1. Chapter One Introduction

1.1- Overview

Mankind today is living in the information era, which is characterized by the multiplicity of its data and the complexity of its aspects. A most important "distinguisher" is information that would determine the extent of the progress of people. Those countries which were able to devise ways to protect the information, and how to make best use of it in all aspects of development will be the winners.

Through the different stages of history mankind has been linked with the spatial context it lives in. This is due to the interrelation between mankind and the surrounding natural, environmental, social and economic factors, which led to enhancing the characteristics of evolution and sustainability in comprehensive development in general and in urban development in particular.

Mankind, nations, regions and the world would be severely limited in development without transportation, which is a key factor for physical and economic growth. Transportation routes are part of distinct development pattern or road networks and mostly described by regular street patterns as an indispensable factor of human existence, development and civilization. The route network coupled with increased transportation investment results in changed levels of accessibility reflected through Cost Benefit Analysis, savings in travel time, and other benefits. These benefits are noticeable in increased catchment areas for services and facilities like shops, schools, offices, banks, and leisure activities.

This emphasizes the need for sciences and modern technologies as well as the use of information systems and their significance in achieving sustainable development, which in turn provides comfort, security and the appropriate living and cultural standard for human being and its spatial context. The significance of modern techniques of information systems including Geographic Information Systems (GIS) lies in its efficient use as a technical and analytical toolbox for planners and decision makers as well as those responsible for the management of environment, population and resources. The use of GIS decreases to a large extent the cost and achieves speed in taking decisions to deal with various urgent physical problems. In addition, it supports the preparation of plans in speedy rates and high quality, which reduces lose in capacities and resources.

This research aims to present transportation network design based on capabilities of Geographic Information System (GIS). Modeling spatial related entities as components of a targeted network is the main aim of this research. Optimizing the connections between them according to proposed criteria is the next step to find out the best network schema, which fulfills the pre-adopted evaluation criteria. This research focuses on transportation network, specifically the metro as transportation model. It will serve the areas of life in many aspects, including economic, social field, transport and infrastructure services, etc. To deal with a map and all the processes we shall use ArcGIS V10.2software to accomplish the final results, which are maps containing Khartoum state data with the digital data linked to the Roadmap and the potentially best Metro network schema.

1.2- Problem Statement

Khartoum State has experienced significant population growth in the past years. Traffic congestion in the city is high and private car ownership is on the rise, as the population in Khartoum State has shown increased demand for public transportations.

The mix of vehicles on the roads is unique, as that road space is shared by non-motorized, pedestrians, as well as motorized vehicles. Unfortunately, the unavailability of mass public transport causes inconvenience in many respects. The excessive dependence on private cars, mini busses, and taxis leads to heavy traffic, a large number of accidents, and high individual expenditure on transport. Therefore, changing the transportation infrastructure, habits and other planning related variables in a spatial context must be examined.

The need of a Metro system in a city is generally considered necessary when population of the city exceeds one million. Khartoum State crossed this milestone in the early 1990"s (2.44) Millions and has now around 8 millions. In this research we will apply the Esri Network analyst to incorporate a GIS into the decision making process for setting-up a new network of Metro railway.

1.3- Research Hypothesis

1. Design a transportation network based on the capabilities of a Geographic Information System (GIS) gives additional information on these sites and will support decision-making processes reducing the risks of taking the wrong decisions based on wrong or incomplete information.

2. Using scientific techniques to analyze road network jointly with professionals in the fields of computer software development. This will reduce the laborious steps involved in graph theoretic analysis and simplify the technique for determining accessibility and connectivity indices for the use of Estate Surveyors Values

3. Create a database of stations, roads, paths and services area of the Metro Network. This will hopefully contribute to increase developments using high level plans accelerating investment growth in Khartoum state.

1.4- Reserach Objectives

1. The research aims to present an approach of development of transportation network design based on capabilities of Geographic Information System (GIS).
2. Modeling spatial related entities as components of the targeted network.
3. Optimizing the connections between them according to proposed criteria to find out the best network schema which fulfills the pre-adopted evaluation criterion. This research focuses on transportation network, specifically the metro as transportation model.
4. Identify the factors that are to be considered when having a new Metro station.
5. Examine the spatial pattern and trend of demand, supply and values of commercial properties in the study area.
6. Determine the relationships between commercial property values and road network, in the presence or absence of other variables, in the study area.
7. Create a database of stations, roads, paths and services area of the Khartoum Metro Network.

1.5- Research Significance

The use of GIS technology in modern planning has become an important mean to achieve development plans. The importance of research to take advantage of GIS technology applications in many areas of daily life includes

1-5-1 Infrastructure and physical planning field

A tool for decision support and facilitate the planning and geographical distribution of the proper services.

1-5-2 Transportation

Giving full information about all primary and secondary roads and design the best Metro Railway stations to figure out the best path to get to a certain area. The benefits will be savings in travel time, costs, and many more. These benefits are noticeable in increased catchment areas for services and facilities like shops, schools, offices, Hospitals, banks, and leisure activities.

1-5-3 Social and Economics

It makes Khartoum City innovative and will rank it into those of developed cities, which apply modern technologies in the field of geographic information systems.

1.6- Purpose of Research

The purpose of this research is to identify the optimal location for a Metro station stop in the Khartoum State using a Network Analyst in ArcGIS, in order to economically transport people and mitigate traffic.

1.7- Scope

This research covers the Transportation field in Khartoum state without villages and rural areas.

1.8- Expected Contribution

1- Database of (Metro network , roads, highways and stations).
2- Suggest Metro network and its stations and terminals.
3- Suggest Metro Lines and paths.
4- Metro services area.

1.9- Research Organization

The first Chapter presents an Overview, highlighting a Problem Statements, Research Hypothesis, Research Objectives, and Research Significance, purpose, scope and Expected Contribution. Chapter (2) presents the Theoretical Framework, Related Work and System Description. Chapter (3) presents the Research Community, followed by the methodologies implemented. System Requirements, System Analysis and design, output and data presentation appears in Chapter (4). Chapter (5) presents Algorithms Implemented and produces final results with some discussions. Chapter (6) presents Conclusions and Recommendations, which will summarize the thesis. Finally a list of references and resources are given in Chapter (7).

2. Chapter Two Theoretical Framework and Related Works

CHAPTER TWO

Theoretical Framework and Related Work

2.1 Theoretical Framework

2.1.1 Introduction

In this section, major theories which have been proposed and been found relevant for this study are discussed. These include concepts of geographic information system (GIS), GIS in Transportation (GIS-T) and basic principles of GIS-based Multi Criteria Decision Analysis (MCDA).

2.1.2 What is GIS

A Geographic Information System (GIS) is a computer application designed for the capture, storage, manipulation, analysis and display of geographic information. Geographic location is the element that distinguishes geographic information from all other types of information. Without location, data are termed to be non-spatial and would have little value within a GIS. Location is, thus, the basis for many benefits of GIS the ability to map, to measure distances and to tie different kinds of information together, because they refer to the same place (Longley et al., 2001).

Another definition of a GIS sounds as follows A Geographic Information System is used for the acquisition, management, analysis and presentation of all data that describe a part of the landscape and the technical, administrative, geo-scientific, economic and ecological objects which are on the landscape (Bartelme, 1995)

Moreover, GIS can also be seen as a widespread collection of tools for the acquisition, management, provision in case of need, transformation and presentation of spatial data of the real world within special applications (Burrough, 1986).

The capability of GIS technology to process both spatial and attribute data offers the opportunity of using GIS in location analysis. GIS facilitates effective decision-making by planners in planning processes. GIS goes beyond the limits of paper maps in manipulating and analyzing spatial data. The advantages of GIS in data documentation and processing include (Al-Ramadan andAina 2004)

- Quick updating of information
- Automated cartography
- Integration of information by linking spatial and attribute data
- Spatial analysis
- Production of maps at different scales and
- Visualization.

2.1.3 Benefits of GIS

The following lines represent some benefits of a GIS (Al-Ramadan 2002)

- Integrating geographic information for display and analysis within the framework of a single consistent system;
- Allowing manipulation and display of geographic knowledge in new and exciting ways;
- Automating geographic information and transferring them from paper to digital format;
- Linking location and attributes of feature(s) within the framework of one system;
- Providing the ability to manipulate and analyze geographic information in ways that are not possible manually;
- Automation of map making, production and updating;

- Providing a unified database that can be accessed by more than one department or agency;
- Storing geographic information in coincident and continuous layers.

2.1.4 GIS in Transportation

GIS-T, the application of geographic information science and systems to transportation problems, represents one of the most important application areas of GIS-technology today. While traditional GIS formulation strengths are in mapping display and geo-data processing, GIS-T requires new data structures to represent the complexities of transportation networks and to perform different network algorithms in order to fulfill its potential in the field of logistics and distribution logistics.

GIS in Transportation is therefore, in a broad sense, a geographic information system specializing in the input, management, analysis and reporting of geographical (spatially related) information. Among the wide range of potential applications GIS can be used for, transportation issues have received a lot of attention. A specific branch of GIS applied to transportation issues, commonly labeled as GIS-T, is one of the pioneer GIS application areas.

Geographic Information Systems for Transportation (GIS-T) refers to the principles and applications of applying geographic information technologies to transportation problems.

GIS-T research can be approached from two different, but complementary, directions. While some GIS-T research focusses on issues of how GIS can be further developed and enhanced in order to meet the needs of transportation applications, other GIS-T research investigates the questions of how GIS can be used to facilitate and improve transportation studies. In general, topics related to GIS-T studies can be grouped into three categories

- Data representations. How can various components of transport systems be represented in a GIS-T?
- Analysis and modeling. How can transport methodologies be used in a GIS-T?
- Applications. What types of applications are particularly suitable for GIS-T?

2.1.5 Antecedents to GIS-T

Many individual developments, both technological and conceptual, have contributed to the rise of GIS-T. Technologically, GIS-T, like GIS as a whole, benefited from developments in management information systems and database techniques in general, and relational databases in particular. The development of ‘stand alone’ packages for carrying out specific operations such as shortest path analysis and location–allocation modeling.

2.1.6 GIS-T Analysis and Modeling

GIS-T applications have benefited from many of the standard GIS functions (querying, geocoding, buffering, overlays, etc.) to support data management, analysis, and visualization needs. Like many other fields, transportation has developed its own unique analysis methods and models. Examples include shortest path and routing algorithms (e.g. traveling salesman problems, vehicle routing problem), spatial interaction models (e.g. gravity model), network flow problems (e.g. minimum cost flow problem, maximum flow problem, network flow equilibrium models), facility location problems (e.g. p-median problem, set covering problem, maximal covering problem, p-centers problem), travel demand models (e.g. the four-step trip generation, trip distribution, modal split, traffic assignment models, and more recently activity-based travel demand models), and land use-transportation interaction models.

While the basic transportation analysis procedures (e.g. shortest path finding) can be found in most commercial GIS software, other transportation analysis procedures and models (e.g. travel demand models) are available only selectively in some commercial software packages. Fortunately, the component GIS design approach adopted by GIS software companies provides a better environment for experienced GIS-T users to develop their own custom analysis procedures and models.

For GIS-T practitioners, such knowledge can help them evaluate different GIS software products and choose the one that meets their needs best. It also can help them to select appropriate analysis functions available in a GIS package and properly interpret the analysis results. GIS-T researchers, on the other hand, can apply their knowledge to help improving the design and analysis capabilities of GIS-T. Due to the increasing availability of tracking data that include both spatial and temporal elements, development of spatial-temporal GIS analysis functions to help better understand the dynamic movement patterns has attracted significant research attention in recent years.

2.1.7 GIS-T applications

GIS-T is one of the leading GIS application fields. Many GIS-T applications have been implemented at various transportation agencies and private firms. They cover much of the broad scope of transportation and logistics, such as infrastructure planning and management, transportation safety analysis, travel demand analysis, traffic monitoring and control, public transit planning and operations, environmental impacts assessment, intelligent transportation systems (ITS), routing and scheduling, vehicle tracking and dispatching, fleet management, site selection and service area analysis, and supply chain management. Each of these applications tends to have its specific data and analysis requirements. For example, representing a street network as centerlines may be sufficient for transportation planning and vehicle routing applications. A traffic engineering application, on the other hand, may require a detailed representation of individual traffic lanes. Turn movements at intersections also could be critical to a traffic engineering study, but not to a regional travel demand study. These different application needs are directly relevant to the GIS-T data representation and the GIS-T analysis and modeling issues.

2.1.8 GIS in Transportation Planning

Geographic Information Systems (GIS) are becoming more widely used in transportation planning agencies, especially among metropolitan transportation organizations. In many developed countries, highway maintenance management is becoming a critical issue. Many more authorities are now able to use GIS for highways and transport management, due to falling costs and the GIS increasing user-friendliness. GIS offers transport planners a medium for storing and analyzing data on population densities, land uses, travel behavior, etc. The most important objectives for using GIS are map/display and data integration. Agencies must identify potential issues that can be addressed through a GIS application more efficiently and effectively, and more economically than with prevailing methods. (Gupta et al. 2003).

The use of GIS for transportation applications is widespread. Typical applications include highway maintenance, traffic modeling, accident analysis, and route planning and environmental assessment of road schemes. A fundamental requirement for most transportation GIS is a structured road network. Additional information concerning general topography, land cover and land use is pertinent to the consideration of the impact of construction. The lack of appropriate data for GIS remains a chronic problem. GIS describes a world in terms of longitudes and latitudes and other projection systems consisting of a hierarchical structure of graphical objects. The typical GIS represent the world as a map. The major requirements and issues surrounding GIS management technology are building and maintaining a database, selecting and upgrading hardware and software, using the technology to solve problems, funding, networking, providing access, and others. Standard GIS functions include thematic mapping, statistics, charting, matrix manipulation, decision support system, modeling and algorithms and simultaneous access to several databases.

2.1.9 The Role of GIS in Transportation Engineering

The application of GIS has relevance to transportation due to the essentially spatially distributed nature of transportation related data, and the need for various types of network level analysis, statistical analysis and spatial analysis and manipulation. Most transportation impacts are spatial. At GIS platform, the transportation network database is generally extended by integrating many sets of its attributes and spatial data through its linear referencing system. Moreover, GIS will facilitate integration of all other socioeconomic data with a transportation network database for a wide variety of planning functions.

The main advantage of using GIS is its ability to access and analyze spatially distributed data with respect to its actual spatial location overlaid on a base map of the area of coverage, that allows analysis options,which would not be possible with other database management systems. The main benefit of using the GIS is not merely the user-friendly visual access and display, but also the spatial analysis capability and the applicability to apply standard GIS functionalities, such as thematic mapping, charting, network-level analysis, simultaneous access to several layers of data and its overlay, as well as the ability to interface with external programs and software for decision support, data management, and user-specific functions (Vonderohe, 1993).

2.1.10 Transportation network analysis

Network analysis reduces a complex transportation network to its fundamental elements of nodes making an evaluation of alternative structures possible through the use of elementary mathematics from graph theory. Common instance treats the road segments as edges and street intersections as nodes in the graph, and it is possible to derive useful descriptive indices by divorcing a transport network from its inert spatial form (Hodder and Lee, 1982).

2.1.11 Basic principles of GIS-based MCDA

2.1.11.1 Decisions

A decision-making process is a choice between alternatives.

2.1.11.2 Multi-Criteria Evaluation

Sometimes it is also referred to as multi-attribute evaluation or Multi-Attribute Decision Analysis (MADA).An example site suitability analysis for housing development (specific single objective).

2.1.11.3 Multiple-criteria Decision-making (MCDM) or Multiple-criteria Decision Analysis (MCDA)

MCDA is a sub-discipline of operations research, that explicitly evaluates multiple conflicting criteria in the decision making process (both in daily life or in professional settings). Conflicting criteria are typical in evaluating options cost or price is usually one of the main criteria, and some measure of quality is typically another criterion, easily in conflict with the cost.

2.2 Related Works

Various studies have proven the effectiveness and functionality of a GIS in projects of this type. For example

2.2.1 A Method Using GIS Integrated Voronoi Diagrams for Commuter Rail Station Identification A Case Study from Brasilia (Brazil)

This paper describes a station location method for a commuter rail system applying GIS integrated Voronoi diagrams. The method comes from a previously defined track line and considers the stations area coverage. As parameters to define area coverage the researcher used point density to representing the maximum concentrated activity area. The researcher also used the trip generating rate weights for point density. The method was applied to the Brasilia Metropolitan Area, and the final product was a “T” Trunk-Feeder framework that allows an integrated transportation system planning considering other existing transit systems. The stations were classified according to their degree of activities density and its importance for integration.

