes the municipalities of Khartoum, Bahry and Omdurman. The state of Khartoum consists seven localities; Khartoum, Bahry, Omdurman, Jebel Awlyia. Sharq Al Neil, Kerary, Um Bedda. This research focuses of the suitability of tram railway lines in the Khartoum locality(Figure 3.2). The locality of Khartoum is situated on the south and west bank of the Blue Nile and the east bank of the White Nile with a population of about a **4,229,432** million inhabitants as of 2012**.**

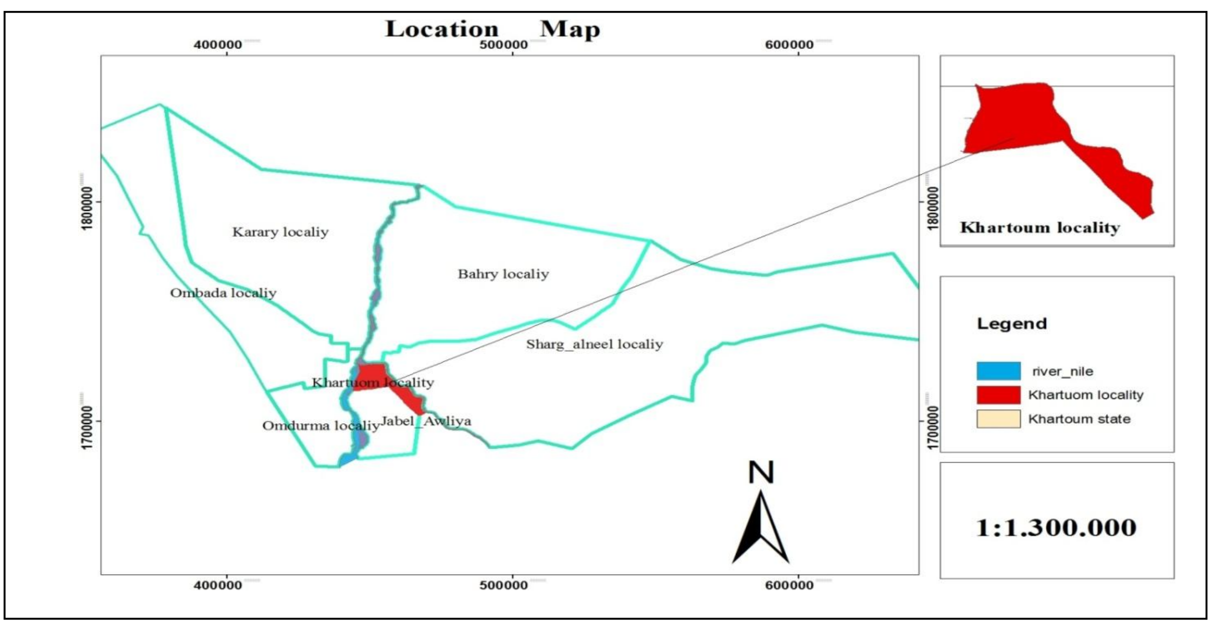


Figure 3.2: Study Area

3.3 Data collection

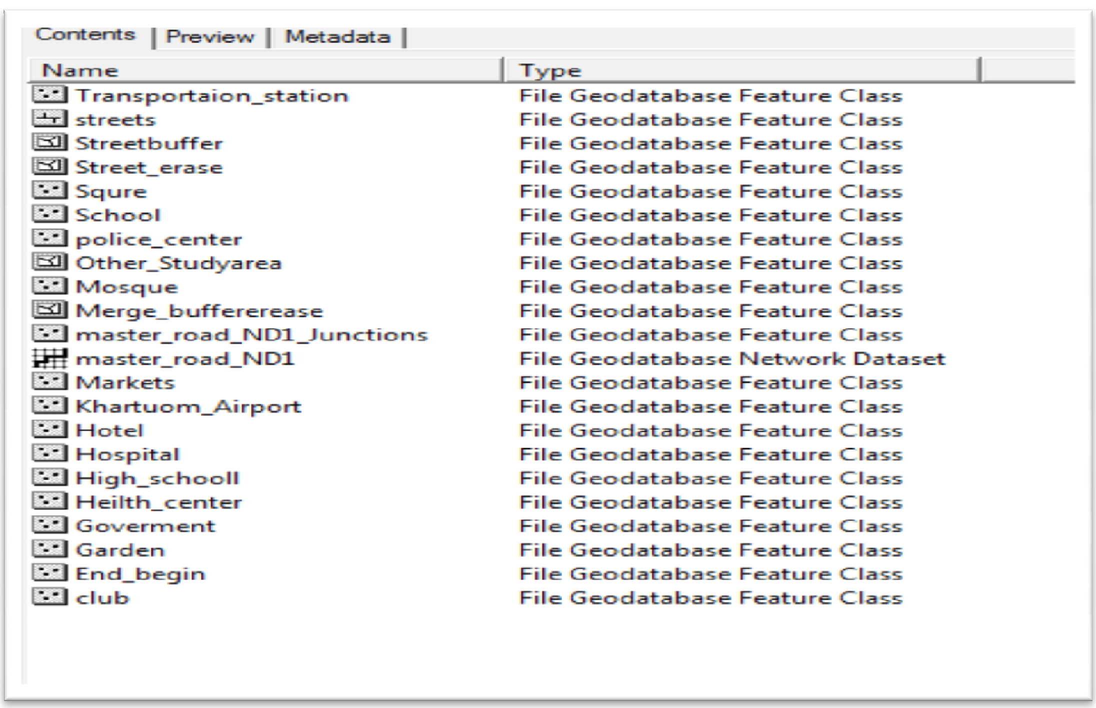
Data collection began with gathering information from local GIS centers. Permission was obtained to take and use data. The Center of Digital Maps and Information in the Ministry of Planning and Infrastructure served as the primary source of information. In addition the Bridges and Roads Corporation was an additional source, particularly for street data. The list of data sets and their description are summarized in Table 3.1

Table 3.1: Description List of Data

No.	Type of Data	Description	Source
.1	Khartoum map	Polygon as a feature class, contain:(resident, commercial and service parcels)	2013Ministry of planning and Infrastructure
.2	Attributes of services parcels and land use	Data in Excel format contain: the name, type and location of service	2013Ministry of planning and Infrastructure
.3	Khartoum image	Satellite image raster format with resolution 60 cm	2013 Universal Mapper Software
.4	Khartoum Streets	Poly line as feature class contain:(name, length, Speed….etc)	2011 Bridges and Roads Corporation

3.4 GIS Geodatabase

The Geodatabase was created including thirteen several feature classes streets and vital utilities (Schools, Hospitals, universities, clubs, Hotels, Health centers, Government offices, Sport fields, Transportation stations and Airport) see Figure 3.2. All the Geographic data was referencing to (WGS1984-UTM zone 36 N). The process of digitizing roads to the study area was performed. Road layer was classified to three categories: highway, main road and secondary road. Database was constructed for the query of attribute included road name, maximum design speed, direction of roads and vehicle capacity per hour. Length and travel time according to daily congestion were calculated (see Table 3.3) All the attribute data for the service layer was added.


Contents | Preview | Metadata |

Name	Type
Transportaion_station	File Geodatabase Feature Class
streets	File Geodatabase Feature Class
Streetbuffer	File Geodatabase Feature Class
Street_erase	File Geodatabase Feature Class
Squre	File Geodatabase Feature Class
School	File Geodatabase Feature Class
police_center	File Geodatabase Feature Class
Other_Studyarea	File Geodatabase Feature Class
Mosque	File Geodatabase Feature Class
Merge_buffererease	File Geodatabase Feature Class
master_road_ND1_Junctions	File Geodatabase Feature Class
master_road_ND1	File Geodatabase Network Dataset
Markets	File Geodatabase Feature Class
Khartuom_Airport	File Geodatabase Feature Class
Hotel	File Geodatabase Feature Class
Hospital	File Geodatabase Feature Class
High_schooll	File Geodatabase Feature Class
Heilth_center	File Geodatabase Feature Class
Goverment	File Geodatabase Feature Class
Garden	File Geodatabase Feature Class
End_begin	File Geodatabase Feature Class
club	File Geodatabase Feature Class

Figure3.3: The Geodatabase components

Table3.2: Street Attribute Data

Attributes of streets

OBJECTID*	SHAPE_Length	FT_MINUTES	TF_MINUTES	METTER	MAX_SPEED	street_name	Normal_timee	ROAD_CAPPACITY	Travel_time	TRAFIC_VOLUME	ROAD_TYPE	CLASS
164	270.333826	0.407393	0.407393	270.333826	40	TAWFEEQ SALEH GEBRIL	0.405501	250	0.407393	105	MS	4
56	325.420458	0.460552	0.460552	325.420458	45	SENKAT STREET	0.433894	1000	0.460552	800	SS	4
154	322.808055	0.661536	0.661536	322.808055	40	SENKAT STREET	0.484212	800	0.661536	1000	SS	6
60	1208.757331	1.879639	1.879639	1208.757331	40	SALEH BASHA STREET	1.813136	1000	1.879639	634	SS	4
67	1119.588006	1.701919	1.701919	1119.588006	40	OSMAN DIGNA STREET	1.679382	938	1.701919	513	SS	4
112	1624.038707	1.964888	1.964888	1624.038707	50	OMNACK STREET	1.948846	2000	1.964888	968	MS	4
7	9230.007454	11.345421	11.345421	10321.030273	60	OBAID KHATEM	10.32103	44000	11.345421	39684	HW	4
118	1113.022441	1.842477	1.842477	1113.022441	40	MOUHNED SALAH ALDEEN STREET	1.669534	2500	1.842477	2279	MS	4
193	6582.871622	11.538961	11.538961	13436.083159	70	MOHAMED MOKHTAR	11.516643	45500	11.538961	15340	HW	2
16	6119.800556	6.129082	6.129082	6119.800556	60	MOBRK ZAROG STREET	6.119801	47250	6.129082	14963	HW	2
53	387.333744	0.582369	0.582369	387.333744	40	MEHERA BNT ABUOD	0.581001	1000	0.582369	354	SS	2
18	4467.493537	5.957296	5.957296	4467.493537	45	MANON BEHIRY STREET	5.956658	2000	5.957296	327	MS	2
195	1744.723626	5.944032	5.944032	3784.049554	40	MAHMUOD SHAREEF STREET	5.676074	2000	5.944032	1498	MS	4
9	10109.156944	11.72508	11.72508	13678.394423	70	MADANI STREET	11.724338	46750	11.72508	6898	HW	2
110	2132.958914	2.635632	2.635632	2132.958914	50	MACKA STREET	2.559551	1250	2.635632	834	MS	4
15	6079.008754	6.081875	6.081875	6079.008754	60	M. NAGEEB STREET	6.079009	37000	6.081875	8761	HW	2
123	940.163901	1.461971	1.461971	940.163901	40	KULYAT ALTIBB	1.410246	1000	1.461971	1237	SS	6
37	878.156786	1.321567	1.321567	878.156786	40	KATREENA STREET	1.317235	1250	1.321567	481	SS	2
119	1630.021422	2.250773	2.250773	1630.021422	50	JUBA STREET	1.956026	3500	2.250773	3504	MS	4
47	2368.844977	2.842917	2.842917	2368.844977	50	IBRAHIM SHAMS ALDEEN	2.842614	1250	2.842917	204	MS	2
36	888.040746	1.332319	1.332319	888.040746	40	IBRAHEEM AHMED KHEER STREET	1.332061	1250	1.332319	237	MS	2
68	1615.281826	2.511792	2.511792	1615.281826	40	HOSPITAL STREET	2.422923	1000	2.511792	1237	SS	6
155	723.157658	1.124523	1.124523	723.157658	40	HASHEM BEY STREET	1.084736	1000	1.124523	1237	SS	6
17	4176.635134	8.505295	8.505295	4176.635134	50	GABRA STREET	5.011962	5000	8.505295	7341	MS	6
23	2385.4614	2.913271	2.913271	2385.4614	50	GABEL AWLYA STREET	2.862554	30750	2.913271	16027	MS	4
19	4188.044707	10.215252	10.215252	8364.511267	50	GABEL AWLYA STREER	10.037414	30750	10.215252	16027	HW	4
186	2247.933906	2.697789	2.697789	2247.933906	50	GABEL AWLYA STREER	2.697521	10000	2.697789	1604	MS	2
49	1179.72644	1.777849	1.777849	1179.72644	40	BYO KWAN STREET	1.76959	2000	1.777849	840	MS	4
181	3522.449204	4.715553	4.715553	3522.449204	45	BURI STREET	4.696599	2000	4.715553	810	MS	4
104	1000.43261	1.200715	1.200715	1000.43261	50	BADR STREET	1.200519	1250	1.200715	227	SS	2
64	881.08837	1.321884	1.321884	881.08837	40	BABEKER BADRY STREET	1.321633	938	1.321884	177	SS	2
69	283.808242	0.441327	0.441327	283.808242	40	ATYAR IZZ ALDEEN STREET	0.425712	1250	0.441327	580	SS	4
26	690.721598	1.037846	1.037846	690.721598	40	ATBARA STREET	1.036082	1250	1.037846	408	SS	2
12	4312.853403	6.660656	6.660656	4312.853403	40	ASAFA STREET	6.46928	1250	6.660656	833	MS	4
188	946.525009	1.262728	1.262728	946.525009	45	ARMY STREET	1.262033	3750	1.262728	923	MS	2
169	157.352811	0.236544	0.236544	157.352811	40	AMOFTI STREET	0.236029	1250	0.236544	434	MS	2
27	2880.429104	4.448018	4.448018	2880.429104	40	ALZABIR BSHA STREET	4.290644	1000	4.448018	555	SS	4
63	590.468668	0.918189	0.918189	590.468668	40	ALTYAR ZULFO STREET	0.885703	1000	0.918189	634	SS	4
62	598.393953	0.930513	0.930513	598.393953	40	ALTYAR IZZ ALDEEN STREET	0.897591	1000	0.930513	634	SS	4
58	1222.46411	1.900953	1.900953	1222.46411	45	ALTYAR GAMEL STREET	1.629952	1000	1.900953	634	SS	4
4	5752.92636	12.554864	12.554864	9387.307022	45	ALTABIA STREET	12.516409	65000	12.554864	24590	HW	2
107	996.665767	1.329218	1.329218	996.665767	45	ALSWAHLY STREET	1.328888	550	1.329218	111	SS	2
128	890.165997	1.189281	1.189281	890.165997	45	ALSOOG ALSHABI	1.186888	2000	1.189281	681	MS	2

Record: 0 Show: All Selected Records (0 out of 178 Selected) Options

EN 5:38 PM 2/4/2014

3.4.1 Network data set

The data was used to create a network dataset based on the street layer in the Network Analyst Extension of ArcGIS 9.3. A network dataset is a representation of a network, in points and lines. In the context of this study the network dataset will represent a street network.