2.2.2 Application of GIS in Transportation Planning The Case of Riyadh, the Kingdom of Saudi Arabia

This paper is intended to illustrate applications of Geographic Information System (GIS) in transportation planning in general, and introduce a symbolic case study of Riyadh City, the capital of Saudi Arabia. The study relied on GIS to identify deficient facilities (i.e. tolerable, moderate, moderate to heavy and heavy road deficiencies) in the vital area within Riyadh’s ring road. The deficiency analysis process is utilized to highlight streets, where demand exceeds capacity. Incorporating the link volumes resulting from the travel demand forecasting into the network attribute table in GIS.

For the short range planning, it will illustrate the usage of GIS in identifying projects on the network using dynamic segmentation, and preparing network link tables for travel demand planning. Moreover, the integration of GIS into the travel demands analysis process is to identify future areas of congestion. Shortest path analyses and travel time allocation of major activity centers are also investigated.

2.2.3 Transportation Network Design Using GIS–Based DSS Baghdad Metro Case Study

This paper aims to present a new approach of transportation network design based on capabilities of Geographic Information System (GIS) and Decision Support Systems (DSS). Geo-database building, visualization, and spatial analysis are the main contribution of GIS. The implementation of Analytic Hierarchy Process (AHP) as a DSS tool facilitated the network elements ranking. New software is developed to map (read and update) data from a geo-database and subject it to AHP steps. The software is AHP Network Design using GIS (AHP-ND-GIS).

The researchers found out, that the proposed metro network planning phases can be supported by the network analysis tools provided in GIS software. The research builds a logic approach to design networks using multi criteria ranking from potential network elements. The variance of assumptions led to slightly deferred outputs. Committee assignment from experts to assign criteria ranking is crucial. Network design problems other than transportation can be subjected to the same modeling approach. The automation of main parts of the research supports the efficiency of final output through the trial of different cases of inputs.

2.2.4 Using GIS-Based Travel Potential Data for Alignment Design of Baghdad Subway

This study visualized digital map data of Baghdad using a GIS. The best routes for the subway, using different corridors, were optimized and aligned using the GIS software and network optimization model, then improved with the aid of land use data and compared to the old proposed alignment of the subway. The study evaluates the proposed routes and access points to the subway - the length of each route has been detected through GIS and the estimated travel time on each route was presented.

2.2.5 A GIS Approach to Bus Service Planning

This paper overviews a study conducted for the Victorian Department of Infrastructure which set out to develop and demonstrate a practical analytical methodology for evaluating new bus service proposals. The paper describes the development of a GIS framework based on the State Cadastre. The approach first makes use of various electronic information sources including the Census, new dwelling approvals, State Planning Scheme and various address files to pin-point the likely location of dwellings in Melbourne and to estimate local area demographics. In the second step, the Victorian Activity and Travel Survey (VATS) and public transport networks are used to estimate the demand for bus travel in each local area. GIS methods are then used to identify and rank areas in greatest need of additional service. Finally, GIS tools are used to estimate patronage changes for new service proposals by aggregating travel demand for residential populations in walk catchments around the routes.

2.2.6 Analysis of Mobility Pattern and Challenges of Transportation Needs of the Elderly in a Fast Growing City in Nigeria (Oyesiku, 2016)

This paper focuses on pattern of elderly mobility in a developing country, using a fast growing city as case study and identifies most important determinant of satisfaction levels of elderly use of existing transport services. The study is part of a travel survey of a fast growing city in Nigeria, using a structured questionnaire as survey instrument. 556 questionnaires administered on 65 years old and over were completed and analyzed, out of m720 respondents.

The main findings show that the frequent modes are by taxi and commercial motorcycles; the latter not only more expensive but also more uncomfortable, very unsafe though ubiquitous, readily available and accessible. The multiple regression analysis employed quantitatively ascertained that inconveniences of the use of public transportation is the most important determinant of factors influencing the level of satisfaction in use of transport services provided. The study notes, that urban land use planning must integrate a functional public transport system towards addressing mobility crisis of the elderly, and the social system must support elderly to financially cope with increasing costs of transportation with a view to restoring their long loss social independence and brings them to the forefront of the realization of their mobility needs.

2.2.7 Geospatial Analysis of Road Transport System in Peri-Urban Areas of Ibadan, Nigeria (Regional PlanTneincgh,nFoalcouglytYO OgfbEonmvoirsoon, Nmiegnertaial Sciences, Ladoke, 2014)

This paper examines existing road transportation facilities in the six local governments, that constitute peri-urban areas of Ibadan using geo-spatial techniques. The methodologies, which consist of Global Positioning System (GPS and Remotely Sensed Images, were used to analyze different types of roads in peri-urban areas of Ibadan. The study reveals highly congested federal and state roads. Many of the existing roads were without any drainage system, a situation which has serious implication for an effective road transport system and quality of life. The results also show, that motor parks and bus stops are not evenly distributed in the study area. Car free cities, car-light cities, eco-cities designed, and park-and-ride system, among others are suggested for effective road transport system in the study area.

In this study, geospatial techniques were integrated for the mapping and analysis of a road transport system in the peri urban areas of Ibadan. The study successively characterized road system and described road transport infrastructure. Ibadan which is a fast growing and major city in Nigeria needs to put up the appearance that benefits its status among its counterparts having a clutter free and appealing landscape. In order to achieve this goal, it is necessary that appropriate planning strategies should be put in place for the improvement of existing road transport facilities in the sub-urban areas.

From the above studies we learned that an opportunity for further research exists in using scientific techniques to analyze road networks jointly with professionals in the fields of computer software development. This will reduce the laborious steps involved in graph theory analysis and simplify the technique for determining accessibility and connectivity indices for the use of Estate Surveyors and Values. This will become handy in feasibility and viability appraisal and site selection process for development projects.

2.3 System Description

This research presents transportation network design by using capabilities of Geographic Information System (GIS) and Decision Support Systems (DSS).Modeling spatial related entities as components of the targeted network is the main aim of this research. Optimizing the connections between them according to proposed criteria is the next step to find out the best network schema, which fulfills the Khartoum Metro Network and the services area.

This research focuses on a transportation network, specifically the Metro as transportation model. To deal with a map and all the processes we shall use Arc GIS V10.3 software and QGIS V2.14.1 to become in the final results a map containing Khartoum state data with the digital data linked to the roadmap and the potential best Metro network schema.

In this research we apply a multi-criteria analysis (MCE) to incorporate a GIS into the decision making process for setting-up a new suggested network of the Metro railway.

3.1- Chapter Three Research Community and Methodology

3.2- Introduction

3.3- Research Community

3.4- Methodoly

3.1 Introduction

This chapter describes the community of research and the study area (Khartoum State), the methodological framework and application used in attaining the stated aims and objectives of the study.

3.2 Research Community

3.2.1 Study Area Khartoum State

Khartoum State is one of the eighteen states of Sudan. Although it is the smallest state by area (22,142 km^2), it is the most populous (5,274,321 in 2008 census) now around 8.1 Million. It contains the country's largest city by population, Omdurman, and the city of Khartoum, which is the capital of the state as well as the national capital of Sudan. The capital city contains offices of the state, governmental and non-governmental organizations, cultural institutions, and the main airport.

The city is located in the heart of Sudan at the confluence of the White Nile and the Blue Nile, where the two rivers unite to form the River Nile. The confluence of the two rivers creates a unique effect. As they join, each river retains its own color the White Nile with its bright whiteness and the Blue Nile with its alluvial brown color. These colors are more visible in the flood season.

The state lies between longitudes 31.5 to 34 °E and latitudes 15 to 16 °N. It is surrounded by River Nile State in the north-east, in the north-west by the Northern State, in the east and southeast by the states of Kassala, Gedaref and Gezira, and in the west by North Kurdufan (see fig. 3.1)

Figure 31 Location of the Study Area

- Longitudes 31.5 to 34 °E
- Latitudes 15 to 16 °N.
- Selection server is CGIAR-CSI (USA).
- The downloaded image format is GEO TIFF

Figure 32 Khartoum Satellite Map

3.2.2 Administrative Divisions

The state is geographically divided into blocks (or clusters), which are further subdivided into localities. There are a total of three blocks and seven localities.

First block

- JabalAwliyā' Locality
- al-Khartoum Locality

This starts from the Mugran (or Almogran), the confluence of the Blue Nile and White Nile, and extends southward between them to the boundaries of Gezira state. The block is characterized by Sundus and Soba agricultural schemes in both the GabalOwlia and Khartoum localities, along with a number of livestock, poultry, fishing, and fodder production projects, as well as vegetable and fruit farms.

Second block

- al-Khartoum Bahrī Locality
- Sharq an-Nīl Locality

This is the northern block, between the Blue Nile and the River Nile. The largest town in this block is Khartoum North. There are many agricultural projects, such as the Soba East and Seleit projects, and the largest dairy project in the state, the Kuku village project. The block also includes the largest industrial areas in Sudan.

Third block

- Umdurmān Locality
- Ombadda Locality
- Kararī Locality

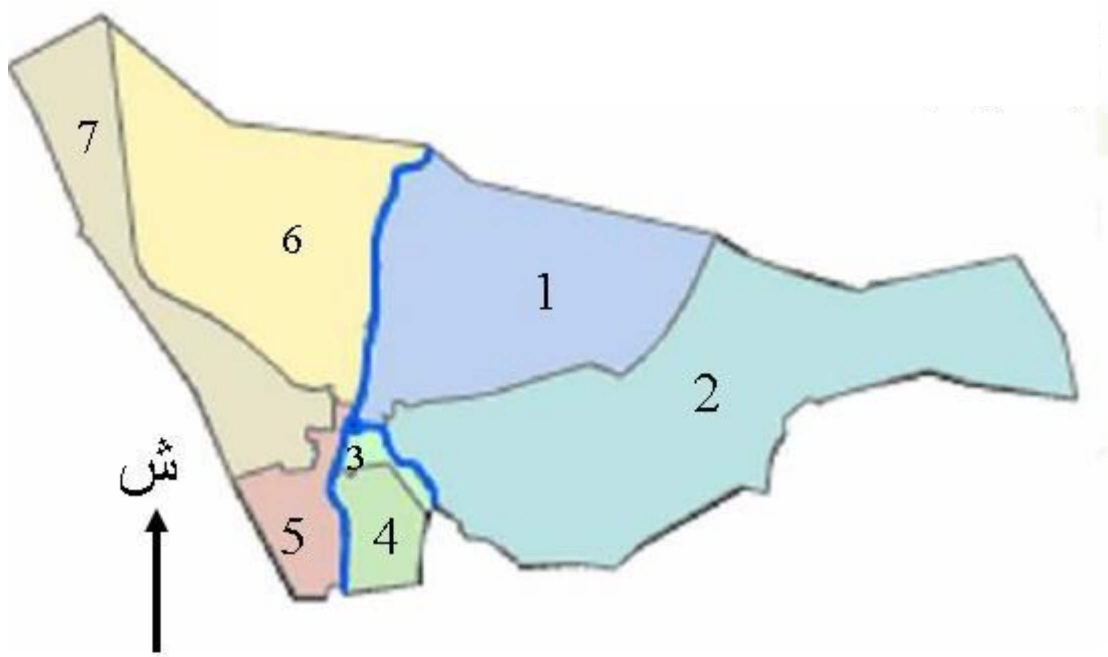


Figure 3.3 The Study Area in more detail

Table 3.1 Featuring Details of Khartoum State

No	Locality	Area Km^2	Population	Hospitals
1	al-Khartoum Locality	179	821,801	13
2	Jabal Awliyā' Locality	615	1,210,900	3
3	al-Khartoum Bahrī Locality	4682	781,992	8
4	Sharq an-Nīl Locality	8188	1,115,457	5
5	Umdurmān Locality	895	659,251	12
6	Hararī Locality	4646	917,507	6
7	Ombadda Locality	2667	1,269,462	1

3.2.3 Transport in Khartoum State

Air

Khartoum is home to the largest airport in Sudan, Khartoum International Airport. It is the main hub for Sudan Airways, Sudan's main carrier. The airport was built at the southern edge of the city; but with Khartoum's rapid growth and consequent urban sprawl, the airport is now located in the heart of the city. A new international airport is currently being built about 40 km (25 mi) south of the city center. There have been delays to start construction because lack of funding of the project but it is expected that the airport will be completed sometime in 2017. It will replace the current airport in Khartoum as Sudan's main airport.

Bridges

The following bridges cross the Blue Nile and connect Khartoum to Khartoum North

1. Mac Nimir Bridge
2. Blue Nile Road and Railway Bridge
3. Burri Bridge
4. Elmansheya Bridge
5. Soba bridge

The following bridges cross the White Nile and connect Khartoum to Omdurman

1. White Nile Bridge
2. Fitayhab Bridge
3. Al Dabbaseen Bridge (Under Construction)

The following bridges cross from Omdurman to Khartoum North

1. Shambat Bridge
2. Halfia Bridge

Khartoum-Tuti bridge cross to Tuti from Khartoum

Rail

Khartoum has rail lines from WadiHalfa, Port Sudan on the Red Sea, and El Obeid. All are operated by Sudan Railways. Some lines are also extended to some parts of south Sudan

3.3 Methodology

We use a set of applications of GIS in this research to carry out an analysis of spatial data to give the results. For that reason we start with geo-referencing and digitizing and contour map generations as 2D references for the stations and the surrounding regions, to determine the Metro Network.

3.3.1 Types and Sources of Data

In this research the following data were collected and used in the analysis. First a high-resolution satellite image of 2015 data (with 10 meter Resolution) covers the study area – it was extracted from the Google Earth web site.

Secondary data were obtained from property pages of websites. The secondary sources of data included Survey Directorate in the Ministry of infra structure and Transportation Khartoum State, Directorate of Land Information Systems in Khartoum. Details of the road network were derived through the analysis of the satellite road maps.

3.3.2 Analytical Techniques

In analyzing the data, a number of techniques were used. The data processing techniques adopted include data evaluation, geo-referencing and digitizing, data sub-setting, feature extraction, terrain modeling, and finally road map updates from satellite images and integration.

Geo-spatial techniques using remotely sensed images were used to analyze different types of roads in Khartoum State. Base maps were used as the field tools to characterize the roads.

3.3.2.1 Geo-referencing

The processing of the spatial data includes geo-referencing, on screen digitization, and map visualization. The download of a Google background image was imported into the GIS environment. For this study the Projected Reference System WGS 84, with UTM Zone 36N was defined. The next operation was geo-referencing, which involves the aligning of geographic data to a known coordinate system. After completing this operation data can be viewed, queried, and analyzed with other geographic data. Geo-referencing may involve shifting, rotating, scaling, skewing, and in some cases warping and rubber sheeting the data. The four corners of the imagery, of which their coordinates were captured from Google Earth, were used as input in the geo-referencing process. The geo-reference tool in ArcGIS 10.3 was turned on. The four (4) edges (corners) coordinates of the map were selected as the control points for the georeferencing. The add control tool was used to register the coordinates.

3.3.2.2 Digitization

The digitizing process starts by creating a layer in the Arc Catalogue. The features on the image were geometrically represented as polyline, polygon and point. The layer created with the same reference system was added to the Arc Map environment, where the sketch tool was used as a pencil to trace the spatial features. Using the polyline feature the road network was then carefully extracted. The important buildings were also extracted using the polygon feature.

3.3.2.3 Proximity Analysis (Buffer)

The buffer of 500m and 250m was defined along the major location such as Main Roads in the Khartoum Study Area to evaluate the number of borehole points within the specified radius. In this process, the analysis tool in Arc toolbox of ArcGIS 10.3 was used. The major road was put as input feature, the distances (1,2,3,5 Km) were defined and the output feature was saved as a buffer shape file.