3.4.2 Model Designing

The model will be created in the Network. Figure 3.4 illustrate diagram of the model which that used to predict the travel time. The first layer in the model depicted below is the Network Dataset layer. This layer is the base streets layer transformed into a Network. This is done so analysis can be conducted in Network Analyst.

The network dataset is created to complete network analysis in network analyst. ESRI has developed the network dataset to represent detailed network models.

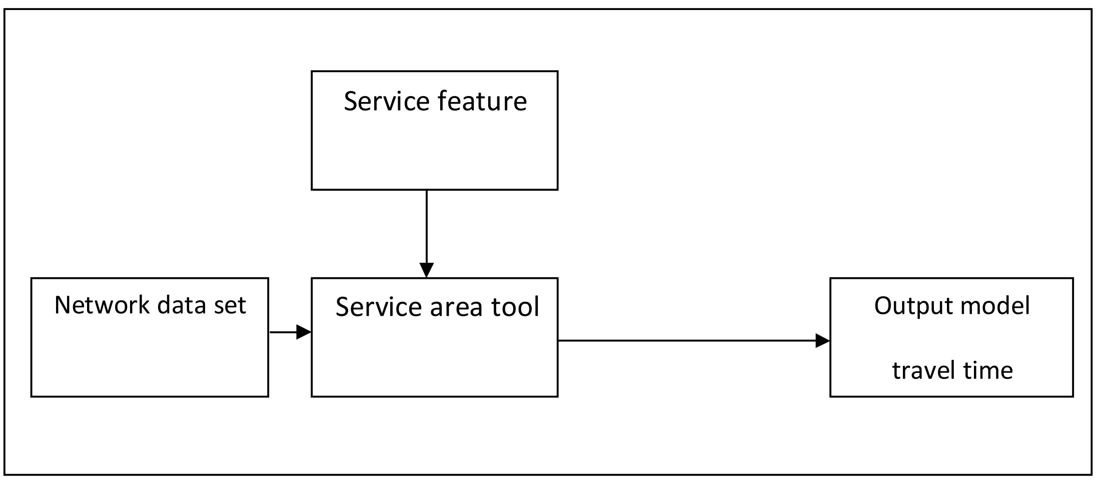


Figure 3.4: The network diagram

The next layer in the model is the service area tool in Network Analyst. This tool is used to find service areas around any location on a network. A network service area is a region that encompasses all accessible streets. For example the 5-minute service area for a polygon includes all the streets that can be reached within five minutes from that polygon. In this study the service area layers (education, health ….etc) were classified into four period (2,5,8,10) minutes. The service area layer contains four components, the facilities layer, the polygon layer, lines layer and the barriers layer as in Figure 3.5.

The facilities layer, in this study, includes all the locations which are used as starting points for travel. The facilities in this study are all the service layers (education , health ,transportation station….etc) in Khartoum city. The next layer is the barrier layer. This layer is used to include barriers in the street network within the analysis. For example if a street is blocked for construction a barrier would be placed in this location. When the analysis is complete the route would be directed around the barrier. The polygon layer stores the resultant polygons of service area analysis. This is the most important layer in the service area tool it's represent the time ranking. The lines layer can be symbolized in the same manner as other line feature layers.

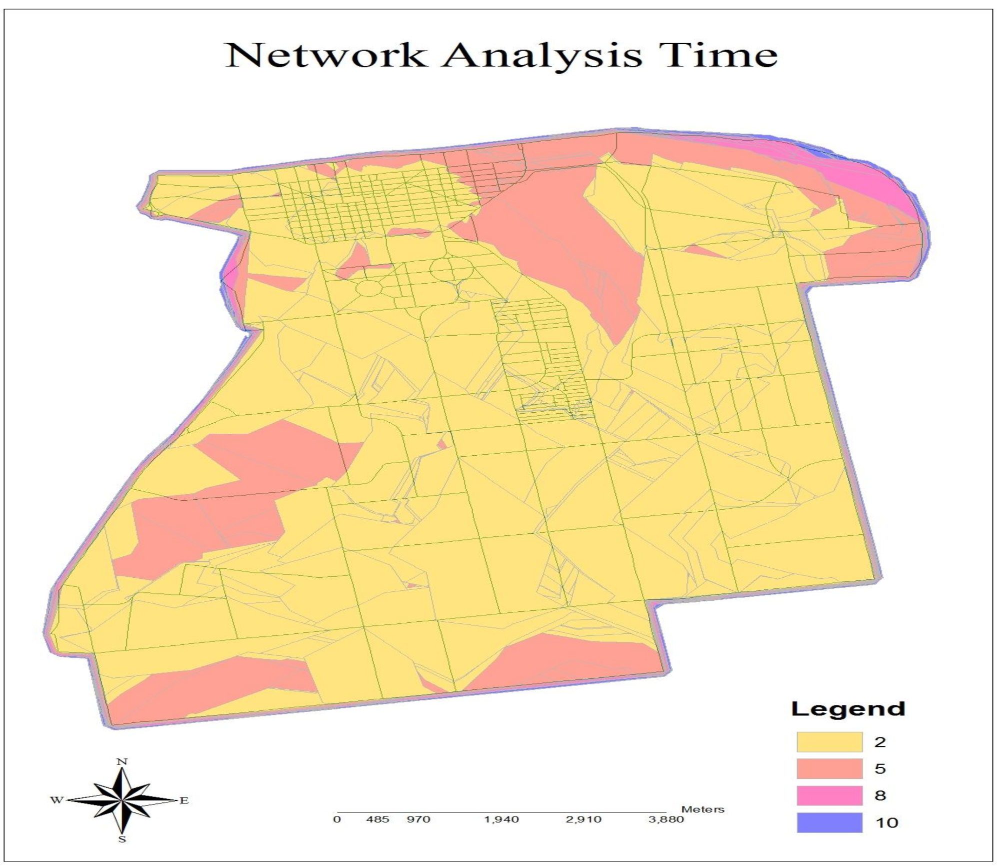


Figure 3.5: Network analysis time

3.5 Multi Criteria Analysis

Multi criteria analysis is applied and integrates with the spatial data in order to describe the causative factors of a phenomenon under concern.In this study ranking method was used, where every criterion under consideration was ranked in the order of the decision maker's preference and network analysis. To generate criterion values for each evaluation unit, each factor was weighted according to the planer expertise and network analysis time for estimated significance. The inverse ranking was applied to these factors. Factor of rank 2 is the least important and 8 is the most important factor. In the third phase, Pair wise Comparison Method was used to determine the weight of each criterion.

3.5.1 Creation of Script

Technical problem arise when convert the service layers to raster. The intersection between the service layers provide false pixel value in the overlap area due to that the script was developed see (Appendix B) to convert each layer separately and collected again with a correct pixel values .The script was created below the toolboxes within the Arc toolbox. Thirteen weight images were provided based on service data. And categorized to four classes (educational, health, general service and tourism) as indicated in the Table 3.3.

3.5.2 Pair wise Comparison Method

This method involved the comparison of the criteria and allows the comparison of two criteria in the same time. It can convert subjective assessments of relative importance into a linear set of weights.

3.5.2.1 Sub-layer weight

The square pair-wise comparison matrix was generated for the sub-layers each factor was weighted according to the estimated significance importance as shown in table 3.3. The Map algebra tool in Arc Gis 9.3 was used to merge the thirteen (see appendix A) sub-layers based on weights of sub layer (after classification into-groups) to form four main layers.

Table 3.3: layer weights

Number	Main layers	Sub layer	Raster Weigh
1.	General service	Government	0.471023483
2.		Transportation	0.329494372
3.		Airport	0.073839321
4.		Police	0.125642824
5.	Tourism	square	0.075436096
6.		Garden	0.07576119
7.		Market	0.3638022
8.		Hotel	0.37865104
9.		Club	0.106349474
10.	Education	School	0.26454
11.		University	0.6753891
12.	Health	Hospital	0.543422
13.		Health center	0.329332

3.5.2.2 Main layer weights

The square pair-wise comparison matrix was generated for a main-layer each factor was weighted see Table 3.4.The normalized matrix is presented in Table 3.5 Meanwhile, the individual judgment, which never agreed perfectly with the degree of consistency achieved in the ratings, was measured by using Consistency Ratio (CR), indicating the probability that the matrix ratings were randomly generated. The Random Indices for matrices are listed in Table 3.6. The rule of thumb is that a CR less than or equal to 0.1 indicates an acceptable reciprocal matrix, while a ratio over 0.1 indicates that the matrix should be revised**.**

Table 3.4: The comparison probability

	Tourism	Health	Education	General service
Tourism	**1**	**0.2**	**0.2**	**1**
Health	**5**	**1**	**0.25**	**4**
Education	**5**	**4**	**1**	**5**
General service	**1**	**0.25**	**0.2**	**1**

Table3.5: Four layer weights

	Tourism	**Health**	**Education**	**General service**	**Sum**	**Weights**
Tourism	0.083333	0.036697	0.121212	0.090909	0.332152	0.083037948
Health	0.416667	0.183486	0.151515	0.363636	1.115304	0.278826105
Education	0.416667	0.733945	0.606061	0.454545	2.211218	0.55280442
General service	0.083333	0.045872	0.121212	0.090909	0.341326	0.085331526

Calculating Consistency Ratio (CR)

CR= CI/RI

Where CI= λ_{max}-n/n-1

RI = Random Consistency Index

n = Number of Criteria

λ max is the priority vector multiplied by each column total

Table 3.6: Shown the Random indices for matrices of various size

N	R1
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

λ_{max}= 4.216396

CI = 0.072132

CR = 0.080147

The diagram in (Figure 3.6) illustrates merging process. Raster calculator was used to form the suitability map combined the four main layers (educational, health, general service and tourism). The street layer was integrated into the analysis in order to ensure that the suggested path and street layer would coincide together in order to avoid razing, the infrastructure and resident regions, the route layer was converted to raster based on the value of traffic volume which was calculated by using the BPR equation.

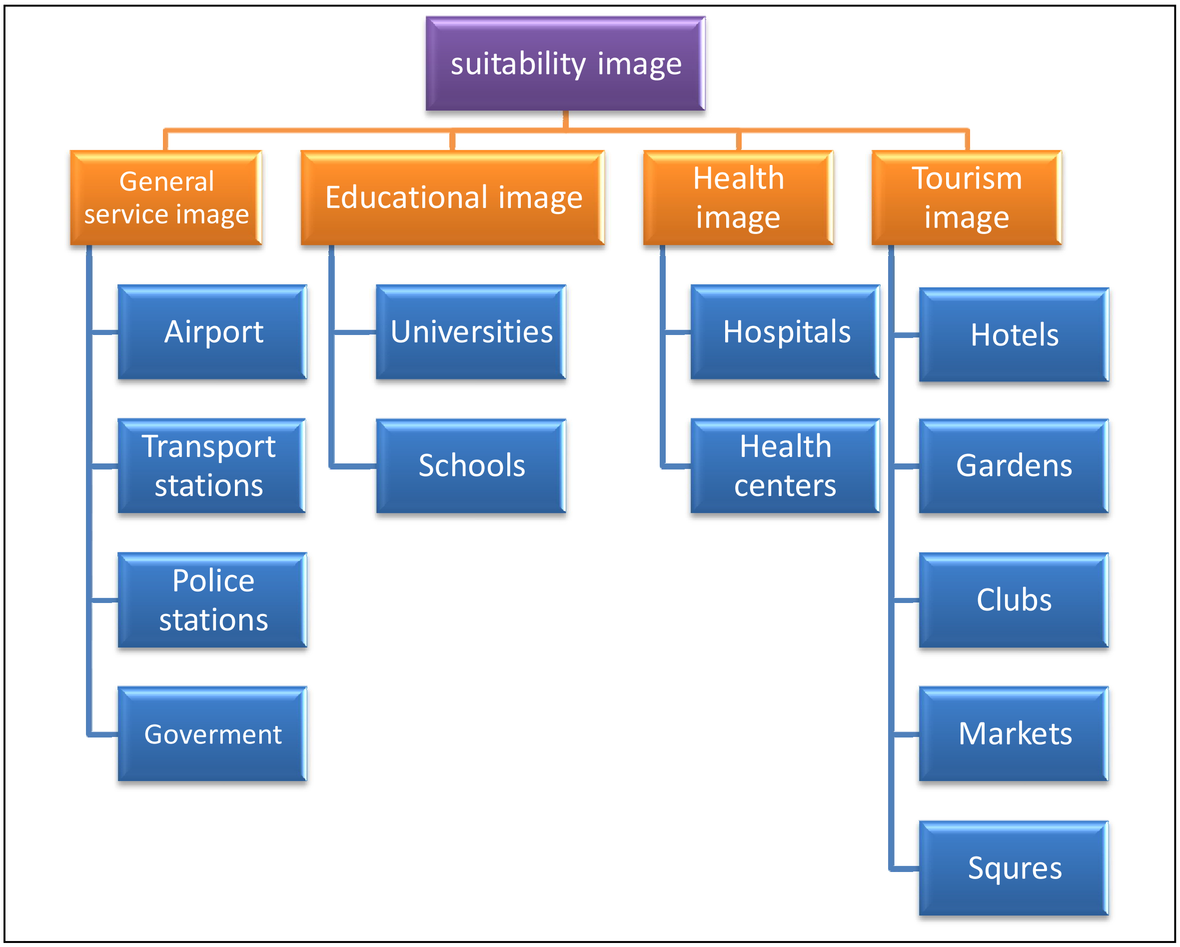


Figure3.6: Data combination

The final suitability map was produced based on the four service layers and the raster street layer as shown in figure 3.7

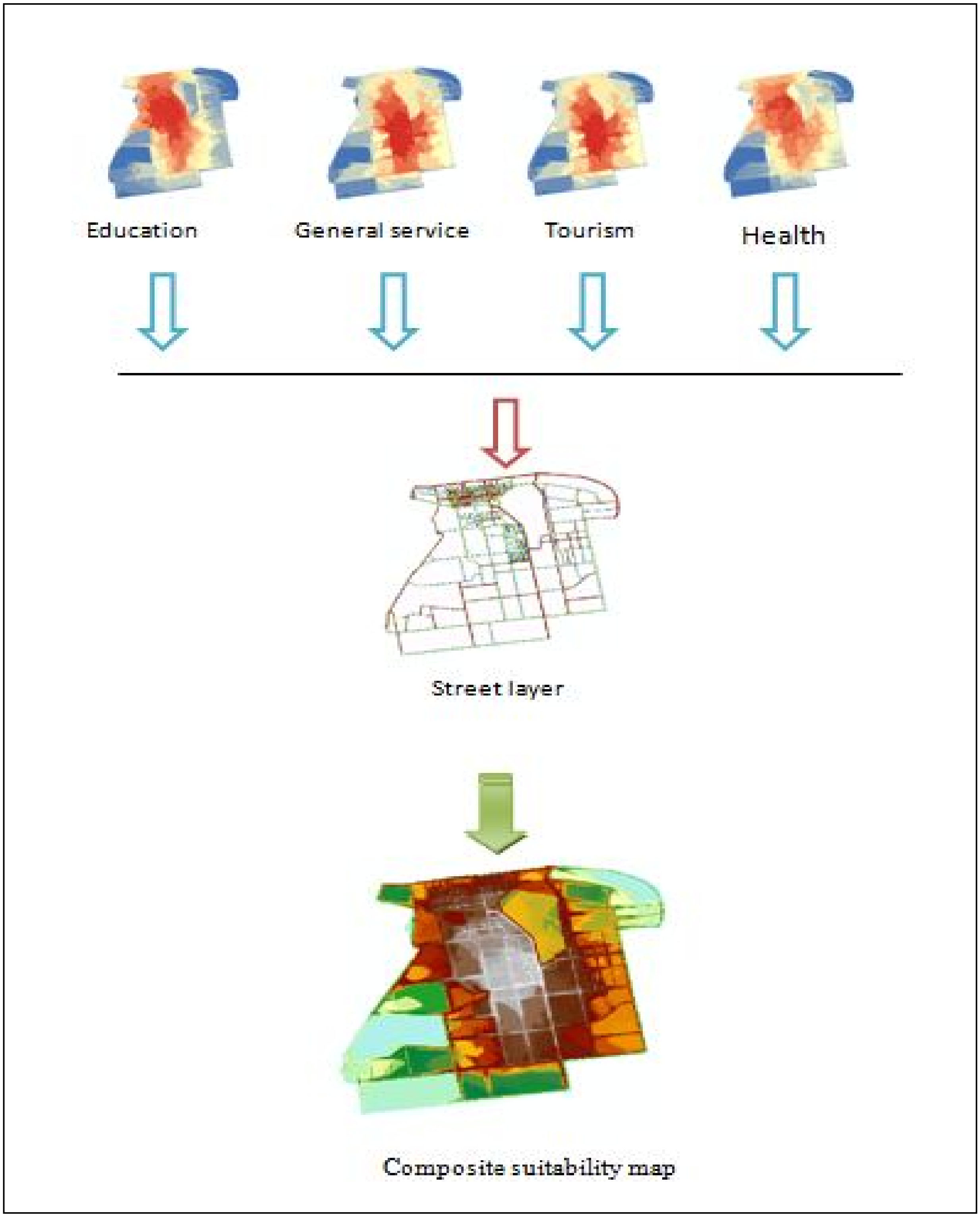


Figure 3.7: Aggregation of suitability maps

3.6 Determine the path

To create a path over a rough or friction surface, there is a need to specify the start and destination points with which the part is to follow. The source feature is the suitability image that indicates the cells from which cost should be determined. The start and destination points for the road path was created using Arc Catalog 9.3. New shape files contain start point, destination points was created, and the cost-weighted path (direction and allocation) were calculated. This was to ensure that the route points created was within minimum cost cell under study area .Table 3.7 indicates the approximate coordinates for the start point and destination point.

Table 3.7: The coordinate of starts and destination points

OID	Name	Path Description	Easting	Northing
.1	R1	**The First path**	450038.5605	1725677.395
.2	R2		452793.264	1715858.094
.3	G1	**The Second path**	446197.9022	1718587.465
.4	G2		455591.4914	1724578.253

The spots in figure (3.8) show the start points and destination points of two road path on the satellite image.

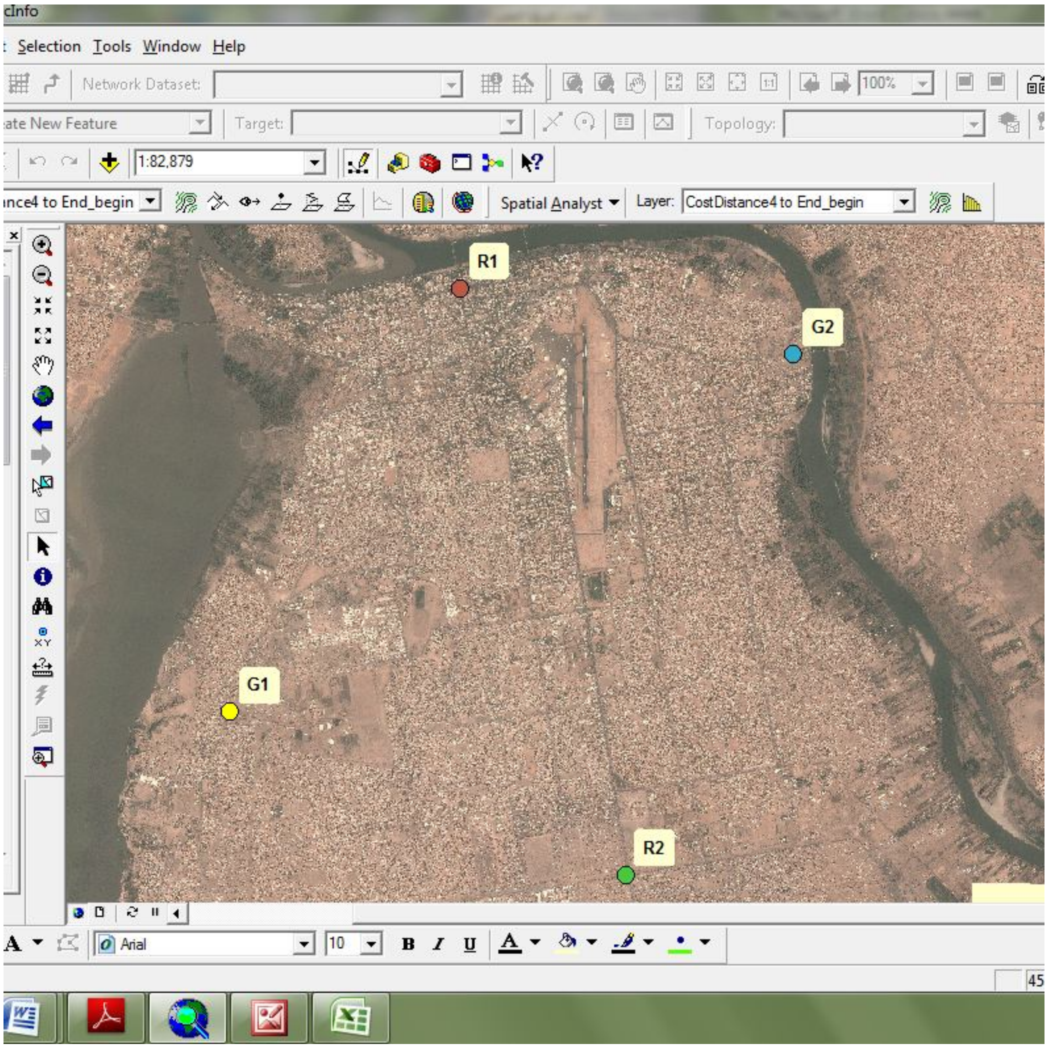


Figure 3.8: shown starts and destination point for two paths

CHAPTER FOUR

Result and Analysis

4.1 Introduction

This chapter of the thesis describes some of the intermediate results that calculated during the analysis of the data and also illustrate a map over the area of study showing the two possible route path obtained using GIS, Network and MCA.

4.2 The main layers

The different vital services in Khartoum (schools, hospitals, malls, transport stations… etc.) classified into four main layers as mentioned in chapter three: education, health, tourism, and general services. This was done in order to simplify the analysis of the final judgment between the four layers thus resulting in the creation of the suitability layer, that used to determine the best route path.

Figure 4.1: The network data set that created for route analysis and processing.

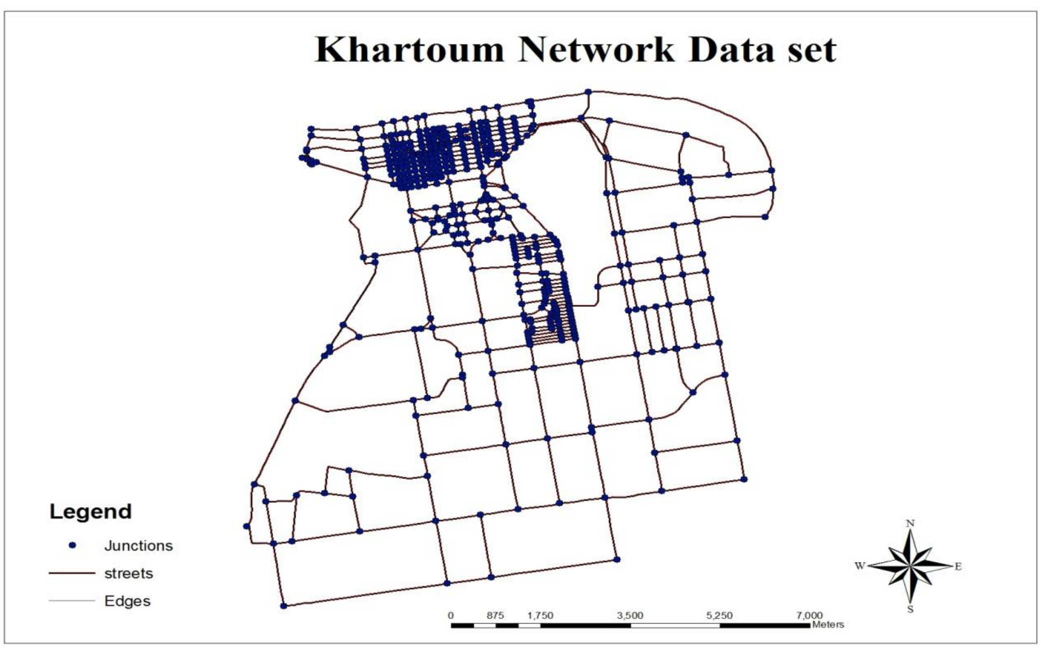


Figure 4.1: Khartoum network data set

All the suitability layers were produced based on travel time and significant weights. Figure 4.2 indicate the suitability map for the general service layer, which was formed by the merging of the government, transportation, airport, and police sub-layers.