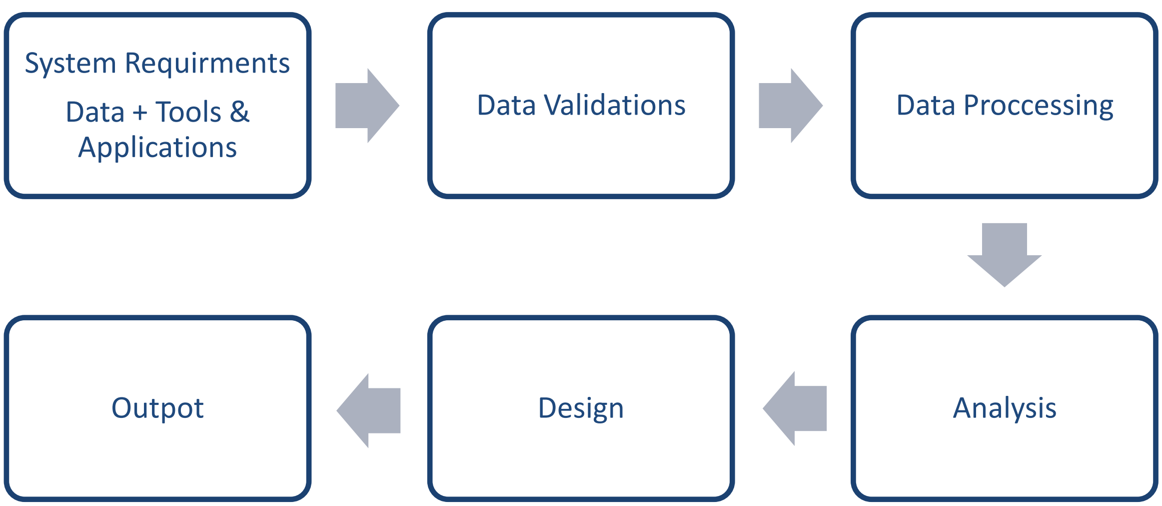


Figure 3.4 Project Flowchart

4. Chapter Four System Requirements, Analysis and Design

4.1- System Requirements

4.2- System Analysis and Design

4.3- Output and Data Presentation

4 Chapter Four System Requirements, Analysisand Design

4.1 System Requirements

4.1.1 Types and Sources of Data

Two sets of data were collected, from primary and secondary sources. First the primary data (geometric data) were collected in digital form from a variety of sources. In this research the following data was used in the analysis A High-resolution satellite image of 2015 (with 10 meter Resolution) covering the study area (Khartoum State), source Google Earth .Details of the road network were derived through the analysis of the shape files of road maps.

Secondary data (attribute data) were obtained from property pages of websites, including the Khartoum State Strategic Report 2014, Ministry of infra structure and Transportation Khartoum State Reports and data of the Directorate of Land Information Systems in Khartoum.

4.1.2 Applications And Tools Used

4.1.2.1 Arc GIS 10.3

The traffic situation maps in this study were generated by creating a digital database of all the selected variables as listed and mapped. The software used was Arc GIS 10.3 Both, overlay techniques and unique tools in the legend editor were used for the analysis.

ArcGIS Desktop is comprised of a set of integrated applications, which are explained in the following

- Arc Map is the main mapping application, which allows you to create maps, query attributes, analyze spatial relationships, and to layout final projects.

- Arc Catalog organizes spatial data contained on your computer and various other locations and allows to search, preview, and add data to Arc Map as well as manage metadata and set-up address locator services (geocoding).
- Arc Toolbox is the third application of ArcGIS Desktop. Although it is not accessible from the start menu, it is easily accessed and used within Arc Map and Arc Catalog. Arc Toolbox contains tools for geoprocessing, data conversion, coordinate systems, projections, and more. This workbook will focus on Arc Map and Arc Catalog.

With ArcGIS extensions, you can do the following

1. Analyze data in a realistic perspective.
2. Conduct advanced spatial analysis to get specific answers from the data.
3. Use advanced statistical tools to investigate the data.
4. Perform complex routing, closest facility, and service area analysis.
5. Reveal and analyze time-based patterns and trends.
6. Represent and understand any network

4.1.2.2 QGIS V2.14

QGIS software is an open source product and very capable for fast data processing and visualizations. It can be download free-of-charge from the Quantum GIS Websites – here we use Version 2.14. QGIS can overlay several layers of geographic data, no matter being in the vector or raster format (see fig. 4.1)

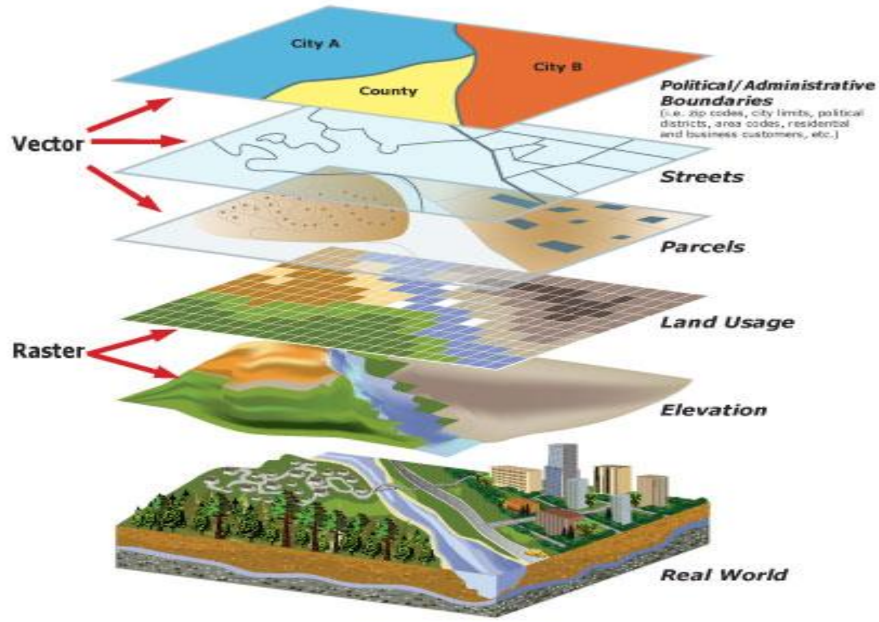


Figure 4.1 Overlay of several geographical data layers in vector and raster format.

4.2 System Analysis and Design

Both geographic information systems (GIS) and network analysis are burgeoning fields, characterized by rapid methodological and scientific advances in recent years.

4.2.1 Data Acquisition

Data acquisition is a primary operation in digital mapping or GIS operation. In this research the following data were collected and used in the analysis. A High-resolution satellite image of 2015 (with 10 meter Resolution) data covering the study area was extracted from the Google Earth web site. Furthermore, we used the Khartoum road map, and the land usage water area type shape files.

Secondary data (attributes data) were obtained from property pages of websites including the Khartoum State Strategic Report 2014, Ministry of infra structure and Transportation Khartoum State Reports.

4.2.2 Types of Data

The following data types were used in detail

1. Satellite image of 2015 (with 10 meter Resolution) of the study area (Khartoum State) (Source Google Earth web site).
2. Open street map (with 10 meter Resolution) satellite image 2015 data (Source created by this study)
3. Khartoum road map type shape file (Source Directorate of Land Information Systems in Khartoum).
4. Khartoum land usage type shape file (Source Directorate of Land Information Systems in Khartoum)

4.2.3 Data Input

After Khartoum state data were collected it was imported into QGIS to create a geo-database of the study area. This has been performed in two levels

First level input spatial database this level includes the following

1. Insert Khartoum land usage type shape file
2. Insert Khartoum road map type shape file.
3. Clip the road data that are out of the study area
4. Update Khartoum road map using open street map data
5. Create layer types of points for the stations depending on importance of the place and world Metro system constraints (distance between stations)
6. Monitoring data quality depending on topology.

Second level input attributes data this level includes data of the following

1. Roads ID, Name, Type, Tunnel, bridge, one way and class
2. Land usage ID, Name, Type and area.
3. Stations ID, Name, Type and description

4.2.4 Data Processing

Data processing is carried out at several levels, including the following

4.2.4.1 Shortest path analysis

By using shorted path analysis in QGIS software we Create shorted path between the point that describe the stations of khartoum Metro.

$$d_{ij}^{o} = min[l_1(i,j), l_2(i,j), \ldots\ldots, l_m(i,j)]$$

where *m* is the number of branches between node *i* and node *j*.

(Equation 4.1) [1]

[1] https://en.wikipedia.org/wiki/Shortest_path_problem , 03 April 2017.12:03pm.

4.2.4.2 Creating network dataset

The ArcGIS Network Analyst extension allows you to build a network dataset and perform analyses on a network dataset.

By Using ArcCatalog we create and build a network dataset from feature classes of Khartoum Roads. We could Perform various network analyses in ArcMap using the Network Analyst toolbar.

4.2.4.3 Service area of Metro Network

We create a series of polygons that represent the distance that can be reached from a facility within a specified amount of distances (2Km). These polygons are known as service area polygons.

By using network analyst in GIS we can specify served area around any point in network service area is roads places that lay inside the boundries of the area in specific distance (1Km, 5Km..) or time (10 minutes 4 houres...)

4.2.4.4 Buffer Zone Metro Network

Same like services area but with specific factor that showing zone with circle around it with out considring roads network. We used Buffer Zone for Metro stations in distances 2 Km.

4.2.4.5 Closest facility

Finding nearest station and specfing shortest path for this station is providing by using GIS Network analyest. We used this function to determined closest station for any point in khartoum map.

4.2.4.6 Accesabilty

By using GIS Network analyest we can Classifing the accesabillity for any services. we used this function to classify khartoum Metro Service maps.

4.2.4.7 Station Location Analysis

Throughout the study over 86 station locations were identified for the station location analysis. Each station location was buffered by both the 2Km distance and overlayed (clipped) to the land use and associated attributes layer.

4.2.4.8 Station Location By Route Analysis

The route analysis consisted of identifying the station locations for each route and buffering the stations by both walking distances.

4.3 Output and Data Presentation

Figure 4.2 The Republic of SUDAN and the Study Area

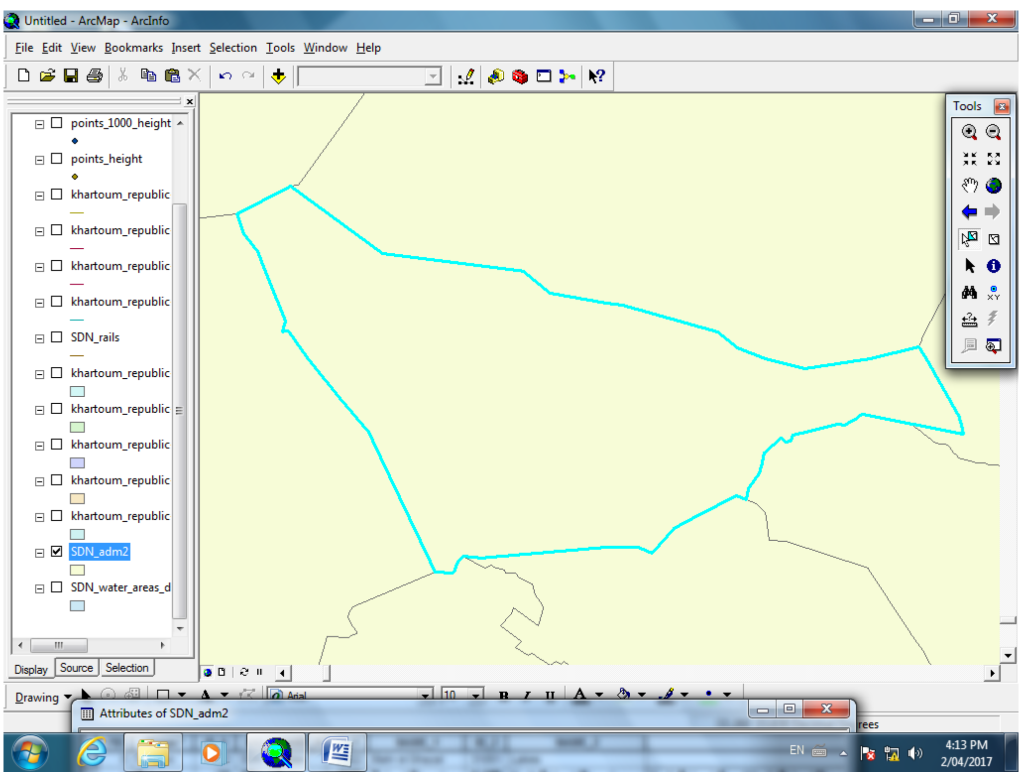


Figure 4.3 Khartoum State, the Study Area

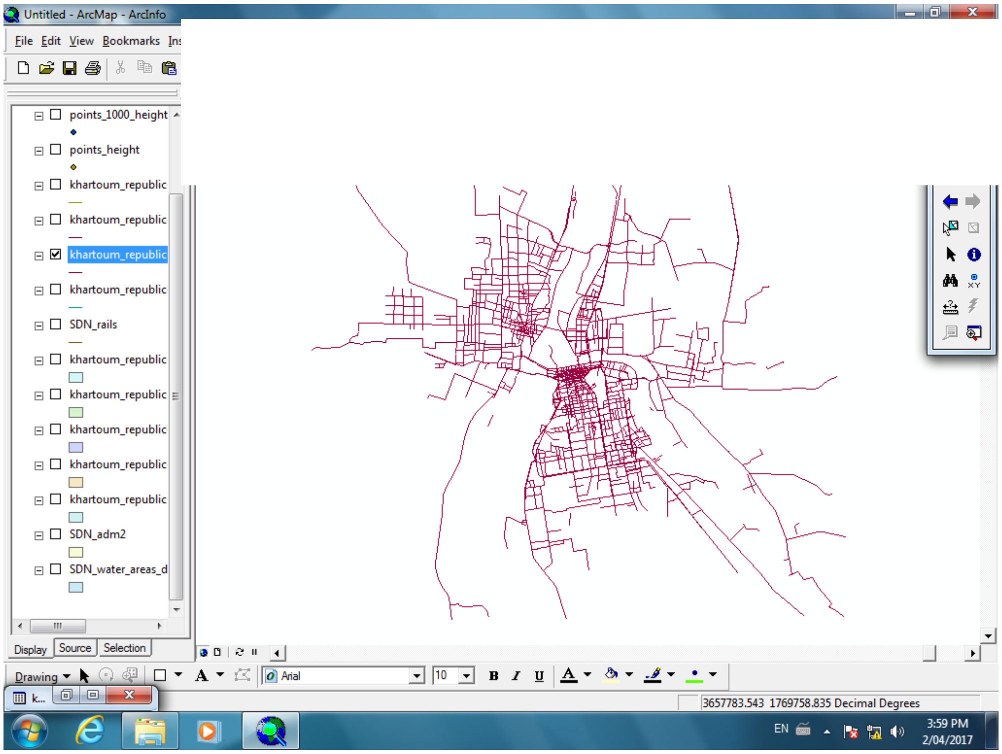
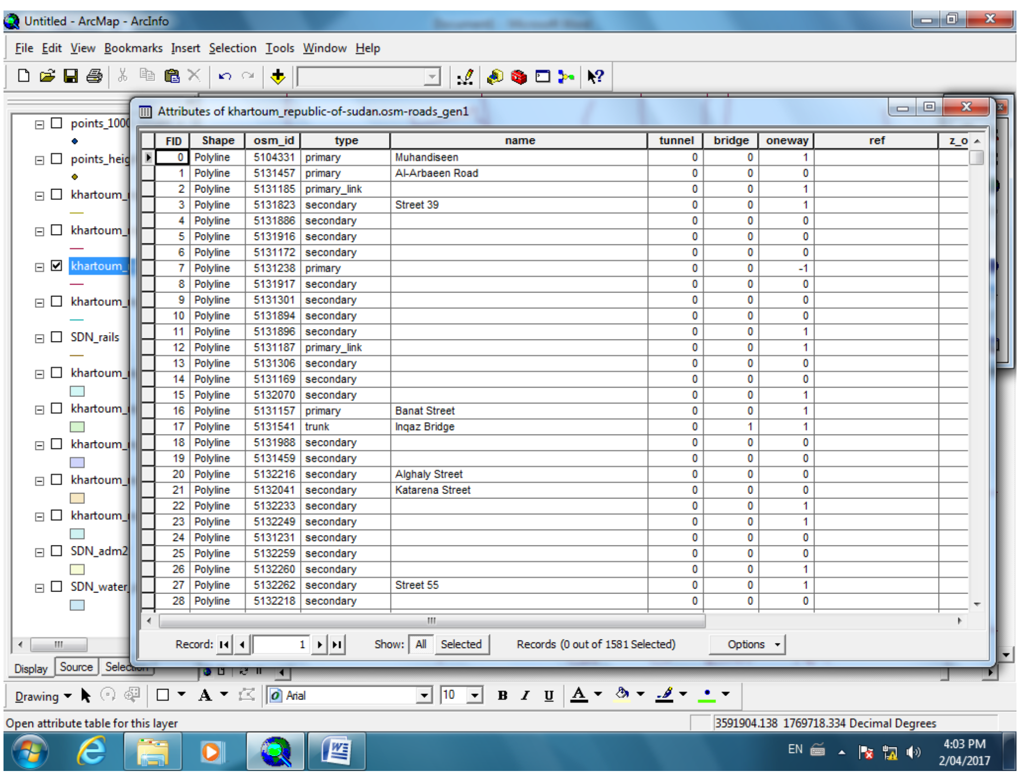