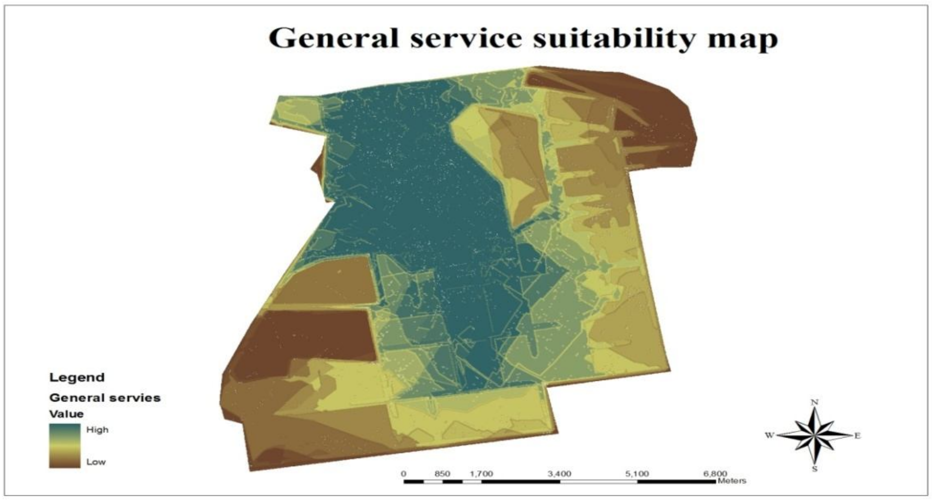


Figure 4.2: The General Service layer

Figure 4.3 shows the suitability map of the tourism layer, which was formed by the merging of the square, garden, market, hotels, and club, sub-layers.

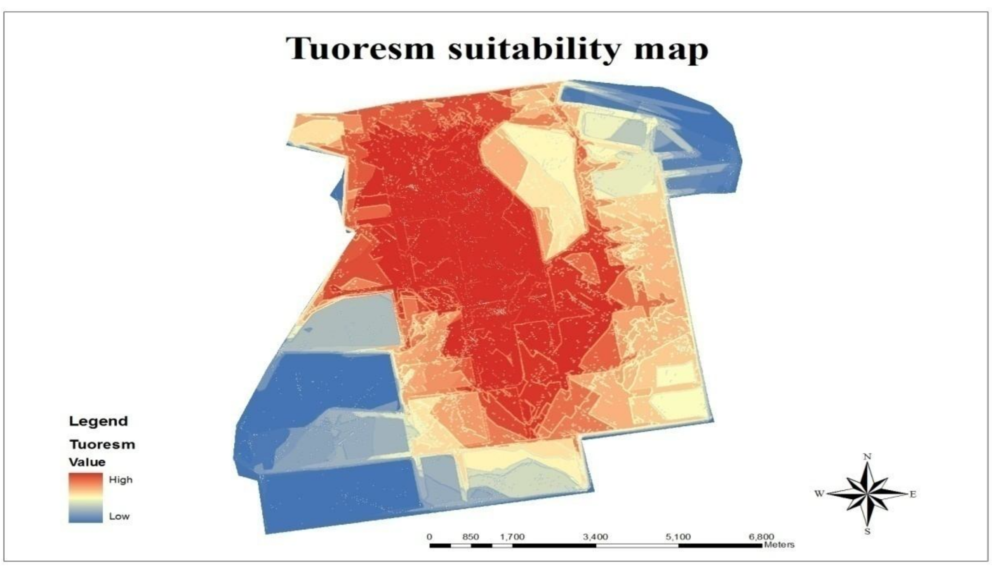


Figure 4.3: Tourism layer

Figure 4.4 shows the suitability map of the education layer which was formed by the merging of the school and university sub-layers.

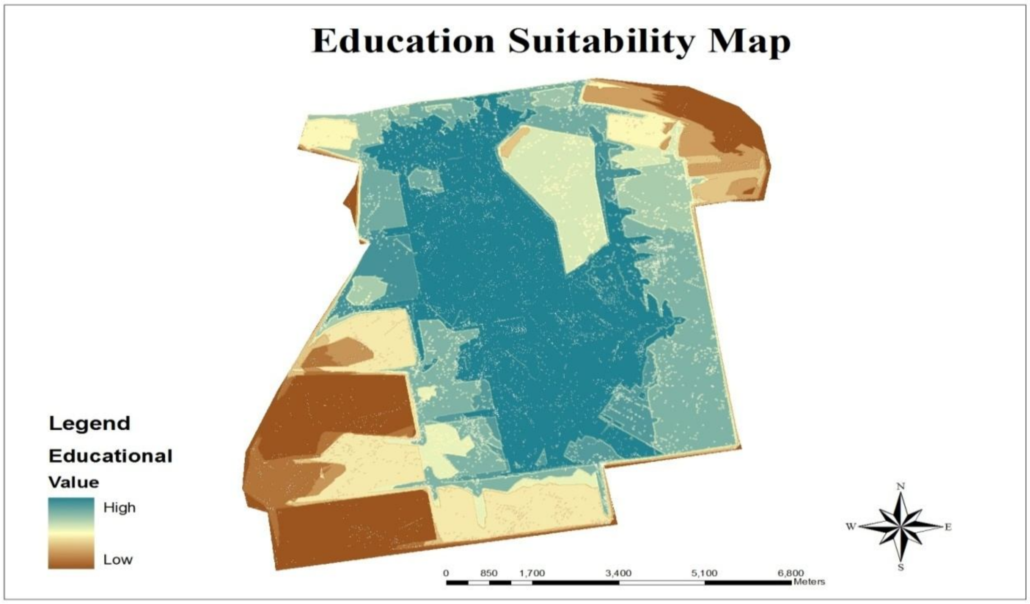


Figure 4.4:Education layer

Figure 4.5 shows the suitability health layer, which was formed by the merging of the hospital and health centers, sub-layers.

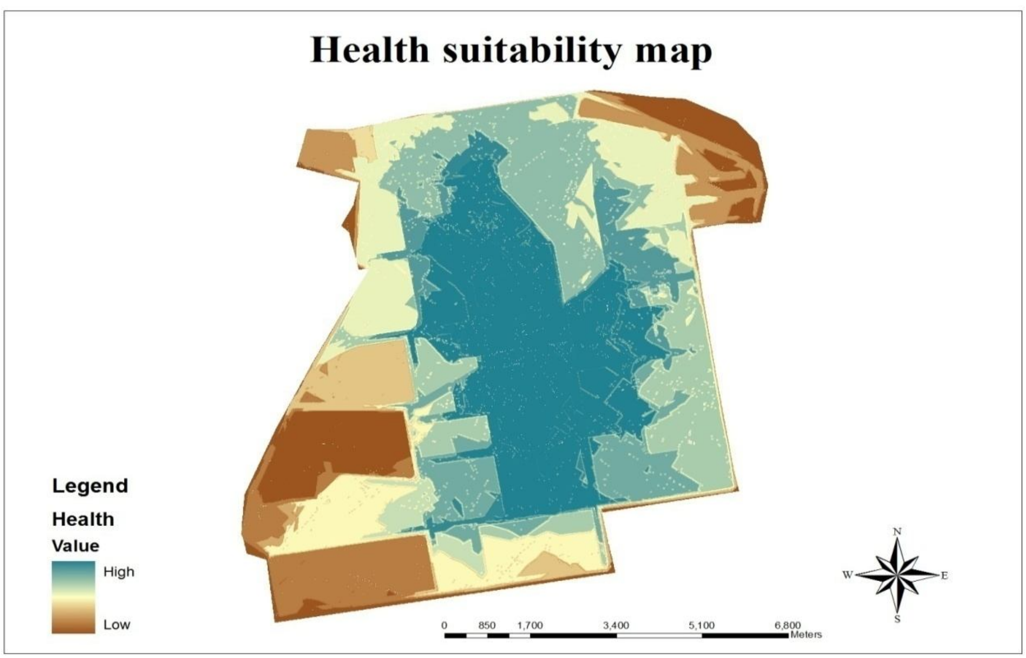


Figure 4.5: The Health layer

4.3 Overall suitability map

Upon completion of the analysis, the result, which was obtained, is a suitability image of the area of study (see Figure 4.6). In the suitability image, two possible routes are shown as the most viable paths throughout Khartoum. The two routes, which are shown on the suitability image, were selected through the application of GIS, Network and MCA. Figure 4.7 shows the result obtained after the final analysis of the different data.

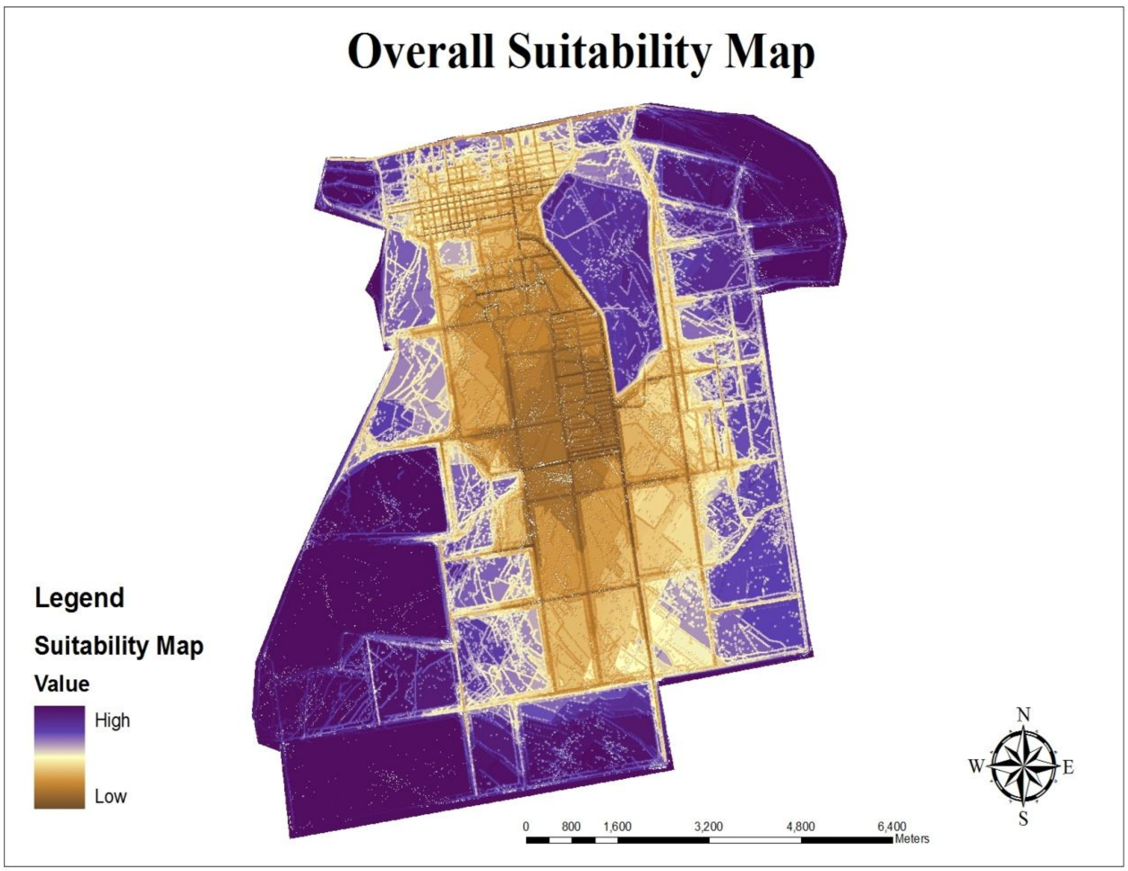


Figure 4.6: overall suitability map

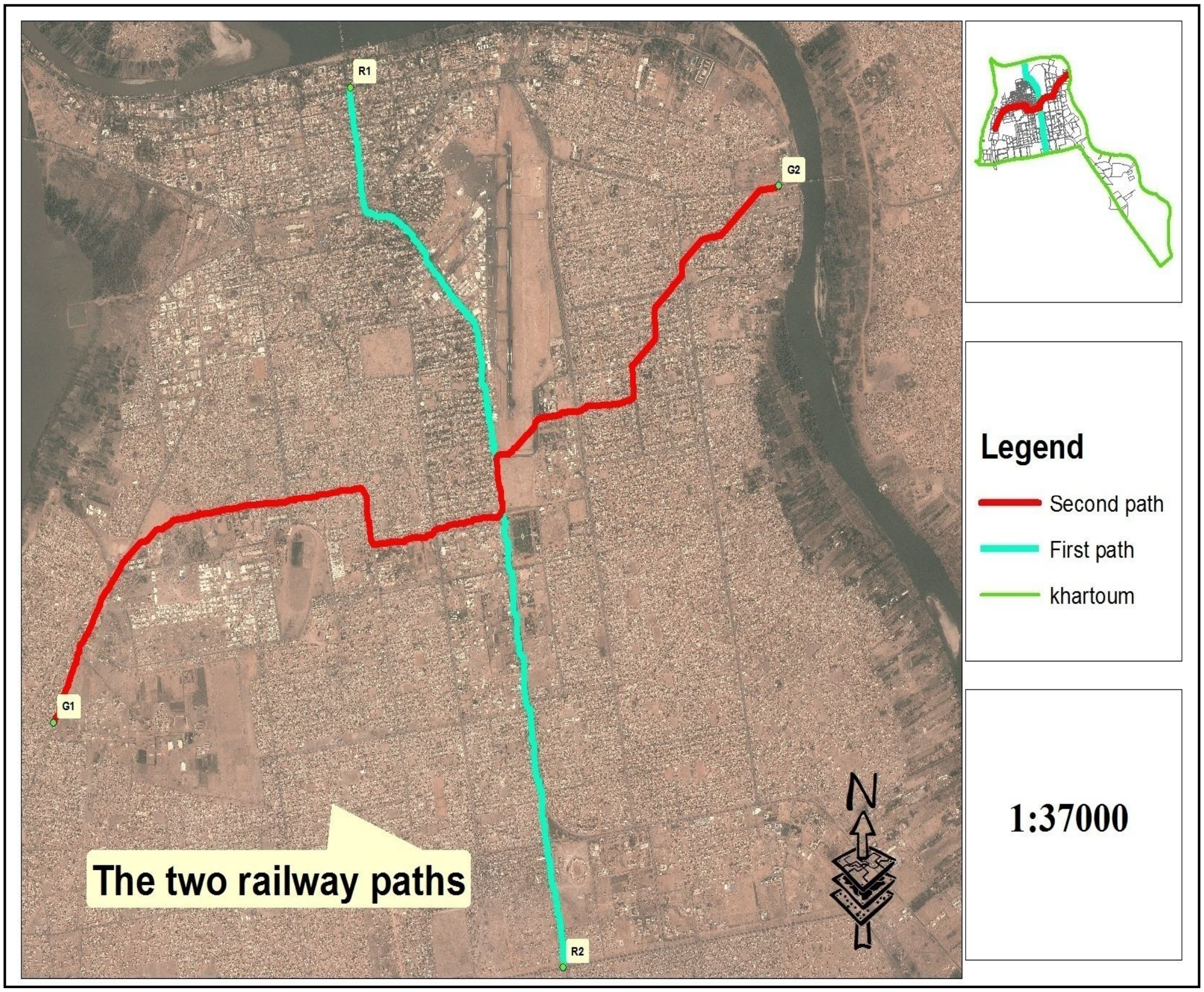


Figure 4.7: Two route paths

4.4 Description of paths

The courses of direction for the two selected routes are described in the following sections. The first path is referred to as (Route A) and the second, (Route B). This is done so for ease in description and to avoid any possible confusion. The starting and ending points of each route is stated, in addition to the vital utilities that are along or near each route.

4.4.1 First path (Route A)

The first proposed path (Route A), having a total length of 11,295m, begins at the main transport station in Khartoum known as Jackson Station. It then heads east along the Al SayidAbd Rahman street and turns south to go along Al MakNimr Street while passing the Khartoum Hospital. From Al MakNimr Street the railway runs into and continuous along Africa Street passing Khartoum International Airport. and a number of major financial institutions. Along this route there are many hospitals and medical centers, parks and recreation areas, in addition to a major shopping center. At the intersection of Africa Street and 61st Street the route turns west and begins to pass through the Al Amaratarea (an upscale residential and commercial area in which are located a number of embassies and non-governmental organizations). The route continues in this direction intersecting Mohammed Nagib Street until reaching SahafaZalat Street where it then turns left to continue southward. At this point, it passes in front of the Sudan University. As the route continues south, it goes through a number of residential areas, ImtidadAsSahafa and Al Nozha. Finally, the route reaches its end at the Khartoum Land Terminal which also in close vicinity to the Khartoum Central Market.

4.4.2 Second path (Route B)

The second of the two proposed paths (Route B) is 14,268m long. This track moves from west to east. Its starting point is within the vicinity of Al Mab residential and industrial areas,then its moves eastward along a major road through the Al Remela and Abu Hammah residential areas, eventually intersecting with Al Sajana Street (which leads to Al Sajana industrial area as well as the central business district of Khartoum.) From this point the route goes through Al Sahafa residential area turning south at Street 41 extension and continues along to Sudan University where it meets up with Route A. Route B turns east, at which point its Route B begins to overlap Route A and continues as so for a distance of 2,268m until it reaches the intersection of Africa and Al Geraif Turn Off at south-west boundary of the Khartoum Airport site. From this point, the route continues eastward (through the vicinity of the University of Medical Sciences) along Mecca Street as it intersects with ObaidKhatim Street. From here, the route passes through a large section of AlRiyad residential area, in which can be found numerous medical centers, international companies and organizations, as well as various places of entertainment. The route comes to an end at the intersection of Nakhel andNefeidi Streets. This point is at the border of AlRiyad and Al Manshiya areas. This point lies in the vicinity of the Al Manshiya Bridge (which leads to the Sharg Al Nil locality) and a number of ministries and companies.

4.5 Analysis result

In identifying the advantages and disadvantages of each route, it is necessary to restate the four-mentioned criteria of an optimum route through the Khartoum metropolitan area. It can be said that an optimum route is one that: offers the shortest route possible while linking a considerably large amount of vital utilities along the way with special regard to transportation lines; preserves existing infrastructure including private residences and businesses; follows a course along the existing street layer as much as possible.

Therefore, based on the above Route A has many advantages while having few disadvantages. The primary advantage of Route A is that it starts from the central bus station of Khartoum thereby linking bus routes from various regions of the tri-city area. Furthermore, it goes as far as the Khartoum Land Terminal thus the path links local transportation lines with interstate transportation lines. This route serves well, numerous amount of medical, educational, financial institutions as well as the airport.

The second major advantage of Route A is that it goes along the existing street layer, and as a result, the construction of it would minimize the need to raze infrastructure and residences.

Contrastingly, it could be argued that Route A does not adequately serve governmental ministries. Another disadvantage is that, although the route goes along Africa road for a considerable distance it fails to link with other vital roads like Mohamed Najeeb Street.

In regards to Route B, there are two noticeable advantages. The first being that, it travels through several major residential areas (Al Mab, Al Remala, Al Diem) of Khartoum along the existing street layer. Thus, potentially, giving access to a large segment of the population. Secondly, Route B intersects with several major roads (Jebel Awlyia Street, Al Sajana Street, SahafaZalat, M. Najib, Africa Street, ObaidKhatim and Nefiedi Street) thereby linking it to a number of bus routes. However, the disadvantages of RouteB are that it is quite long in terms of distance which, could lead to an increased cost expenditure. Moreover, it does not serve a significant amount of high priority locations like Khartoum University.

In comparing the two routes, it can clearly be seen that Route A is the most optimum rout. Firstly, Route A is 11,295m and Route B is more than 14,000m long, making the former the shortest route, while clearly serving a greater number of vital utilities than Route B. For instance Route A begins at the the central bus station and ends at the Land Terminal for innter-state travel while along the route there are a number medical, financial and educational institutions that are served. Moreover Route A more closely follows the existing street layer, thereby reducing the need to alter the landscape of infrastructure and other buildings. Although Route A is the most suitable of the two routes if only one were to be selected, the use of two routes together provides to the most ideal situation in that a sort of network is created reaching the largest area.

4.6 Discussion

The purpose of this thesis was to introduce the applicability of geographic information system (GIS) and Multi-criteria analysis (MCA) to identify a least cost path between two points using the Khartoum locality as a case study. The use of (GIS) in this thesis has helped to incorporate digital layers of different scales. Planning a route path is complex and presents a number of challenges. The level of the complexity in the planning process comes from the consideration of different factors, which must be considered in the analysis. In order to minimize environmental impacts and to achieve sustainable development in the determination of a route path, it is essential to determine the relative importance of the considered parameters. There are numerous considerations in determining parameters and selecting methods which all depend on the trade-offs between: ease of use, accuracy, the degree of understanding on the part the decision maker, the theoretical foundation underlying that method, the availability of computer software, and method can be incorporated into GIS-based multi-criteria decision analysis.

In this thesis the Analytical Hierarchy Process, which uses a pair-wise comparison matrix, was used to determine the relative importance of the parameters. Empirical applications suggest that the pair-wise comparison method is one of the most effective techniques for spatial decision-making, including GIS-based approaches (Malczewski, 2006). It is necessary to consider environmental and civil experts' views regarding the relative priority of the parameters. Alternative methods, such as the outranking method, were not tested in this thesis.

In this thesis, the weighting of the criterion was based on the understanding of experts in the geographical area under study.

The use of ArcGIS desktop which includes the extension of spatial network analyst has proven to be efficient in managing, integrating, performing advanced analysis, model and automated operational processing of data as well as displaying final results.

In analyzing the results obtained in this thesis, it is clearly possible to determine least cost path between two points over an area without having a direct contact with the given area. The application of MCA and GIS in the planning process has proven to be less time consuming and more cost efficient than traditional methods of planning.

One of the major requirements to using MCA and GIS in the planning process is that it has to be applied by an expert in the use and application of GIS and MCA.

CHAPTER FIVE

Conclusion and recommendation

5.1 Conclusion

In conclusion, the final result obtained in this thesis supports other research in the application of GIS and MCA in complex planning. The result has demonstrated the applicability of GIS and MCA principles and techniques identifying a route path while avoiding the rigors of route planning using the traditional method.

The possibility of using GIS and Multi criteria analysis in complex planning processes in Khartoum has been successfully shown in this thesis. GIS and MCA can not only be used in route planning but also in the planning processes of other projects such as airports and industrial areas.

5.2 Recommendation:

GIS and Multi criteria analysis are complex applications that require in-depth knowledge and understanding. Based on the research findings of this study it is recommended to:

1- Expand the geographic area of the study to include the entire three cities (Khartoum, Omdurman and Khartoum North) so as to link transportation routes in a more comprehensive manner and give access to a greater number of people.

2-Include additional data in the multi-criteria analysis such as:

- **a.)** Census data indicating the most densely-populated areas in order to ensure that the route serves the maximum number of people.

b.) Elevation layer figures so as to ensure that the route is situated along level land as much as possible.

c.) Predicted construction cost figures to compare the relative cost-benefit of a selected route.

d.) Income per capita of residential areas to ensure that low-income areas are served by the route.

3. Program the basic steps of MCA and GIS (which are mentioned in this thesis) in order that they can be more utilized by planners who do not possess a detailed understanding of these applications.

4. Determine the potential environmental impact (whether positive or negative) of the results according to environmental experts.