Figure 4.4 Khartoum State Main Streets



FID	Shape	osm_id	type	name	tunnel	bridge	oneway	ref	z_o
0	Polyline	5104331	primary	Muhandiseen	0	0	1		
1	Polyline	5131457	primary	Al-Arbaeen Road	0	0	0		
2	Polyline	5131185	primary_link		0	0	1		
3	Polyline	5131823	secondary	Street 39	0	0	1		
4	Polyline	5131886	secondary		0	0	0		
5	Polyline	5131916	secondary		0	0	0		
6	Polyline	5131172	secondary		0	0	0		
7	Polyline	5131238	primary		0	0	-1		
8	Polyline	5131917	secondary		0	0	0		
9	Polyline	5131301	secondary		0	0	0		
10	Polyline	5131894	secondary		0	0	0		
11	Polyline	5131896	secondary		0	0	1		
12	Polyline	5131187	primary_link		0	0	1		
13	Polyline	5131306	secondary		0	0	0		
14	Polyline	5131169	secondary		0	0	0		
15	Polyline	5132070	secondary		0	0	1		
16	Polyline	5131157	primary	Banat Street	0	0	1		
17	Polyline	5131541	trunk	Inqaz Bridge	0	1	1		
18	Polyline	5131988	secondary		0	0	0		
19	Polyline	5131459	secondary		0	0	0		
20	Polyline	5132216	secondary	Alghaly Street	0	0	0		
21	Polyline	5132041	secondary	Katarena Street	0	0	0		
22	Polyline	5132233	secondary		0	0	1		
23	Polyline	5132249	secondary		0	0	1		
24	Polyline	5131231	secondary		0	0	0		
25	Polyline	5132259	secondary		0	0	0		
26	Polyline	5132260	secondary		0	0	1		
27	Polyline	5132262	secondary	Street 55	0	0	1		
28	Polyline	5132218	secondary		0	0	0		

Figure 4.5 Streets Attribute Table

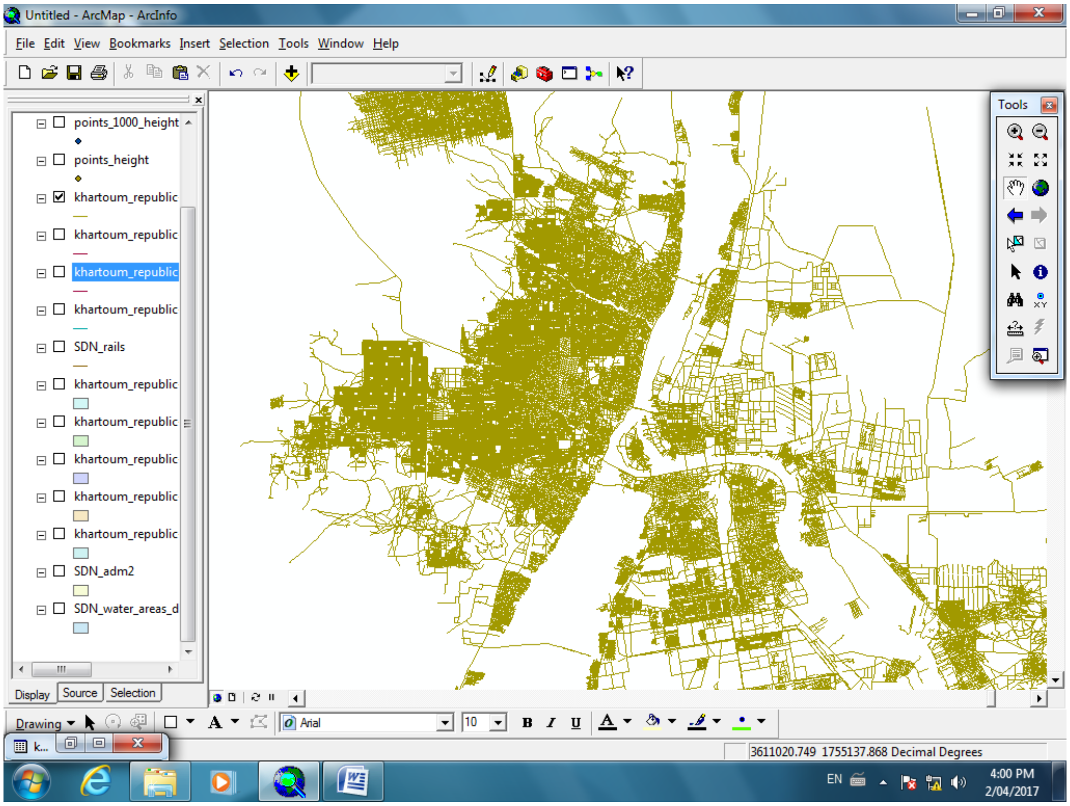
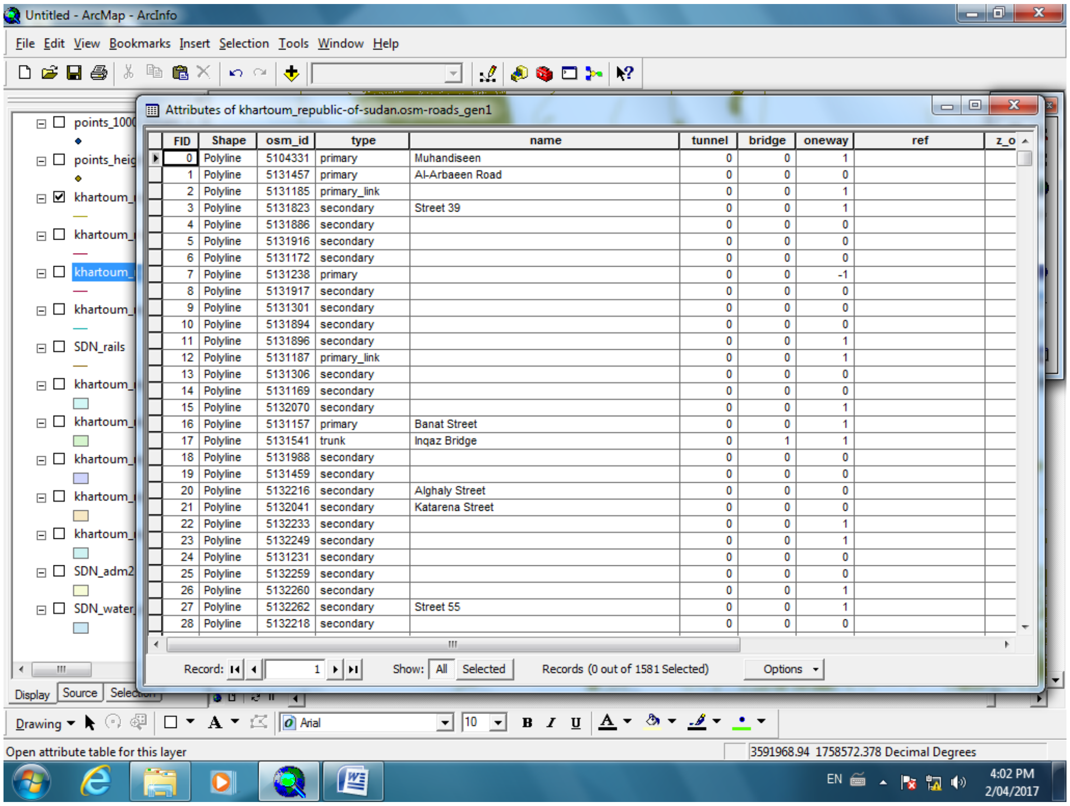


Figure 4.6 Khartoum State Roads



FID	Shape	osm_id	type	name	tunnel	bridge	oneway	ref	z_o
0	Polyline	5104331	primary	Muhandiseen	0	0	1		
1	Polyline	5131457	primary	Al-Arbaeen Road	0	0	0		
2	Polyline	5131185	primary_link		0	0	1		
3	Polyline	5131823	secondary	Street 39	0	0	1		
4	Polyline	5131886	secondary		0	0	0		
5	Polyline	5131916	secondary		0	0	0		
6	Polyline	5131172	secondary		0	0	0		
7	Polyline	5131238	primary		0	0	-1		
8	Polyline	5131917	secondary		0	0	0		
9	Polyline	5131301	secondary		0	0	0		
10	Polyline	5131894	secondary		0	0	0		
11	Polyline	5131896	secondary		0	0	1		
12	Polyline	5131187	primary_link		0	0	1		
13	Polyline	5131306	secondary		0	0	0		
14	Polyline	5131169	secondary		0	0	0		
15	Polyline	5132070	secondary		0	0	1		
16	Polyline	5131157	primary	Banat Street	0	0	1		
17	Polyline	5131541	trunk	Inqaz Bridge	0	1	1		
18	Polyline	5131988	secondary		0	0	0		
19	Polyline	5131459	secondary		0	0	0		
20	Polyline	5132216	secondary	Alghaly Street	0	0	0		
21	Polyline	5132041	secondary	Katarena Street	0	0	0		
22	Polyline	5132233	secondary		0	0	1		
23	Polyline	5132249	secondary		0	0	1		
24	Polyline	5131231	secondary		0	0	0		
25	Polyline	5132259	secondary		0	0	0		
26	Polyline	5132260	secondary		0	0	1		
27	Polyline	5132262	secondary	Street 55	0	0	1		
28	Polyline	5132218	secondary		0	0	0		

Figure 4.7 Roads Attribute Table

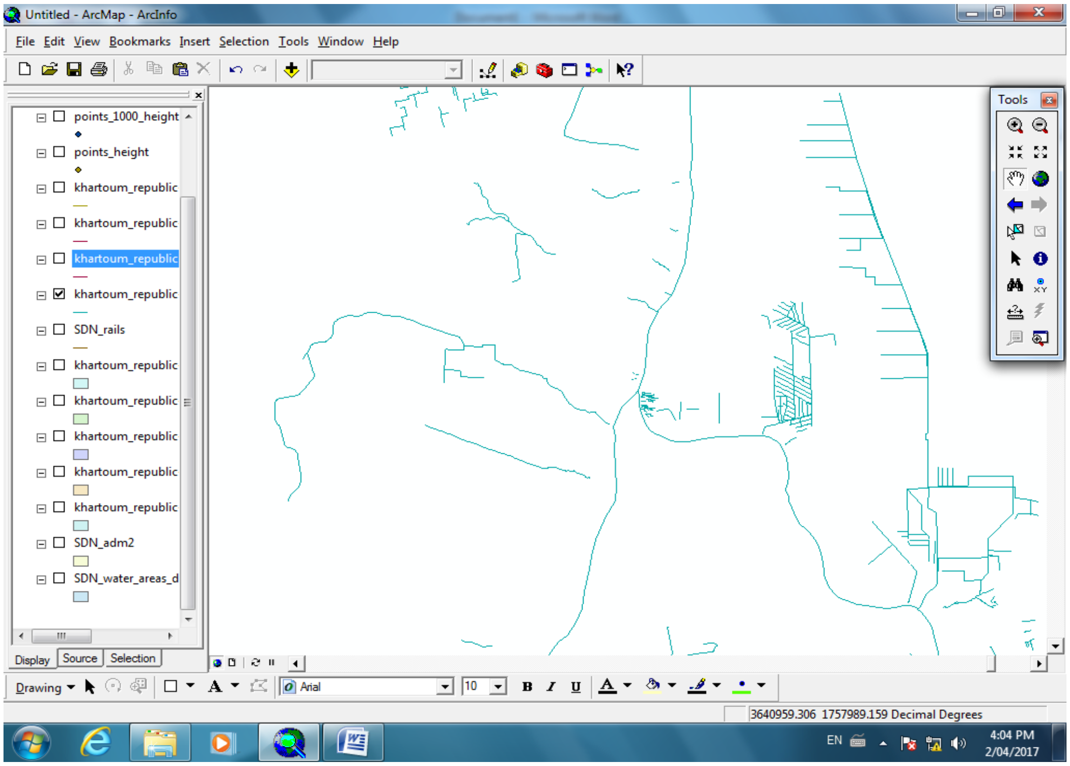
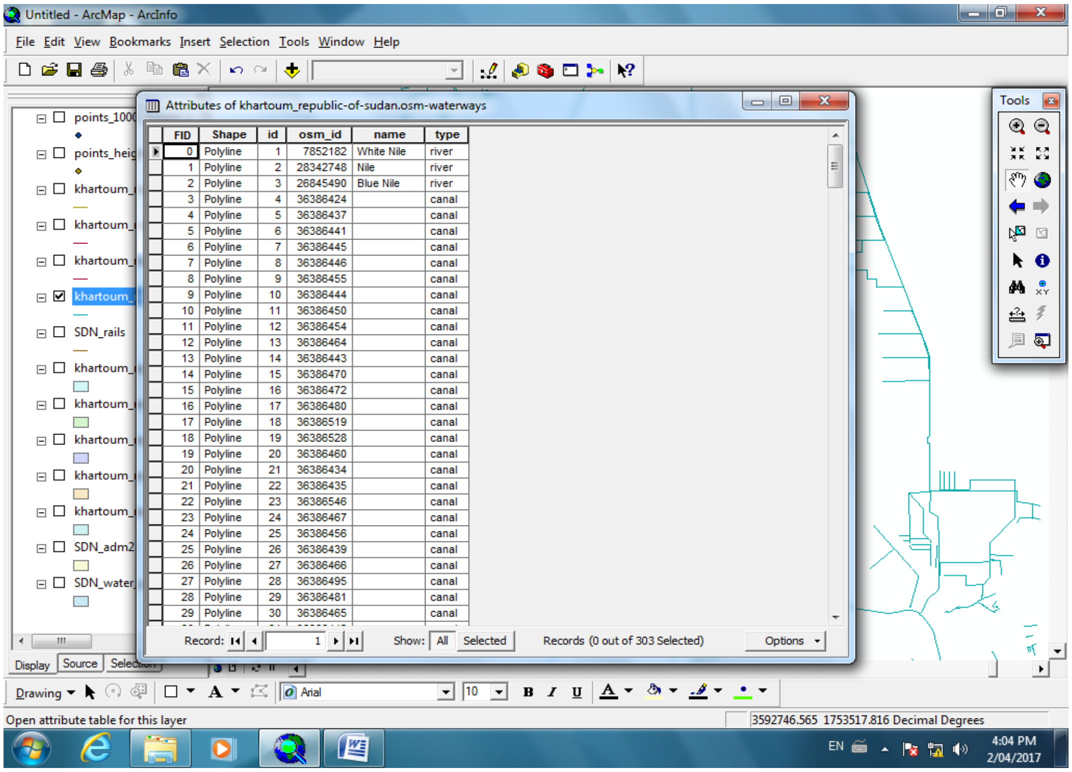


Figure 4.8 Waterways - Vectors



FID	Shape	id	osm_id	name	type
0	Polyline	1	7852182	White Nile	river
1	Polyline	2	28342748	Nile	river
2	Polyline	3	26845490	Blue Nile	river
3	Polyline	4	36386424		canal
4	Polyline	5	36386437		canal
5	Polyline	6	36386441		canal
6	Polyline	7	36386445		canal
7	Polyline	8	36386446		canal
8	Polyline	9	36386455		canal
9	Polyline	10	36386444		canal
10	Polyline	11	36386450		canal
11	Polyline	12	36386454		canal
12	Polyline	13	36386464		canal
13	Polyline	14	36386443		canal
14	Polyline	15	36386470		canal
15	Polyline	16	36386472		canal
16	Polyline	17	36386480		canal
17	Polyline	18	36386519		canal
18	Polyline	19	36386528		canal
19	Polyline	20	36386460		canal
20	Polyline	21	36386434		canal
21	Polyline	22	36386435		canal
22	Polyline	23	36386546		canal
23	Polyline	24	36386467		canal
24	Polyline	25	36386456		canal
25	Polyline	26	36386439		canal
26	Polyline	27	36386466		canal
27	Polyline	28	36386495		canal
28	Polyline	29	36386481		canal
29	Polyline	30	36386465		canal