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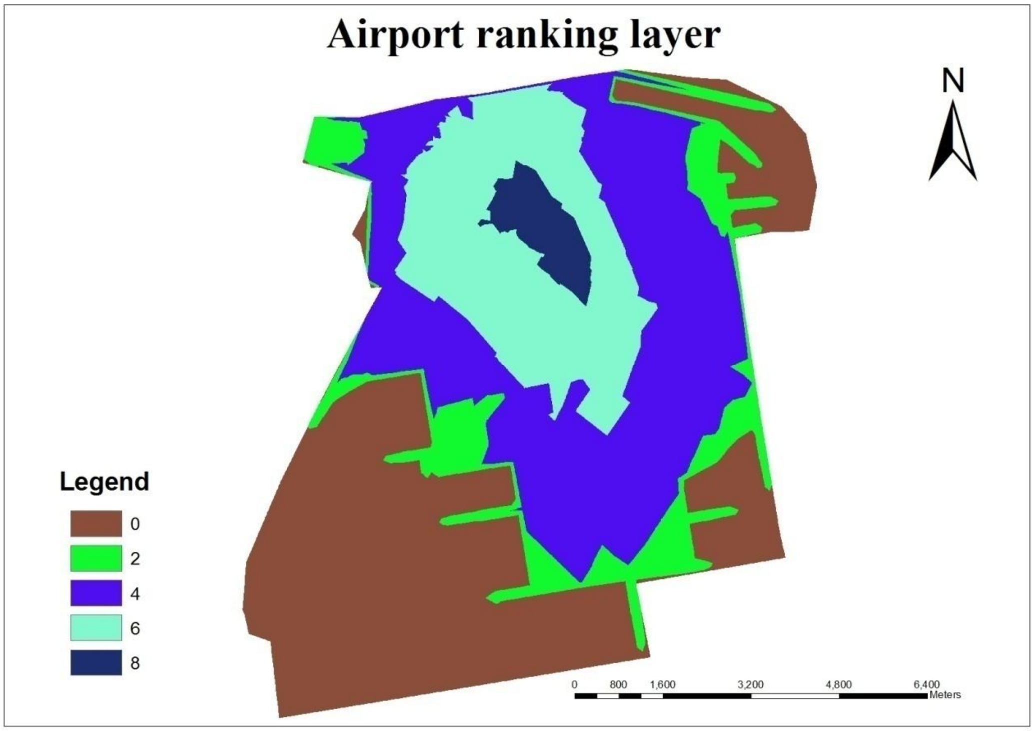
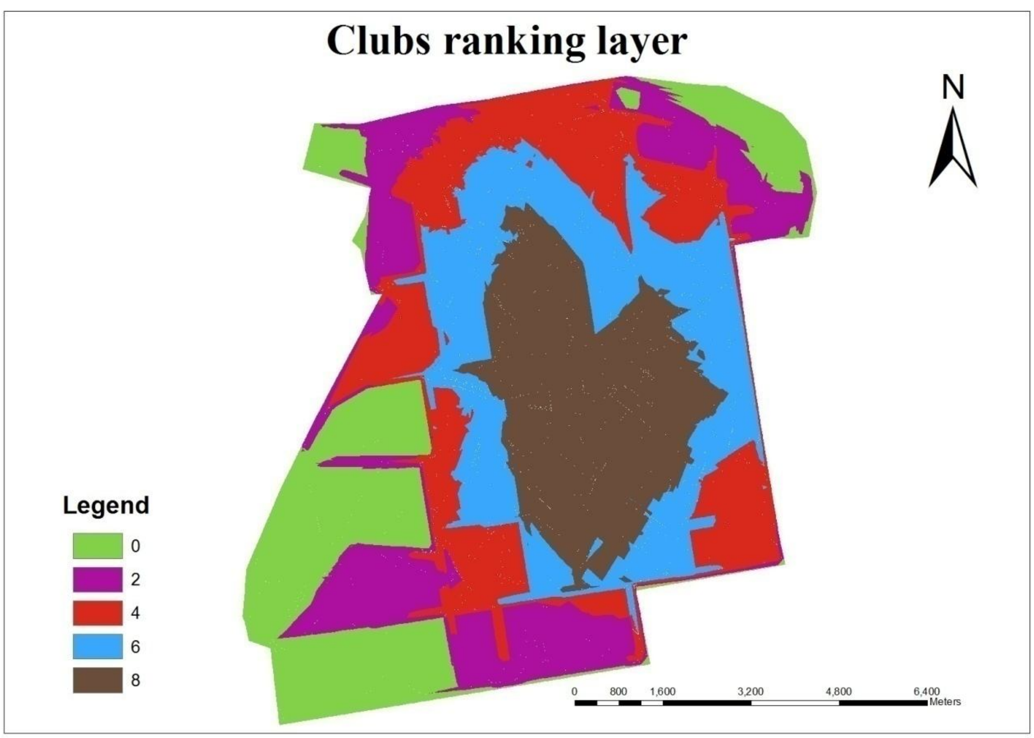
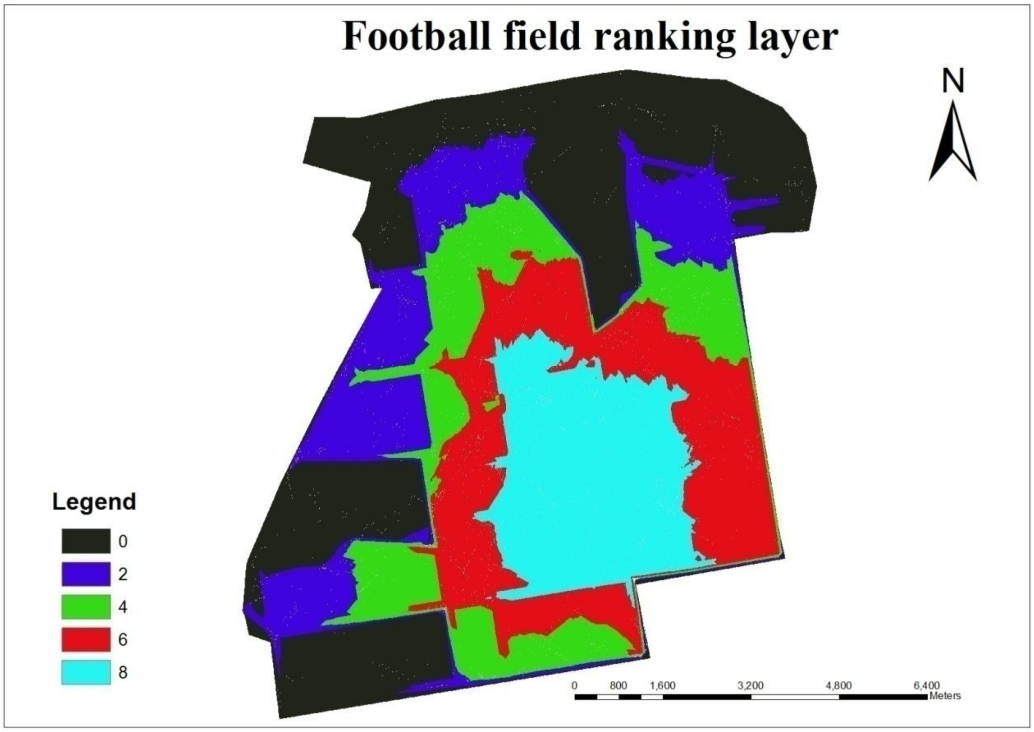
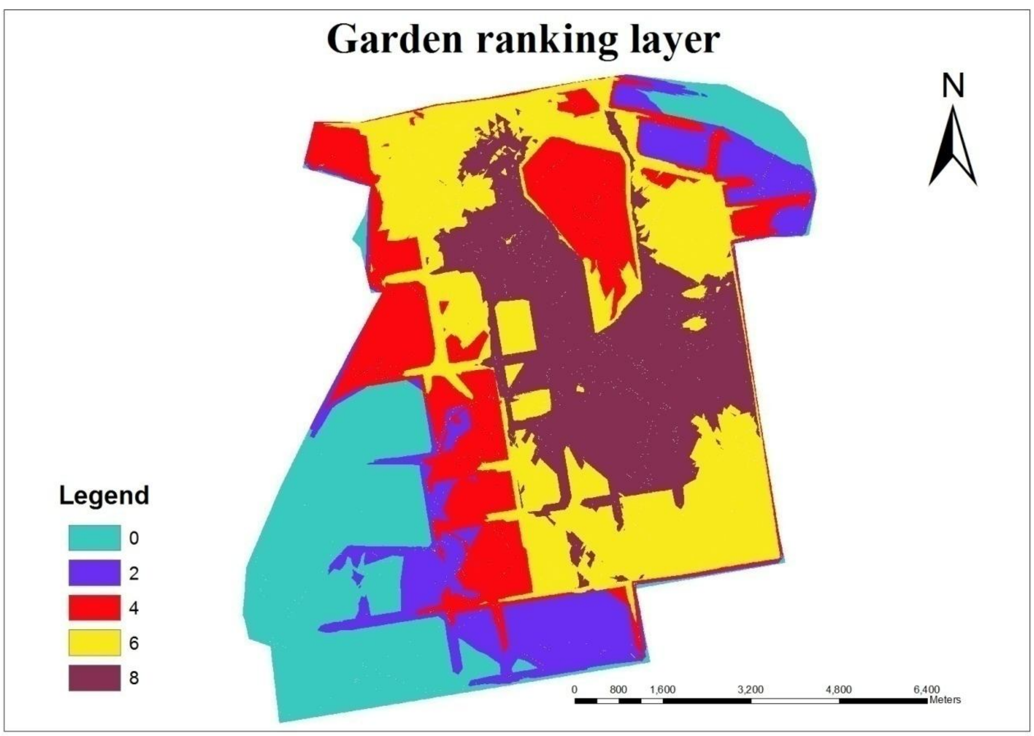
APPENDICES

Appendix A: Figures of Vital utilities ranking :






Football field ranking layer
N
Legend
0
2
4
6
8
0 800 1,600 3,200 4,800 6,400
Meters


Garden ranking layer
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Legend
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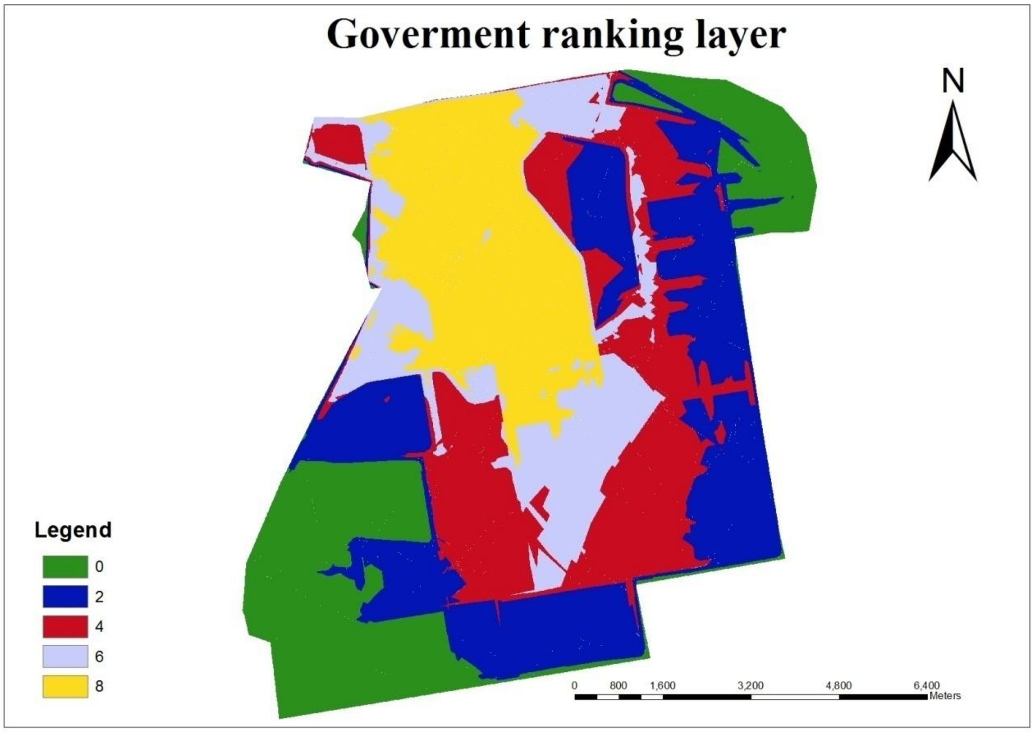
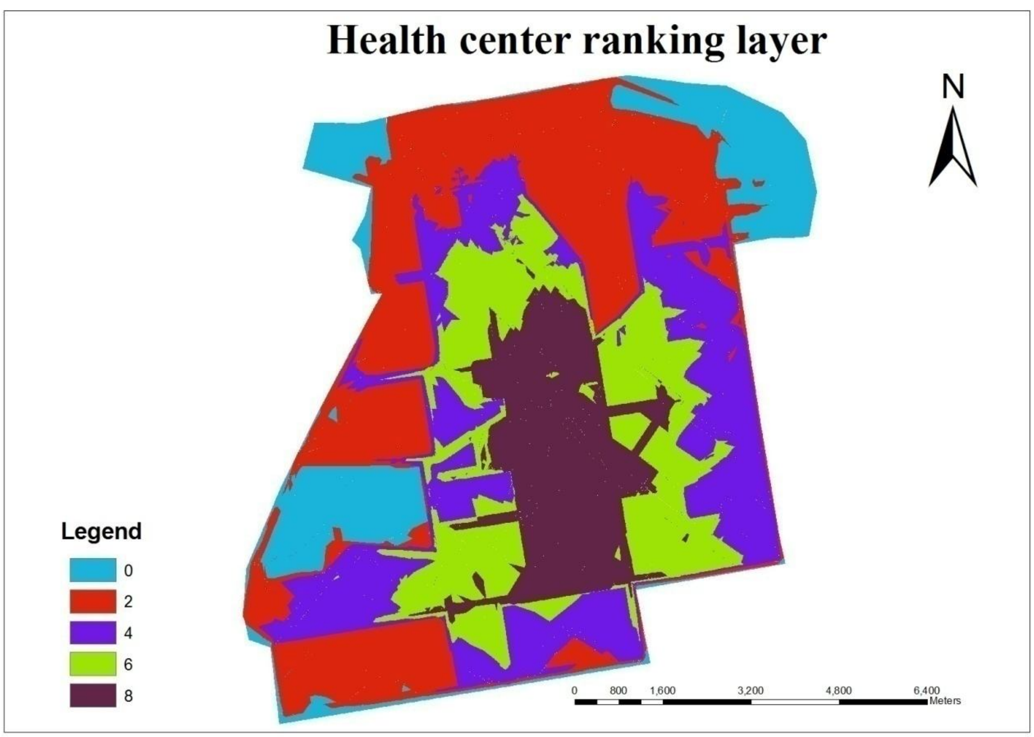
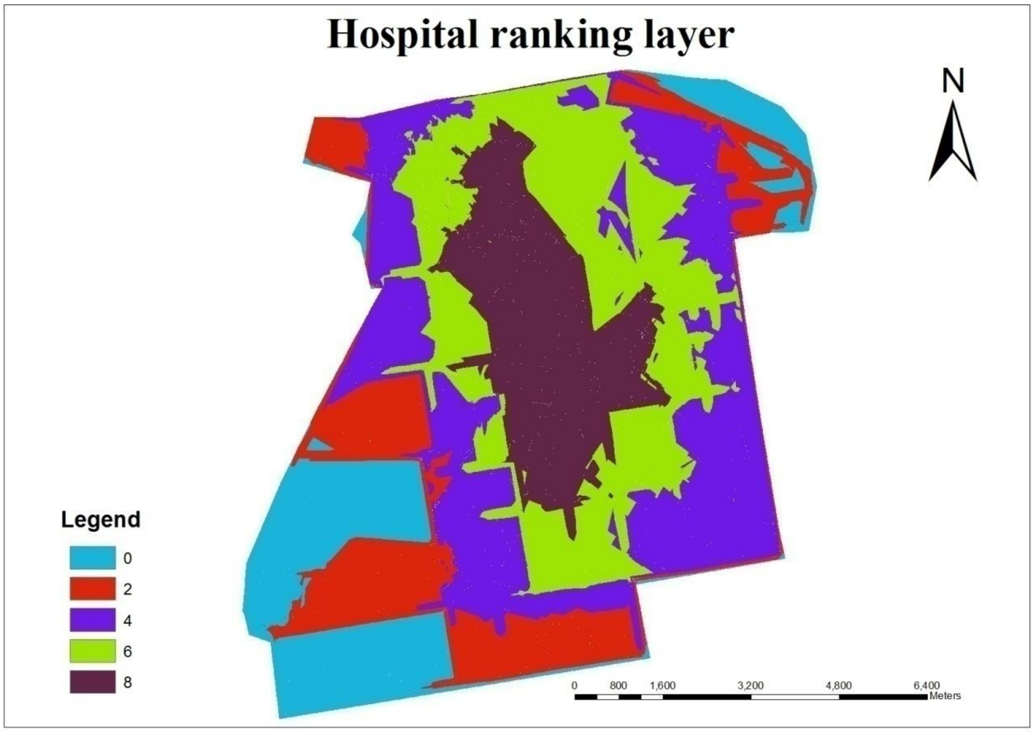
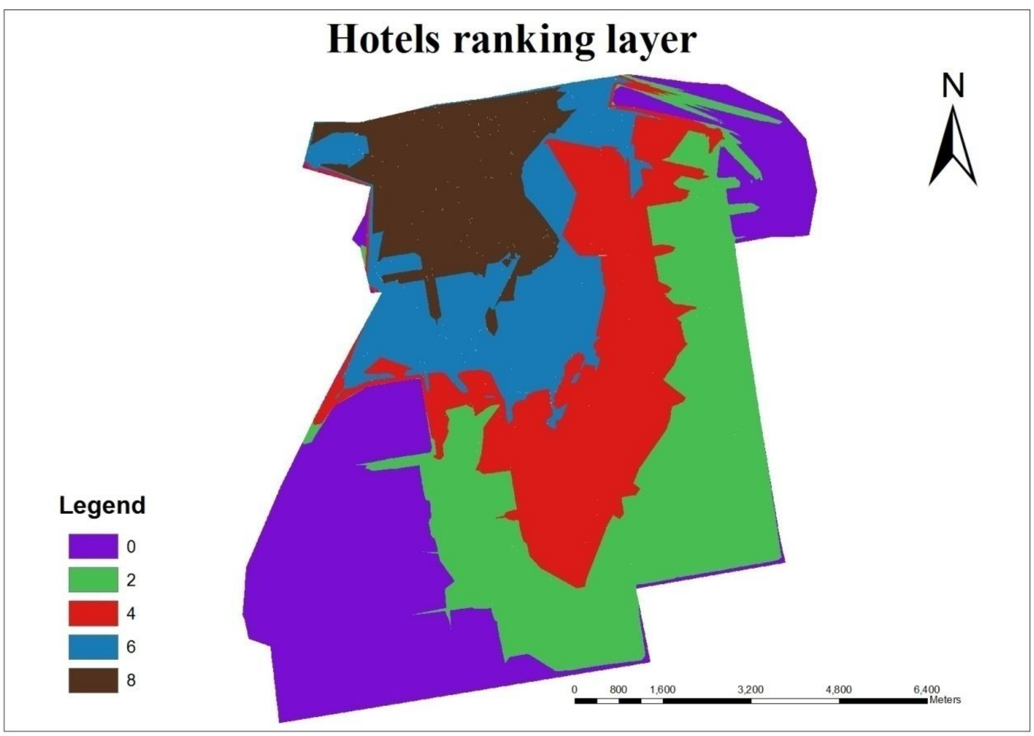
2
4
6
8
0 800 1,600 3,200 4,800 6,400
Meters


Goverment ranking layer
N
Legend
0
2
4
6
8
0
800
1,600
3,200
4,800
6,400
Meters


Health center ranking layer
N
Legend
0
2
4
6
8
0
800
1,600
3,200
4,800
6,400
Meters


Hospital ranking layer
N
Legend
0
2
4
6
8
0 800 1,600 3,200 4,800 6,400
Meters


Hotels ranking layer
N
Legend
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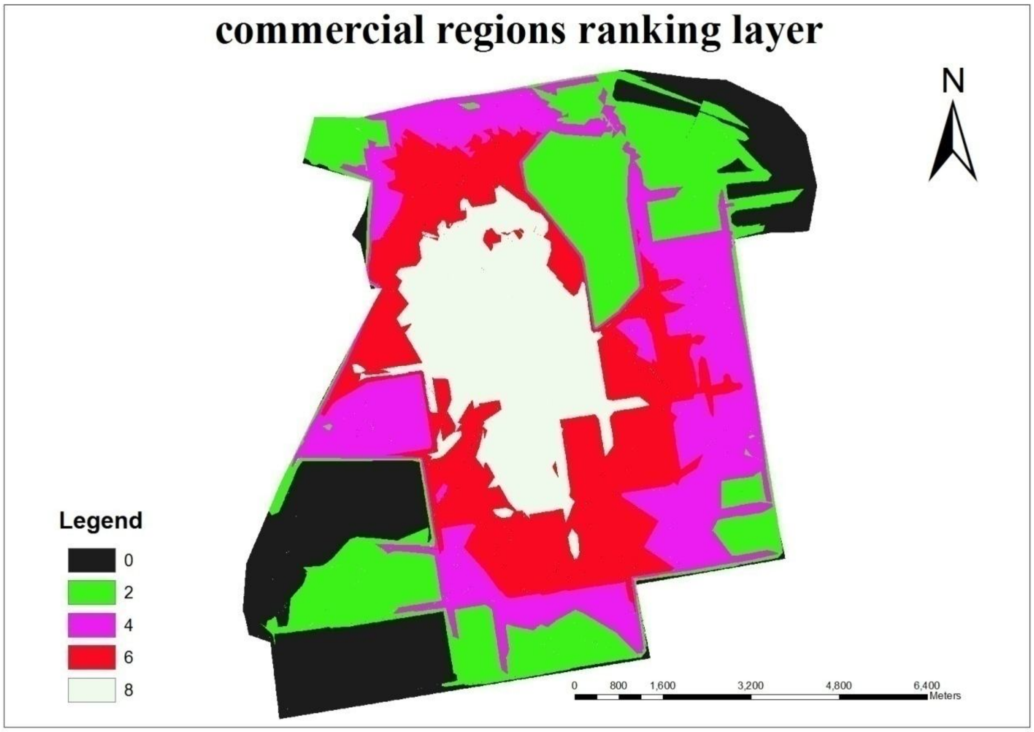
2
4
6
8
0 800 1,600 3,200 4,800 6,400
Meters


commercial regions ranking layer
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Legend
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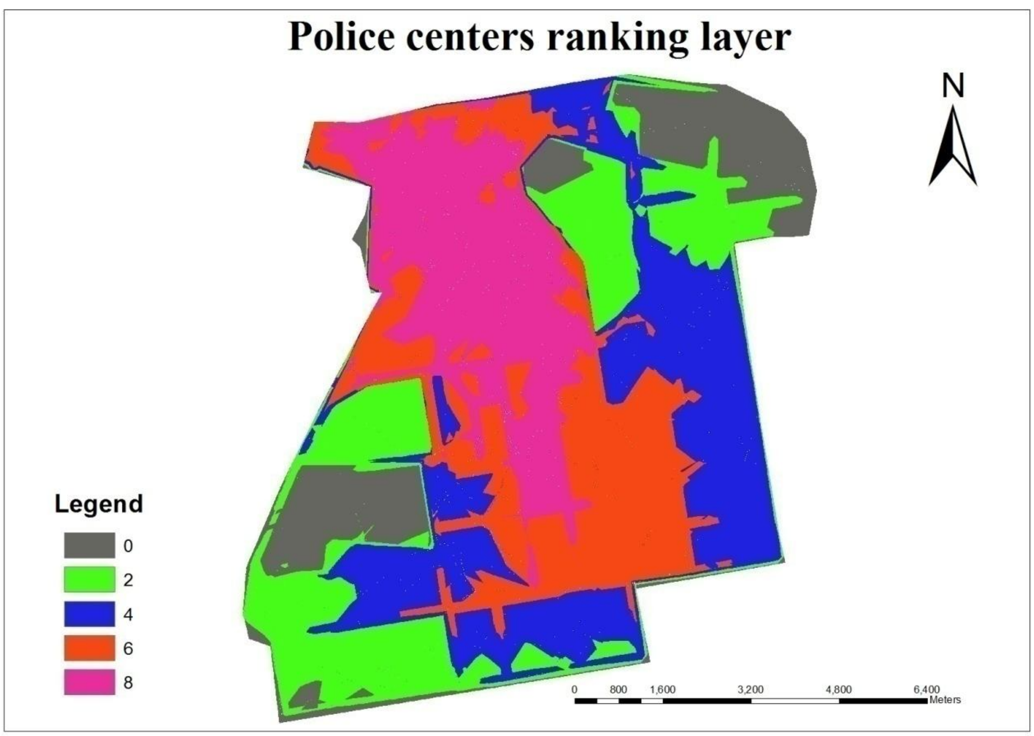
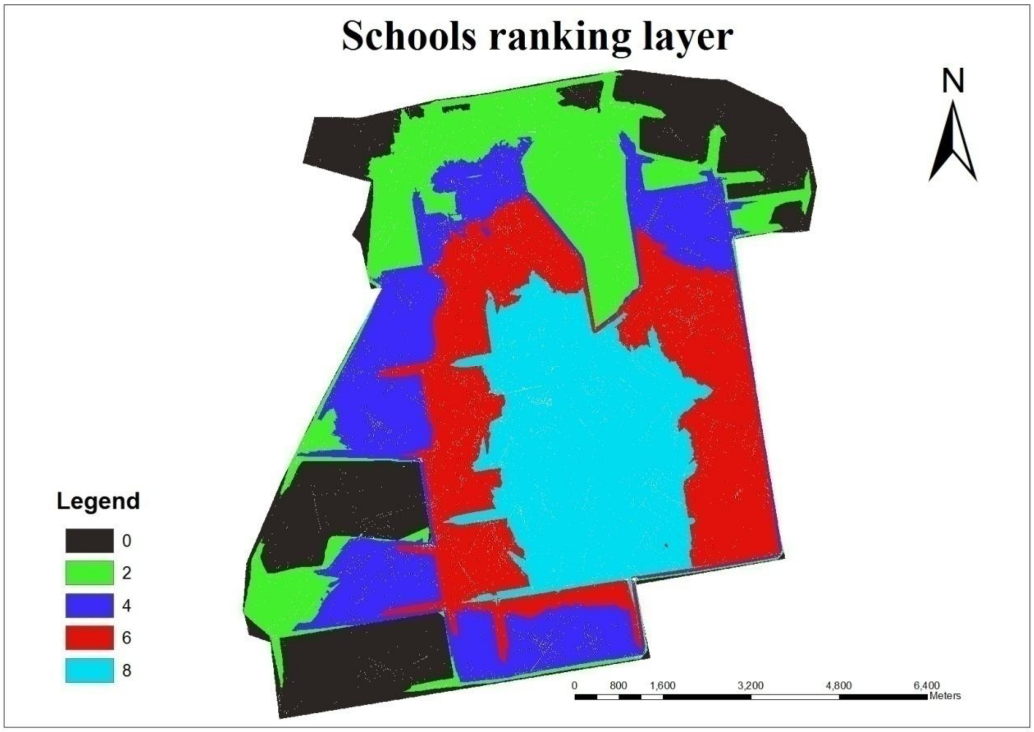
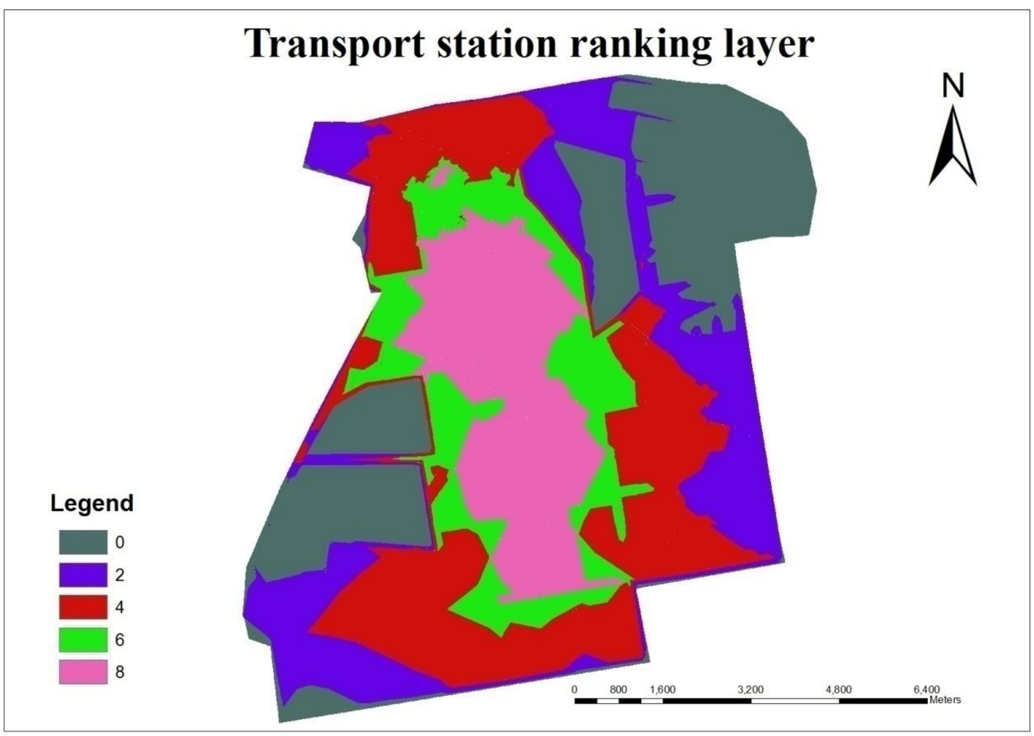
2
4
6
8
0
800
1,600
3,200
4,800
6,400
Meters