Figure 4.9 Waterways - Attributes

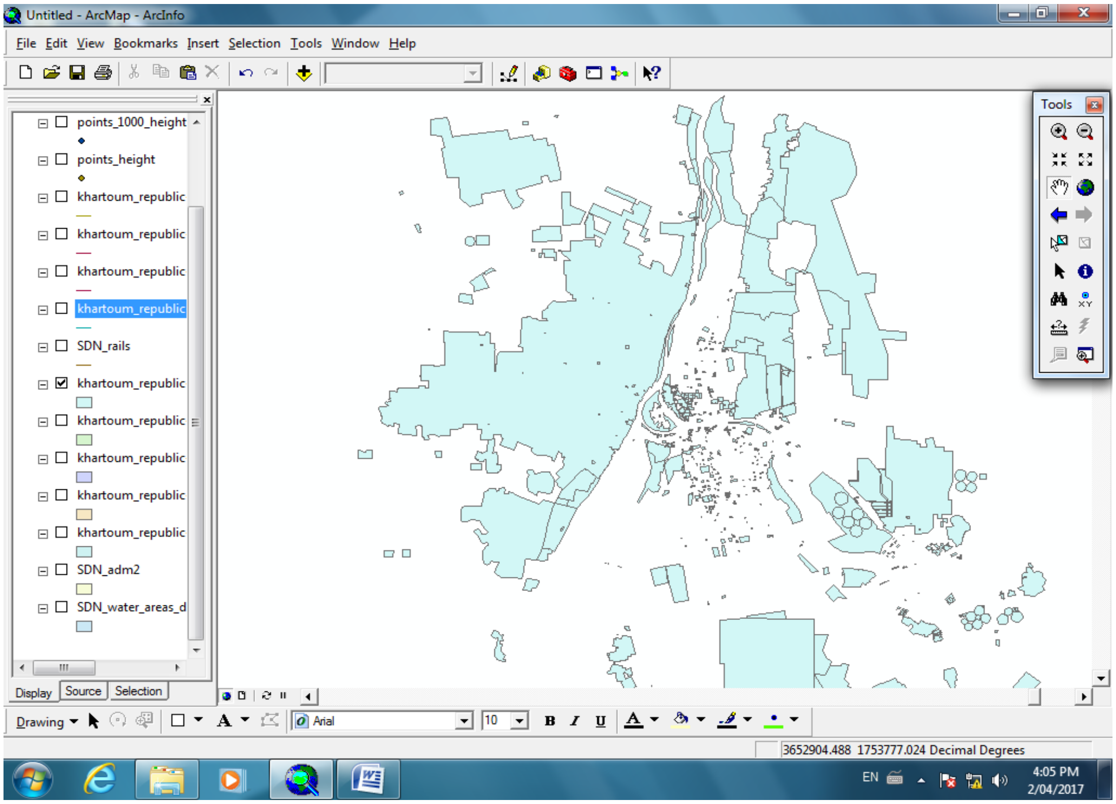
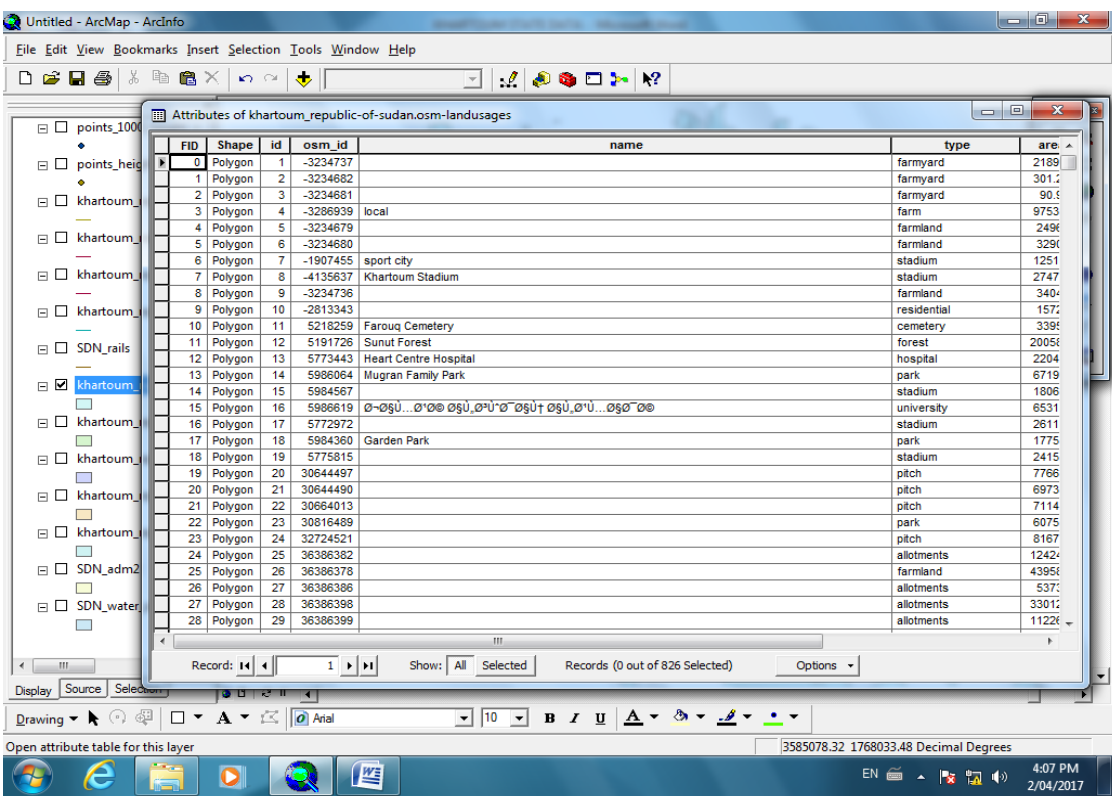


Figure 4.10 Land Usage



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1	Polygon	2	-3234682		farmyard	301.2
2	Polygon	3	-3234681		farmyard	90.9
3	Polygon	4	-3286939	local	farm	9753
4	Polygon	5	-3234679		farmland	2496
5	Polygon	6	-3234680		farmland	3290
6	Polygon	7	-1907455	sport city	stadium	1251
7	Polygon	8	-4135637	Khartoum Stadium	stadium	2747
8	Polygon	9	-3234736		farmland	3404
9	Polygon	10	-2813343		residential	1572
10	Polygon	11	5218259	Farouq Cemetery	cemetery	3395
11	Polygon	12	5191726	Sunut Forest	forest	20058
12	Polygon	13	5773443	Heart Centre Hospital	hospital	2204
13	Polygon	14	5986064	Mugran Family Park	park	6719
14	Polygon	15	5984567		stadium	1806
15	Polygon	16	5986619	Ø¬Ø§Ù…Ø¹Ø© Ø§Ù„Ø³Ù˜Ø¯Ø§Ù† Ø§Ù„Ø¹Ù…Ø§Ø¯Ø©	university	6531
16	Polygon	17	5772972		stadium	2611
17	Polygon	18	5984360	Garden Park	park	1775
18	Polygon	19	5775815		stadium	2415
19	Polygon	20	30644497		pitch	7766
20	Polygon	21	30644490		pitch	6973
21	Polygon	22	30664013		pitch	7114
22	Polygon	23	30816489		park	6075
23	Polygon	24	32724521		pitch	8167
24	Polygon	25	36386382		allotments	12424
25	Polygon	26	36386378		farmland	43958
26	Polygon	27	36386386		allotments	5373
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Figure 4.11 Land Usage Attribute Table