Police centers ranking layer
N
Legend
0
2
4
6
8
0
800
1,600
3,200
4,800
6,400
Meters


Schools ranking layer
N
Legend
0
2
4
6
8
0 800 1,600 3,200 4,800 6,400
Meters


Transport station ranking layer
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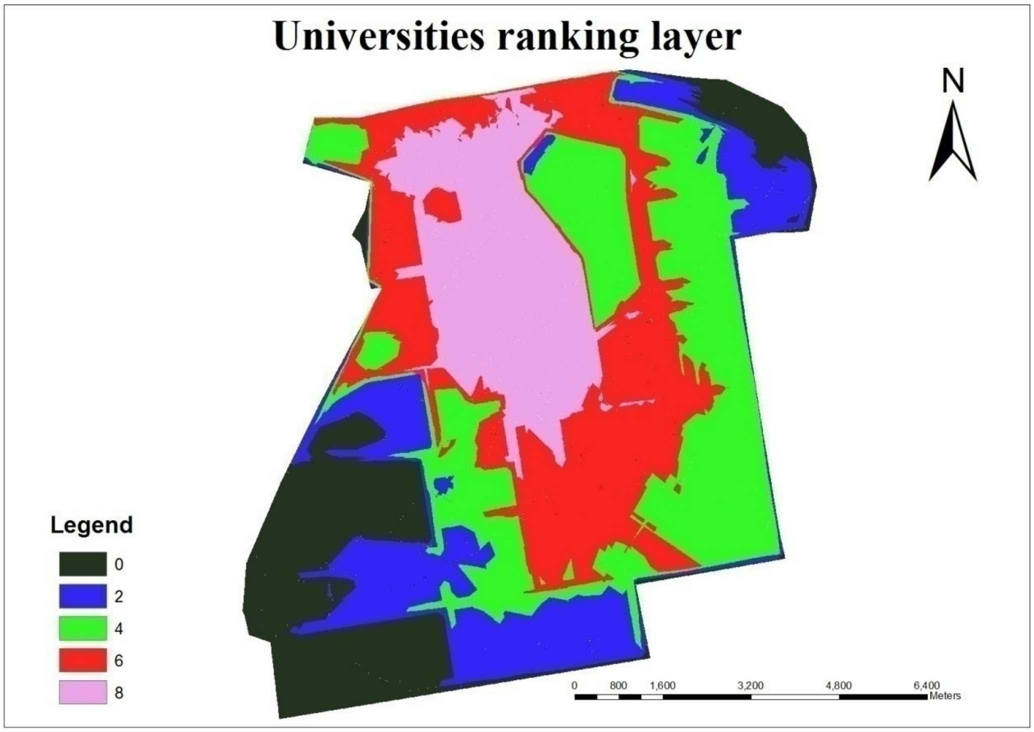
Legend
0
2
4
6
8
0 800 1,600 3,200 4,800 6,400
Meters


Universities ranking layer
N
Legend
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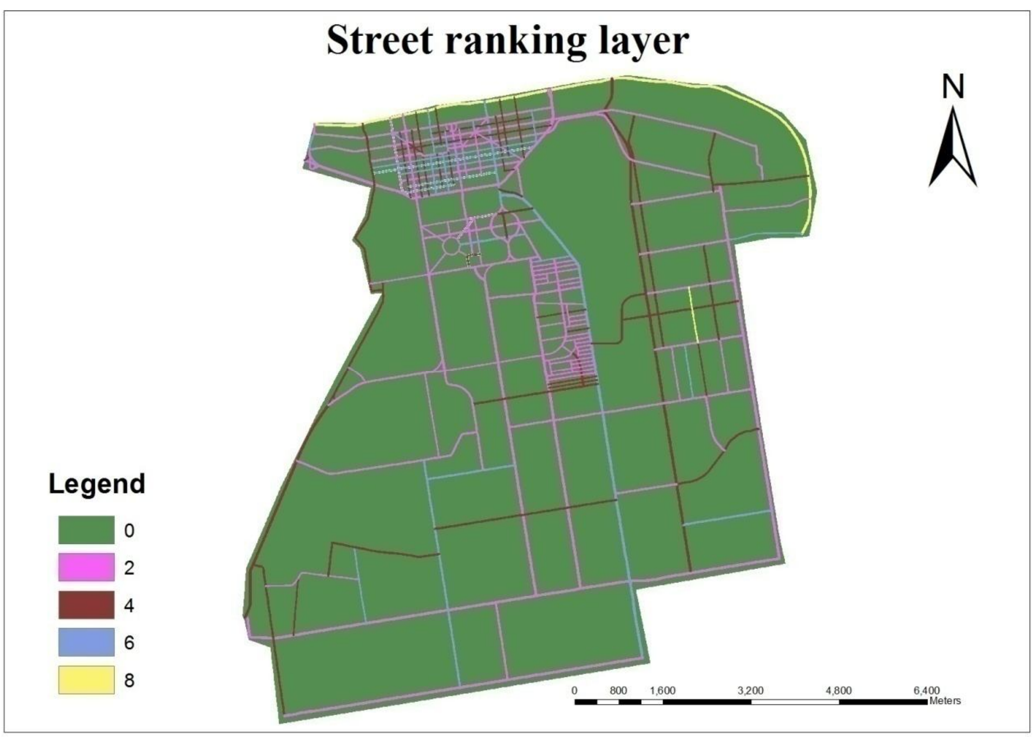
2
4
6
8
0
800
1,600
3,200
4,800
6,400
Meters


Street ranking layer
N
Legend
0
2
4
6
8
0
800
1,600
3,200
4,800
6,400
Meters

Appendix B :Python Script

```
importarcgisscripting, os, sys, traceback, math
gp = arcgisscripting.create(9.3)
gp.overwriteoutput = True
gp.CheckOutExtension("spatial")
gp.CheckOutExtension("management")
gp.AddToolbox("C:/ProgramFiles/ArcGIS/ArcToolbox/Toolboxes/SpatialAnalyst Tools.tbx")
```

```
ParameterAsText(0)
  inFields1 = gp.GetParameterAsText(1)
  inFields0 = gp.GetParameterAsText(2)
scrapDir = gp.GetParameterAsText(4)
OutRasterFinal = gp.GetParameterAsText(3)
InCellSize = gp.GetParameterAsText(5)
StdyArea = gp.GetParameterAsText(6)
FinalRaster = gp.GetParameterAsText(7)
Dir + "\\"
printinTable
inTable = inTable.replace ("\\","/")
scrapDir = scrapDir.replace ("\\","/")
OutRasterFinal = OutRasterFinal.replace ("\\","/")
StdyArea = StdyArea.replace ("\\","/")
printinTable
```

```
dList = inFields0.split(";")
rows = gp.searchcursor(inTable)
row = rows.next()
result = gp.GetCount_management(inTable)
count = int(result.GetOutput(0))
parameterIndex = 0
Exepression = ""
row = rows.next()
```

```
InFeatures = inTable
    outFeatures1 = str(scrapDir) +str(val)+"_1.shp"
outFeatures = str(scrapDir) +str(val)+".shp"
erased = str(scrapDir)+str(val)+"_erased.shp"
gp.select_analysis(InFeatures, outFeatures1, str(inFields0)+ " = " +str(val))
gp.erase(StdyArea, outFeatures1, erased, "1.3")
gp.Merge_management(str(outFeatures1)+";"+str(erased), outFeatures,"")
OutRaster = str(scrapDir)+str(val)+".tif"
gp.FeatureToRaster_conversion(outFeatures, inFields1, OutRaster, InCellSize)
parameterIndex = parameterIndex + 1
ifparameterIndex == 1: Exepression = OutRaster
ifparameterIndex> 1:
Exepression = Exepression + " + " + OutRaster
Exepression = Exepression.replace ("/","\*",)
Exepression = Exepression.replace ("*","",)
gp.SingleOutputMapAlgebra_sa(Exepression, OutRasterFinal + "/" + str(FinalRaster))
tb = sys.exc_info()[2]
tbinfo = traceback.format_tb(tb)[0]
pymsg = "PYTHON ERRORS:\nTraceback Info:\n" + tbinfo + "\nError Info:\n    " + \
str(sys.exc_type)+ ": " + str(sys.exc_value) + "\n"
gp.AddError(pymsg)
msgs = "GP ERRORS:\n" + gp.GetMessages(2) + "\n"
gp.AddError(msgs)
```

Appendix C

Square and normalized matrixes for general service is presented below:

Table 5.1: General service square

	Government	Transportation	Airport	Police station
Government	1	2	4	5
Transportation	0.5	1	5	4
Airport	0.25	0.2	1	0.333333
Police station	0.2	0.25	3	1

Table 5.2: General service normalized

	Government	Transportation	Airport	Police station	Sum	Weight age
Government	0.512821	0.57971	0.307692	0.483871	1.884094	0.471023483
Transportation	0.25641	0.289855	0.384615	0.387097	1.317977	0.329494372
Airport	0.128205	0.057971	0.076923	0.032258	0.295357	0.073839321
Police station	0.102564	0.072464	0.230769	0.096774	0.502571	0.125642824

The square and normalized matrixes for tourism layer :

Table 5.3: tourism square matrix

	Square	Garden	Market	Hotel	Club
Square	1	1	0.2	0.33	0.33
Garden	1	1	0.2	0.2	1
Market	5	5	1	1	4
Hotel	3.030303	5	1	1	7
Club	3.030303	1	0.25	0.142857	1

Table 5.4: tourism normalized matrix

	Square	Garden	Market	Hotel	Club	Sum	Avg Weightage
Square	0.076566	0.076923	0.075472	0.123463	0.024756	0.377180478	0.075436096
Garden	0.076566	0.076923	0.075472	0.074826	0.075019	0.378805951	0.07576119
Market	0.382831	0.384615	0.377358	0.374131	0.300075	1.819011001	0.3638022
Hotel	0.232019	0.384615	0.377358	0.374131	0.525131	1.8932552	0.37865104
Club	0.232019	0.076923	0.09434	0.053447	0.075019	0.53174737	0.106349474