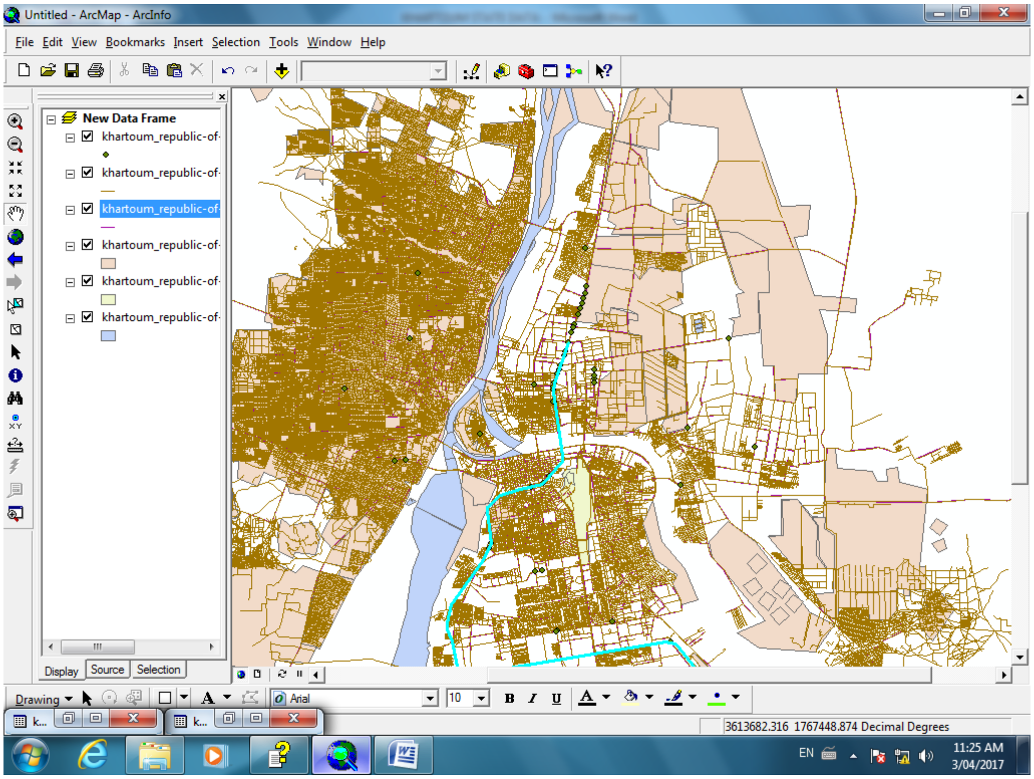

Figure 4.12 Current Railway Pathways

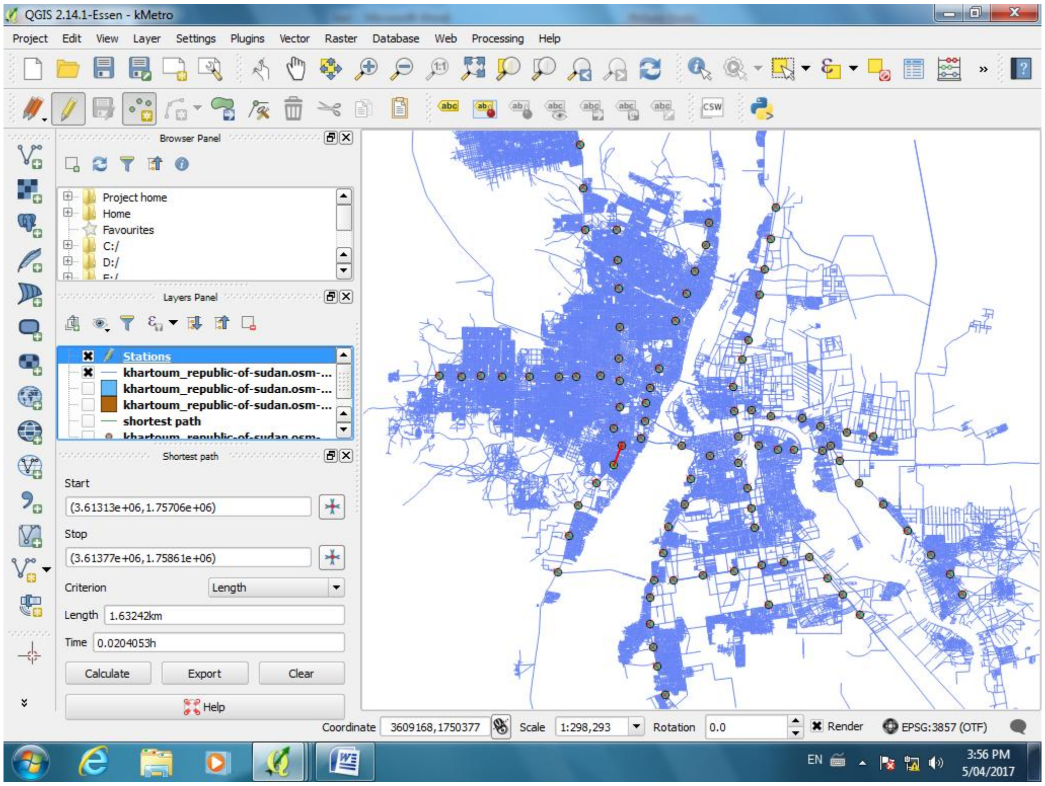

Figure 4.13 Metro Stations with Road Layers

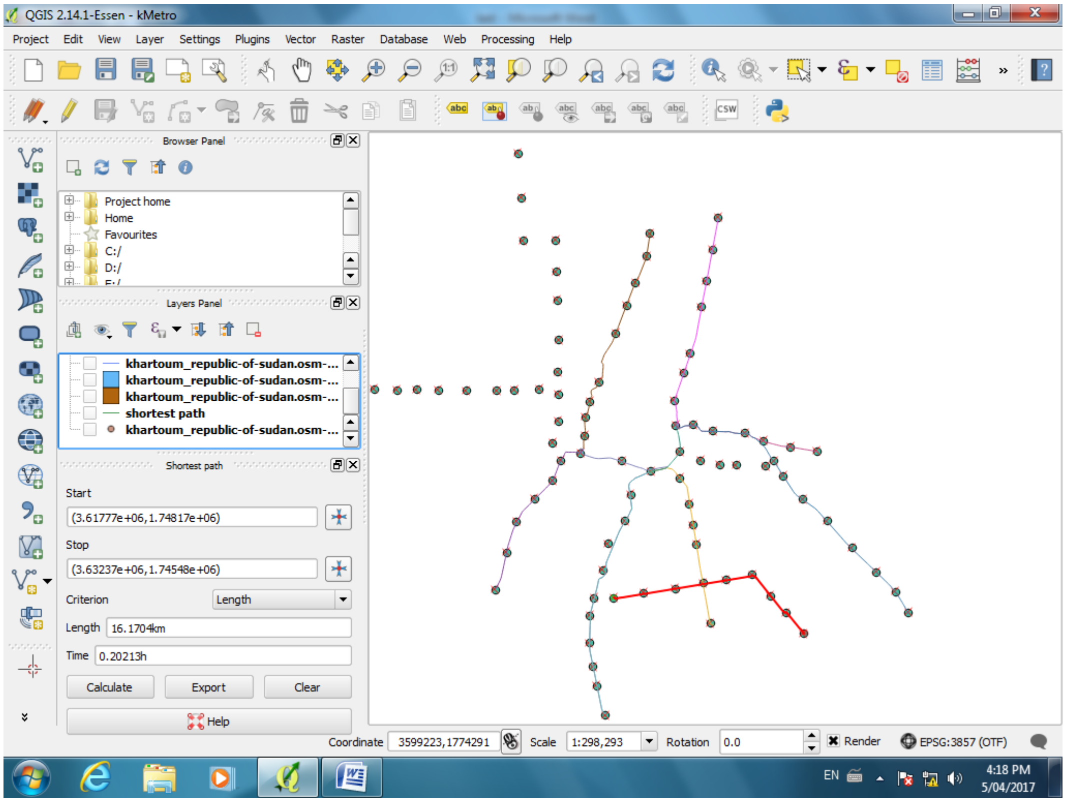

Figure 4.14 Metro Stations and Lines

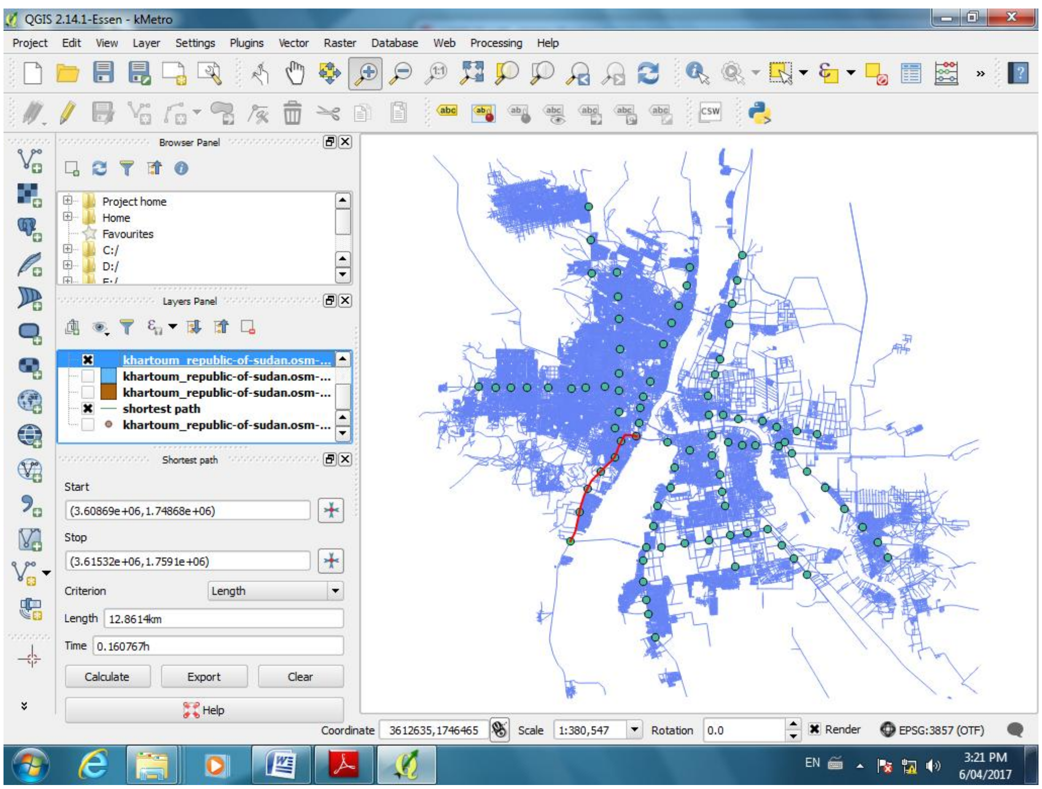

Figure 4.15 Abusaid Line

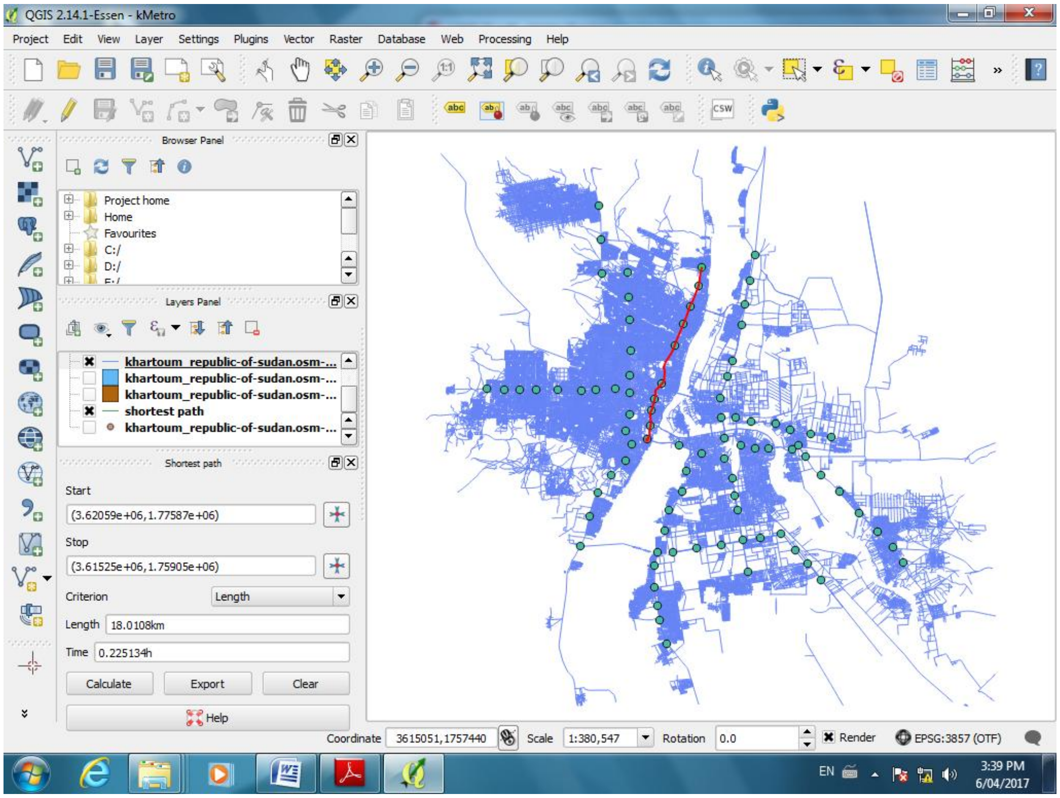

Figure 4.16 Karari Line

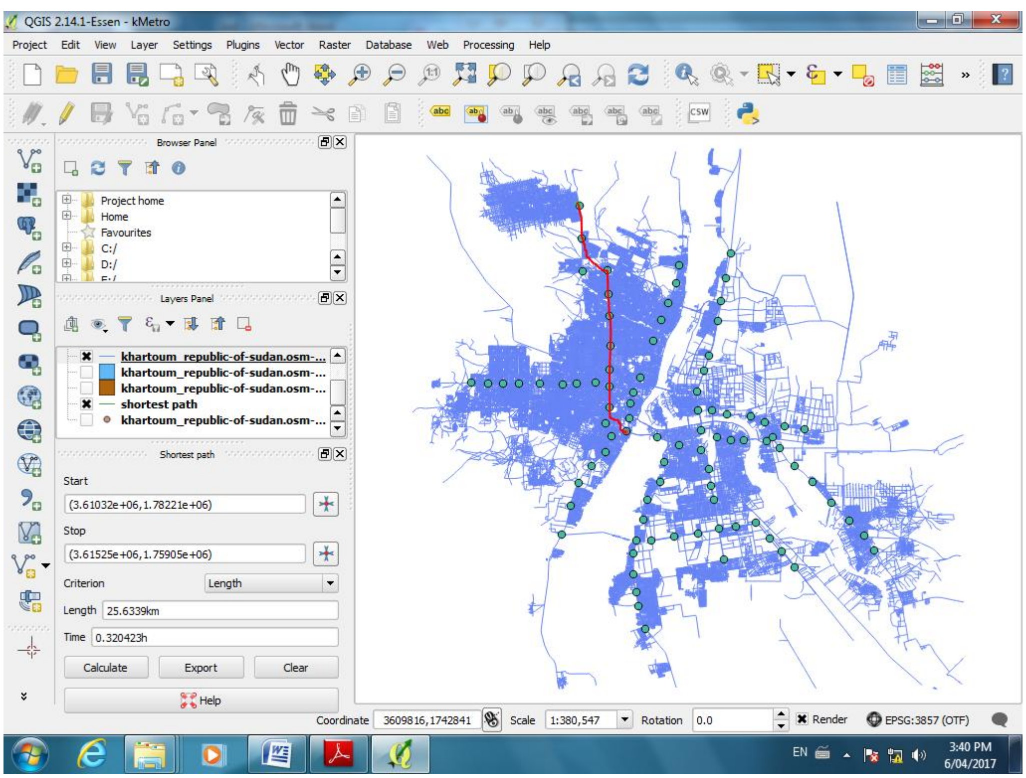

Figure 4.17 Garya Line

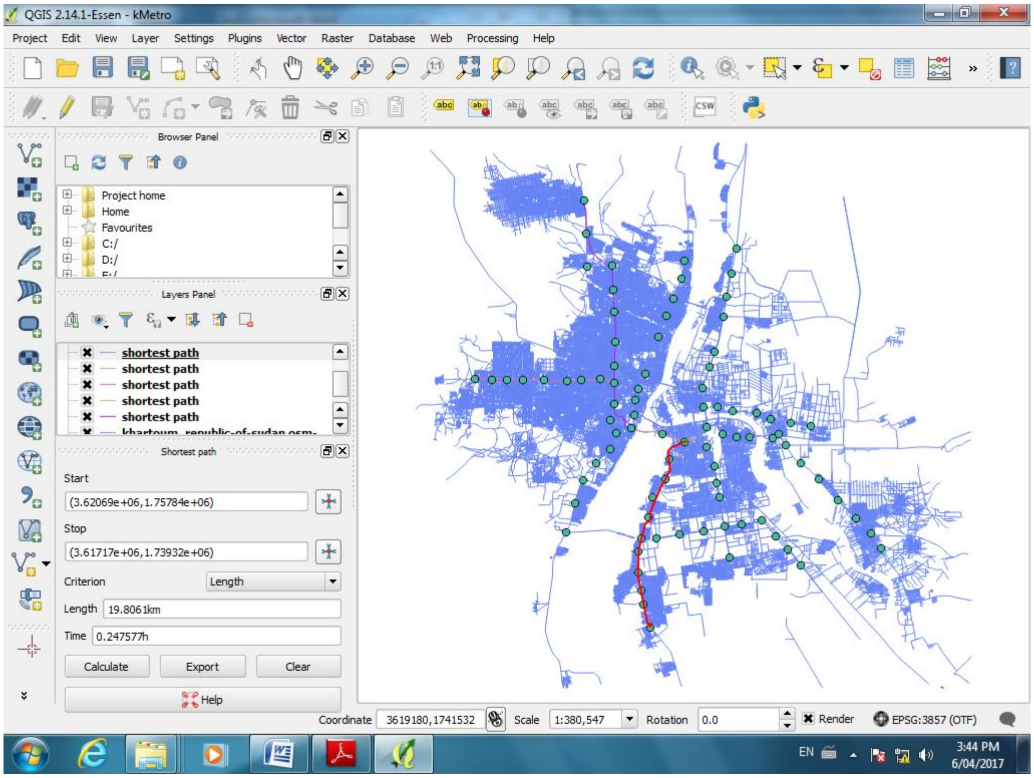

Figure 4.18 KalaklaLine

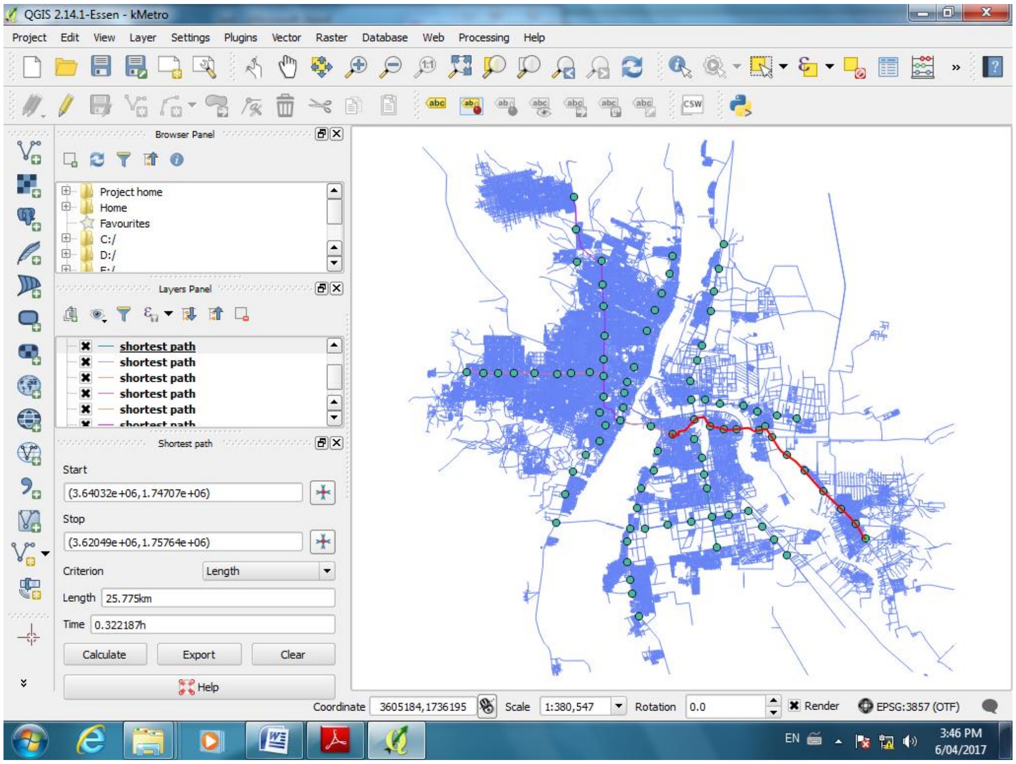

Figure 4.19 Soba Line

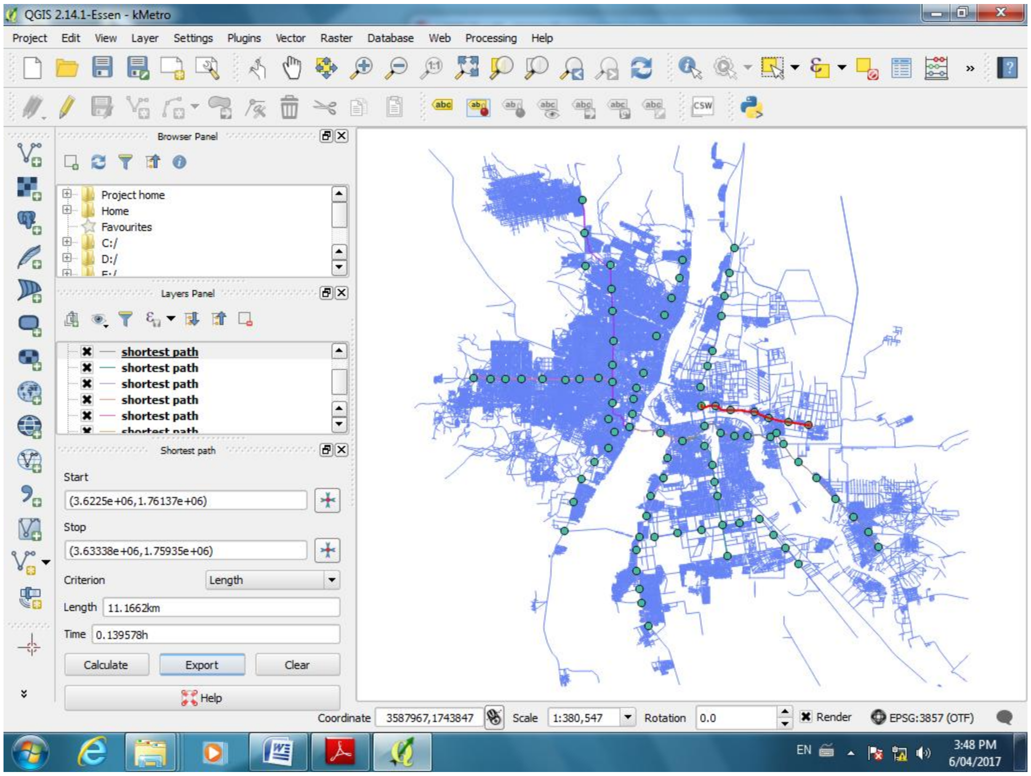

Figure 4.20 Haj Yousef Line

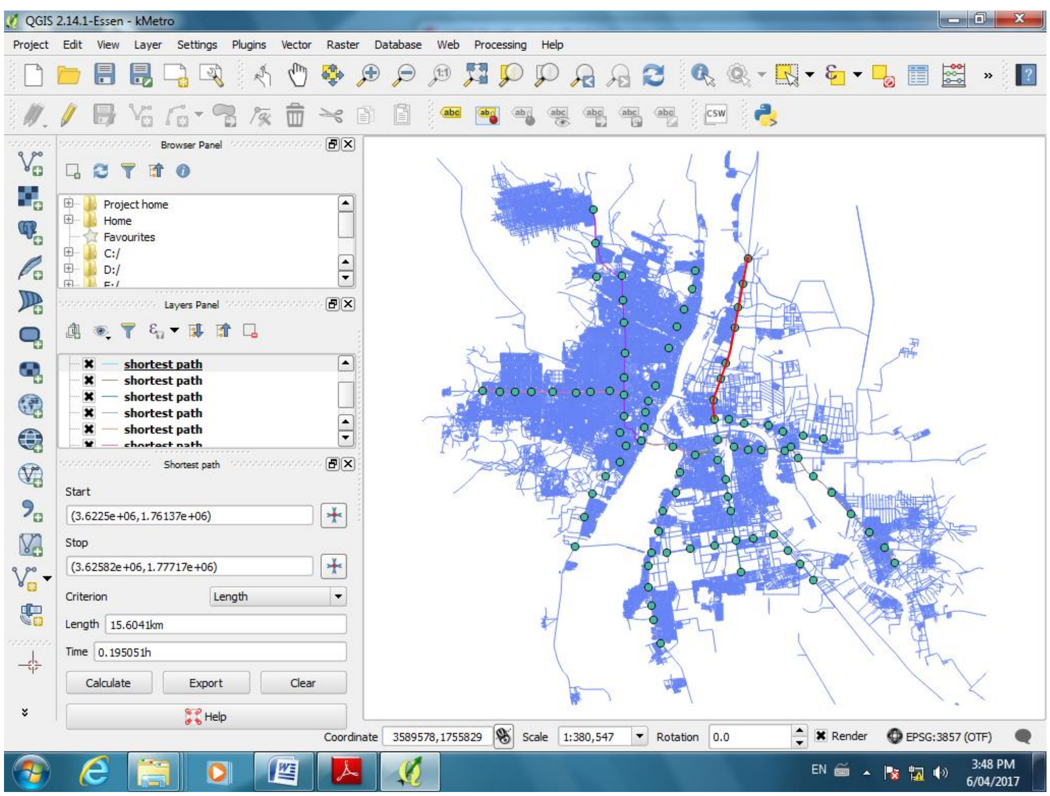

Figure 4.21 Bahri Line

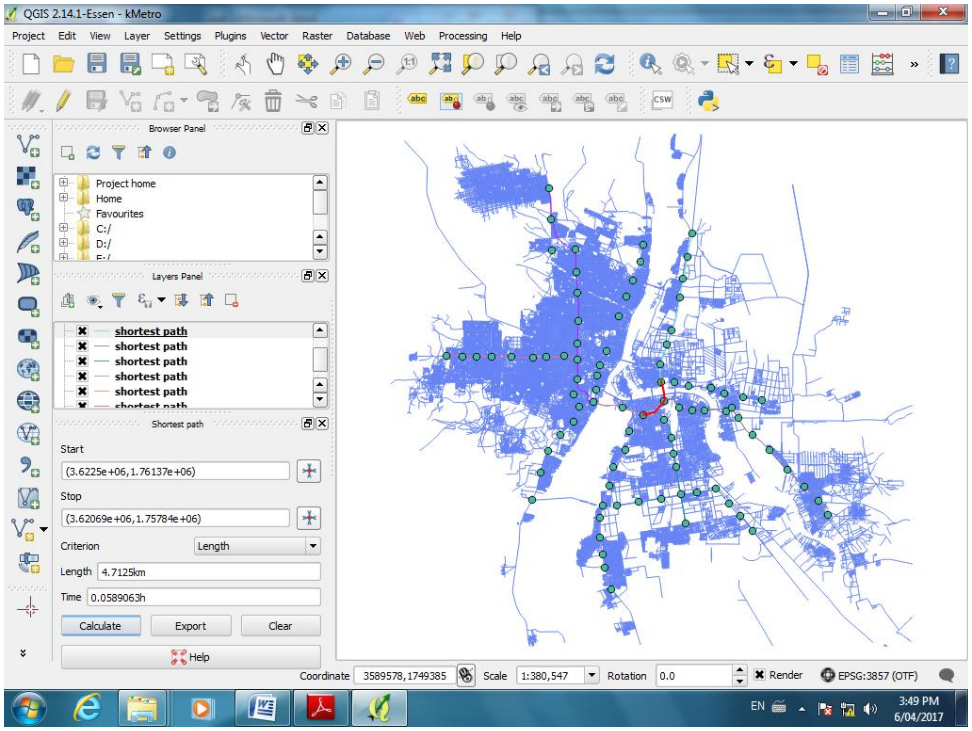

Figure 4.22Khartoum to Bahri Line

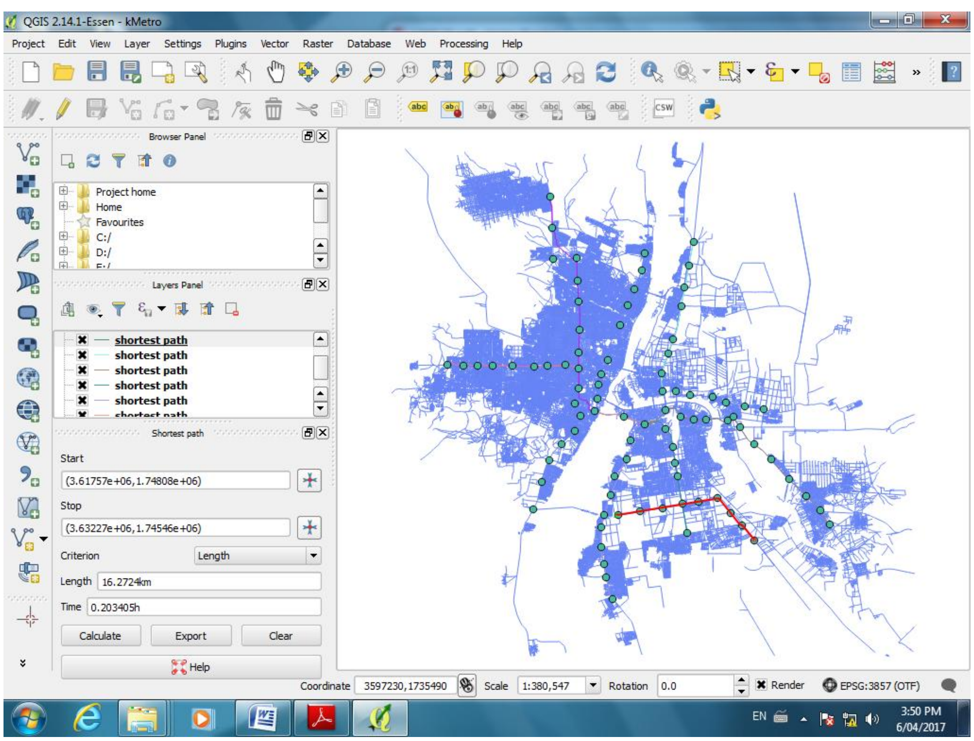

Figure 4.23 Soba West Line

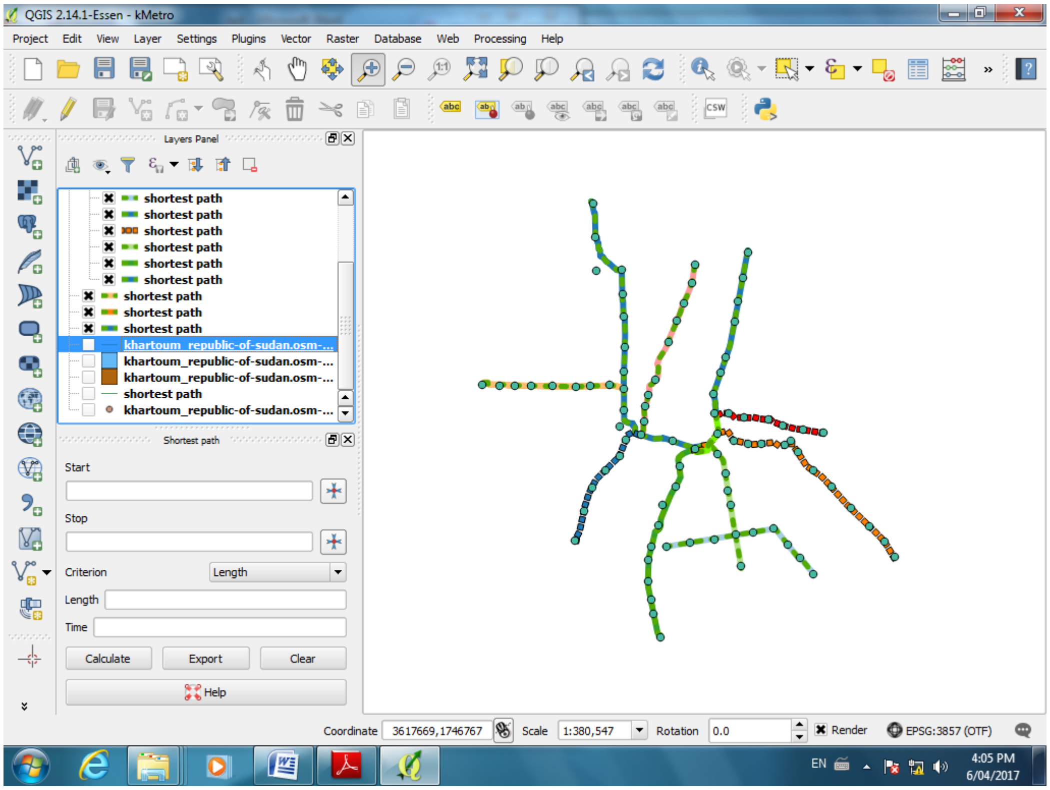

Figure 4.24 All Metro Lines

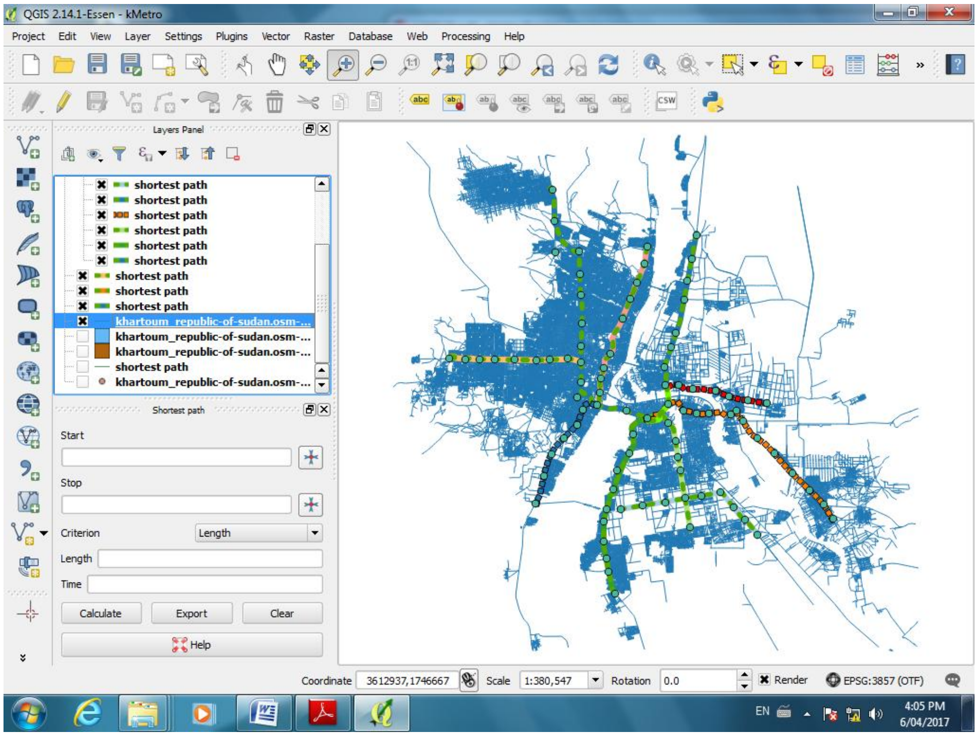

Figure 4.25 All Metro Lines overlayed with Roads

4 Chapter Five Experiments and Results

4.1 Algorithms Implemented

4.2 Results and Discussions

5.1 Algorithms Implemented

In this chapter, the network routing problems of this study are described: the travelling salesman problem, the vehicle routing problem and the shortest path problem.

5.1.1 The Traveling Salesman Problem

The simplest node routing problem is the travelling salesman problem (TSP). The TSP is a classical combinatorial optimization problem that is simple to state but very difficult to solve. The problem is to find the least cost tour through a set of nodes so that each node is visited exactly once. The tour starts and ends from a specific location, called depot. The problem is similar to many other problems in that it is easy to describe but difficult to actually find a solution in real world contexts. It is in a precise mathematical sense difficult, namely NP-complete (non-deterministic polynomial time complete), and cannot be solved exactly in polynomial time. Although there are many ways to formally state the TSP a convenient way in doing so is an integer linear programming formulation.

$$\sum_{i=0}^{n-1} d_{\pi(i),\pi((i+1)\bmod n)}$$

- Given n £ n distance matrix (d_{ij}) find *permutation* π of {0,1,2,..,n-1} minimizing
- The special case of d_{ij} being actual distances on a map is called the ***Euclidean*** TSP.

(Equation 5.1) [2]

2 https://en.wikipedia.org/wiki/Distance03 April 2017.12:43pm.

5.1.2 Shortest Path Problems

The section will be concluded by considering the shortest path (or least cost) problem (SPP) with time windows. This problem appears as a sub-problem in many time-constrained routing and scheduling problems and, thus, deserves some specific attention. The problem consists of finding the least cost route between any two specified nodes in a network, whose nodes can only be visited within a specified time interval.

Algorithms Solving the Problem

1. Dijkstra's algorithm
   Solves only the problems with nonnegative costs, i.e.,

$$C_{ij} \geq 0 \text{ for all } (i, j) \in E$$

(Equation 5.2) [3]

2. Bellman-Ford algorithm
   Applicable to problems with arbitrary costs.

3. Floyd-Warshall algorithm
   Applicable to problems with arbitrary costs
   Solves a more general all-to-all shortest path problem

Floyd-Warshall and Bellman-Ford algorithm solve the problems on graphs that do not have a cycle with negative cost.

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3 https://en.wikipedia.org/wiki/Dijkstra%27s_algorithm 03 April 2017, 01:22pm

5.2 Results and Discussions

4. The Khartoum state geo-database is created including the following layers

Table 5.1 Khartoum state geo database layers

No	Layer	Type	Content
1	Land use	polygon	Land use with types of it
2	Khartoum main street	Line	Street lines with types of it
3	Khartoum roads	line	Roads with types of it
4	Metro stations	Points	Metro station with types of it
5	Metro lines	lines	Metro lines

5. With the geo-database a number of thematic maps are produced, like shortest path between two points in Khartoum map, metro station services area and closest facility.

5.2.1 Station Location Analysis

Throughout the study over 86 station locations were identified for the station location analysis. Each station location was buffered by both, the 2Km distance and overlayed (clipped) to the land use and associated attributes layer.

5.2.2 Station Location By Route Analysis

The route analysis consists of identifying the station locations for each route and buffering the stations by both walking distances.

5.2.3 Stations and Paths

- Altogether we represent 86 stations (in Khartoum 31, as shown in table 5.2, in Bahri 23, as shown in table 5.3, and in Omdurman 32, as shown in table 5.4).
- 11 Routes (3 in Khartoum Part (Kalakla, West Soba, Aid Hussien), 3 in Bahri Part (Haj Yousef, Kadaro, East Soba), 4 in Omdurman Part(Umbada, Abusaid, Karari, Garya) and one to connect Khartoum Bahri and Omdurman)
- The minimum distance between stations is 1Km between 13 stations and street 105 in East Nile locality.
- The maximum distance between stations is 3km between Iskan 96 station and Garya in Karary locality.

Table 5.2 Khartoum Stations

Id	Name	Type	Description	Distance Km	Notes
100	Khartoum central Station	Main	Hospitals, commercial, educational, services, tourism	0	
101	Nafag	Cross	Educational, military	2.8	
102	Khartoum Airport	Pass	Airport , commercial	2.5	
103	Geraif	Pass	Commercial	1.6	
104	Afraa Mall	Pass	Tourism , commercial	1.6	
105	Future university	Pass	Educational , commercial	1.6	
106	Central Market	cross	Commercial	2.8	
107	Aid Hussien	Terminal	Residence, Commercial	3	
130	Naseer	Cross	Residence , Hospitals	2	Nafag
131	60s	Cross	Commercial ,Hospitals	1.5	
132	Manshya	Pass	Tourism	1.5	
133	Mogran	Pass	Tourism, Educational , commercial	3	KCST
140	Alamrya	Pass	Residence	2.4	Shijrah industrial
141	Jepra	Pass	Residence	2.3	
142	Kh Land port	Pass	Travel, Commercial	2.2	Central Market
143	Mojahdeen	Pass	Residence, Educational	1.8	Central Market
144	Sexteens	Pass	Commercial	2	
145	Golf	Pass	Sport, Tourism	2	
146	Khayrya	Pass	Residence	1.8	
147	Diplomatic city	Terminal	Residence, industrial	2.9	
151	Old industrial	Pass	industrial	2	KCST
152	Lamab	Pass	Residence	2.1	
153	Shijrah	Pass	Residence, Commercial	2	
154	Shijrah industrial	cross	industrial	2	
155	Azozab	Cross	Residence, Commercial	2.5	
156	Abu Adam	Pass	Residence	1.5	
157	Nopatia	Pass	Residence, Commercial, Hospitals	2	
158	Lafa	Pass	Residence, Commercial, Hospitals	1.8	
159	Kalakla Gardens	Pass	Tourism, Residence	1.7	
160	Fitih	Pass	Residence	2	
161	Um Haraz	Terminal	Residence	2	

Table 5.3 Bahri Stations

Id	Name	Type	Description	Distance Km	Notes
300	Bahri central Station	Main	Hospitals, commercial,Travel, services, tourism, military	0	
301	Moassassa	Cross	Commercial	1.84	
302	Siga	Pass	Commercial, Industrial	2.13	
303	Baraha	Pass	Educational , Hospital, Commercial	1.5	
304	Halfaya	Pass	Residence, Commercial	2	
305	Samrab	Pass	Residence, Commercial	1.5	
306	South daroshab	Pass	Residence, Commercial	2	
307	North Daroshab	Pass	Residence, Commercial	2.3	
351	Kadaro	Terminal	Residence, Commercial	2.35	
352	Koper	Cross	Residence, Commercial	1.5	Bahri
353	Kafori	Pass	Tourism, Educational , commercial	1.6	
354	HiIlat KOKO	Pass	Tourism, Educational , commercial	2.4	
355	Libya street	Cross	Residence, Commercial	1.5	
356	One street	Pass	Residence, Commercial	2	
371	Wehda	Terminal	Residence, Commercial	2	
372	13	Cross	Residence, Commercial	2	Manshya
373	105	Pass	Residence, Commercial	1	
374	Manshya East	Pass	Educational , commercial	2	
375	Hay Mustafa	Pass	Residence	2	
376	Kyryab	Pass	Residence	2	
377	Marabee	Pass	Residence	3	
378	Soba	Cross	Residence, Commercial	2	
379	Faith	Terminal	Residence	2	

Table 5.4 Omdurman Stations

Id	Name	Type	Description	Distance Km	Notes
200	Umdorman central Station	Main	Hospitals, tourism, military	0	
201	Banat	Pass	Residence, Commercial	1.8	
202	Gawazat	Pass	Residence, Commercial	1.3	
203	Doma	Pass	Educational , Residence, Commercial	2	
204	Tigana	Pass	Educational , Residence, Commercial	2	
205	Nile city	Pass	Residence, Commercial	1.7	
206	Thawra 20	Pass	Residence, Commercial	2	
207	Halfaya bridge	Cross	Residence, Commercial, military	1.9	
208	Idriss	Pass	Residence, Commercial	2	
209	Garafa	Terminal	Residence, Commercial	2	
250	Mansora	Pass	Tourism, Educational , commercial	2.8	**Omdurman CST**
251	Ahlya	Pass	Tourism, Educational , commercial	1.7	
252	Wad Elbashir	Cross	Residence, Commercial,travel	2	
253	Soug shabi	Pass	Residence, Commercial	1.7	
254	Alashra	Pass	Industrial, Commercial	1.9	**Manshya**
255	Halaybe	Pass	Residence, Commercial	1.8	
256	Sabreen	Pass	Residence, Commercial	1.7	
257	Iskan 73	Pass	Residence , commercial	2	
258	Iskan 102	Pass	Residence , commercial	3	
259	Iskan 96	Pass	Residence , commercial	3	
260	Garya 1	Terminal	Residence , commercial	3.4	
261	Bahar	Pass	Residence, Commercial	1.6	**Wad albashir**
262	Meraj	Pass	Residence , commercial	1.7	
263	Libya market	Pass	Residence , commercial	1.5	
264	Maslakh	Pass	Residence , commercial	1.5	
265	Iskan	Pass	Residence	1.9	
266	Salam 1	Pass	Residence	1.5	
267	Salam 2	Pass	Residence	2	
268	Salam 3	Terminal	Residence	1.5	
269	Sabri	Pass	Residence	1.9	
270	Old fitihab	Pass	Residence , commercial	1.6	
271	Omdurman unvercity	Pass	Educational , commercial	1.8	
272	Gamash	Pass	Residence	2.6	
273	Salha	Pass	Residence	2.4	
274	Dubaseen	Terminal	Residence	2.5	

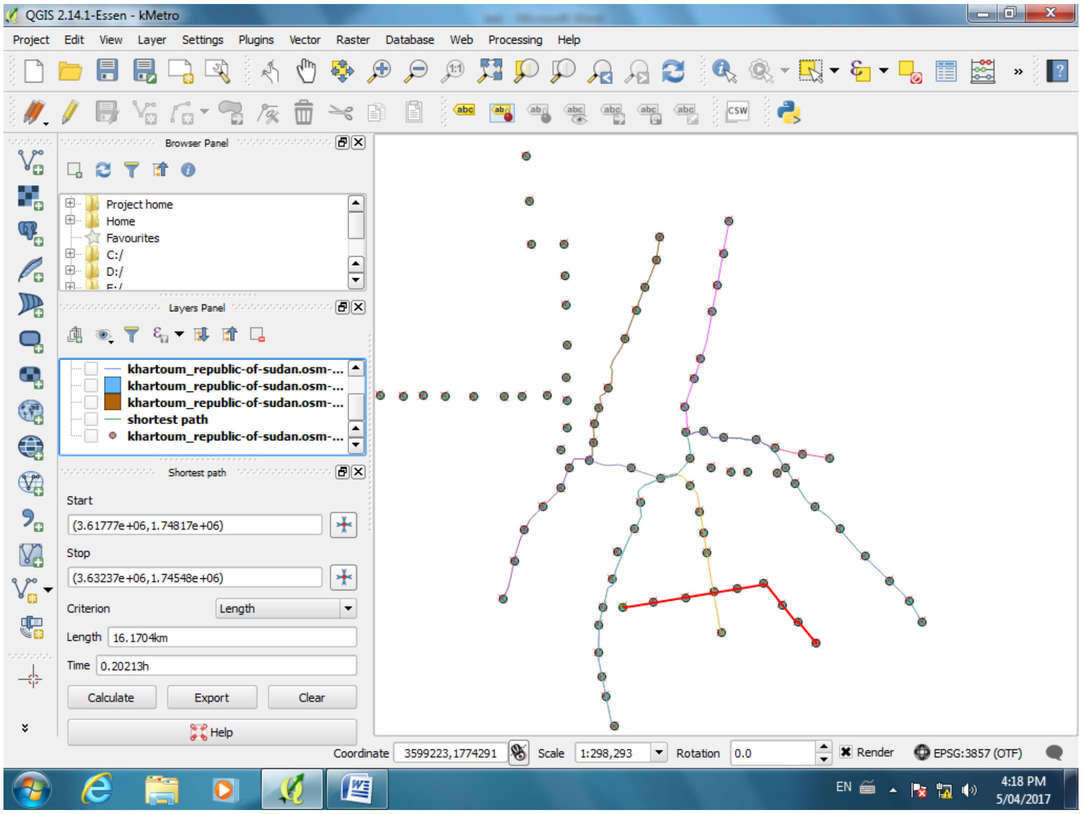

Figure 5.1 Metro Stations

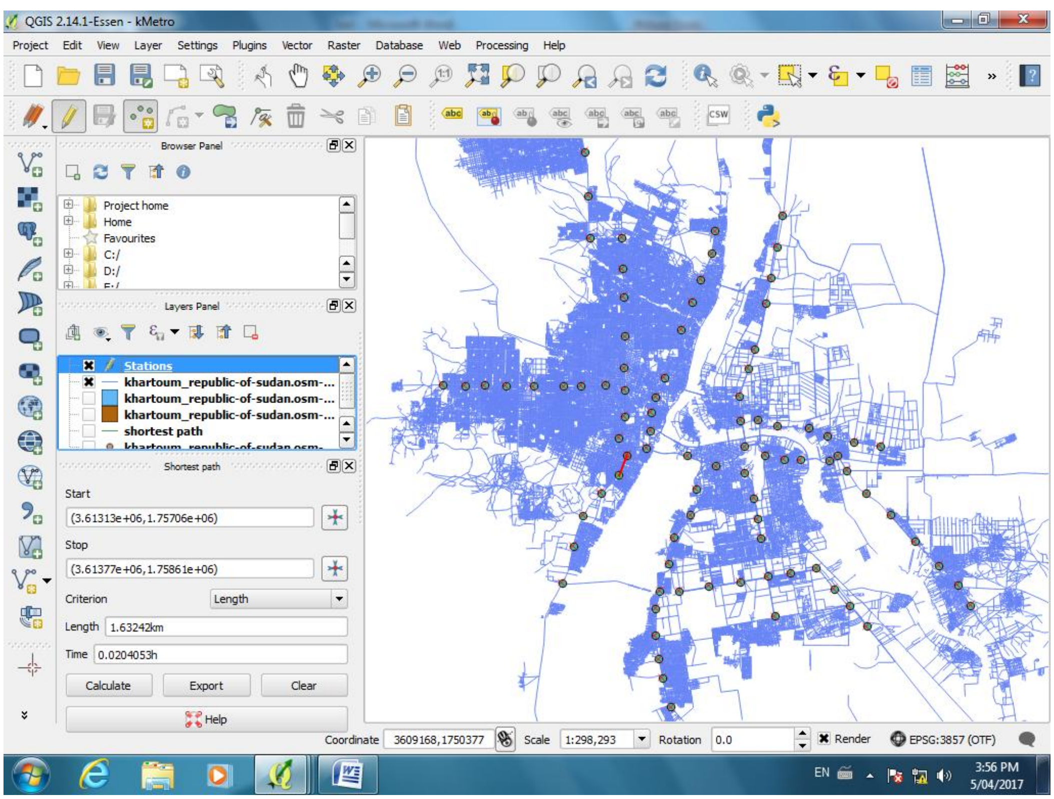

Figure 5.2 Metro Stations with Road Layers

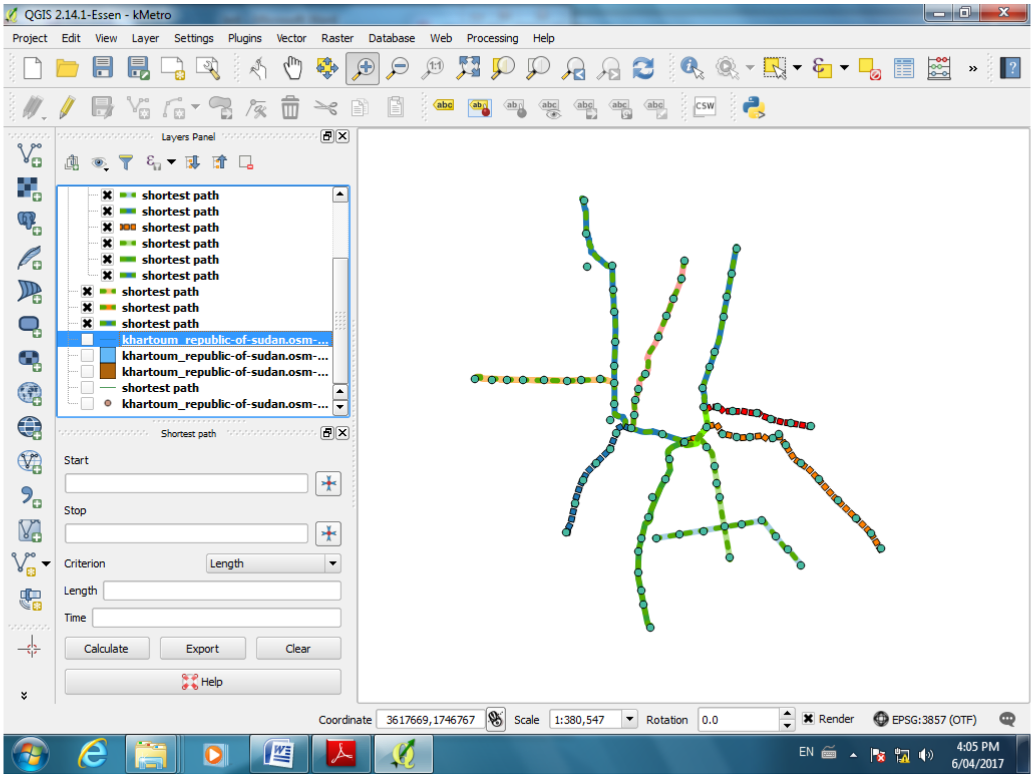

Figure 5.3 All Pathways

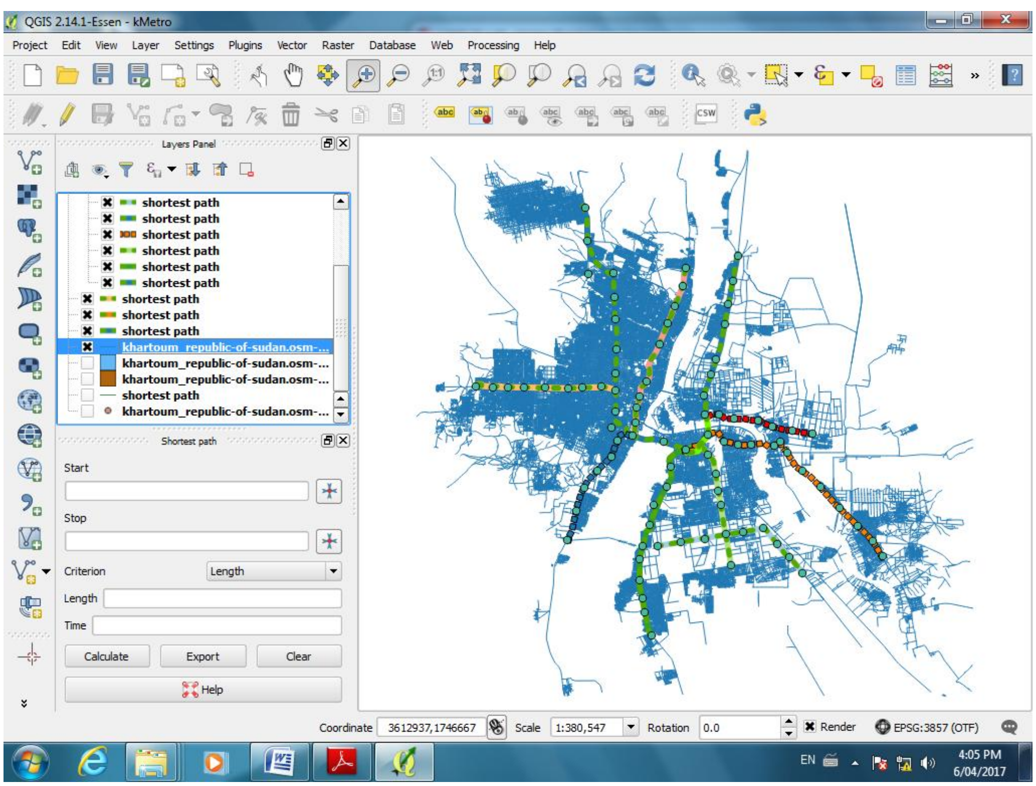

Figure 5.4 All Pathways with the Road Layer

5.2.4 Discussion of the Results

At the core of many procedures in GIS software are algorithms for solving network routing problems. The problems are mathematically complex and challenging, but using Network analysis in GIS software is very simple. In addition to that, by using GIS network analysis we will get the best path or low cost path. Moreover we can specify service areas and closest facilities. In the following we demonstrate few examples.

5.2.4.1 Shortest Path

One of the important function that GIS Network analyst can do, is finding the shortest path between the points. This study applied this function to specify the route of Khartoum Metro, as shown in fig. 5.5 below.

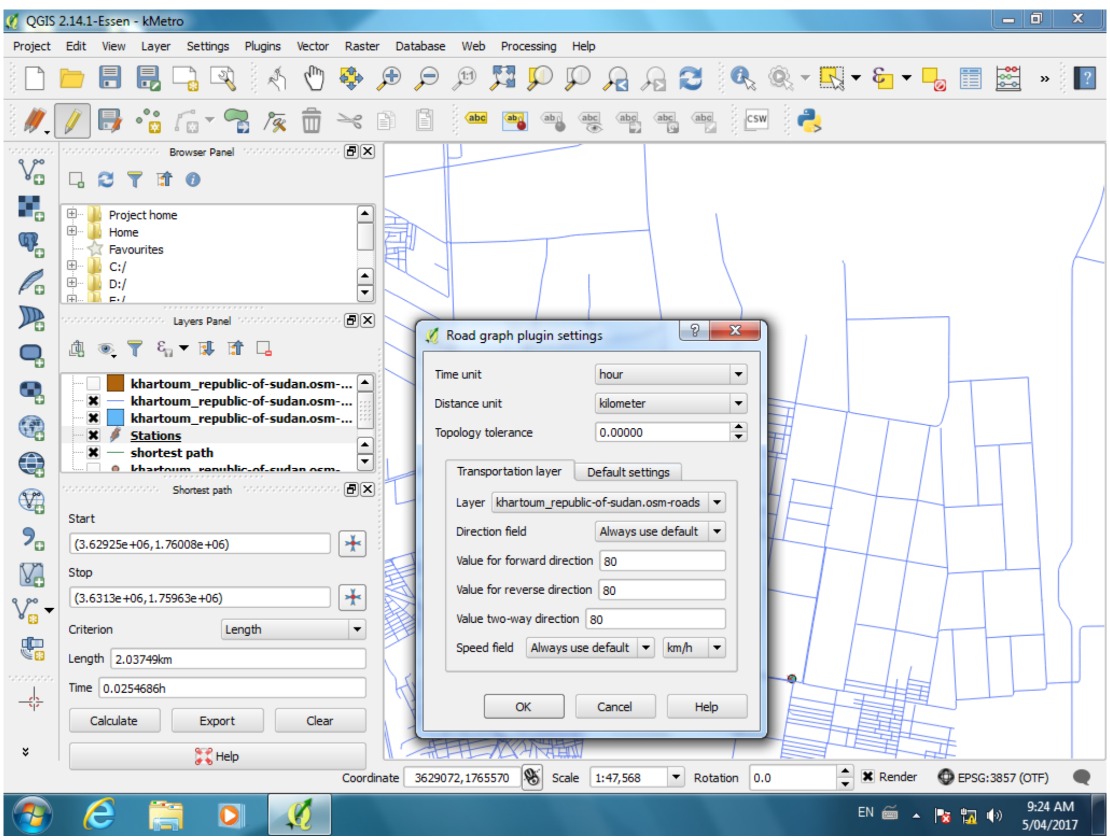

Figure 5.5 Road graph setting

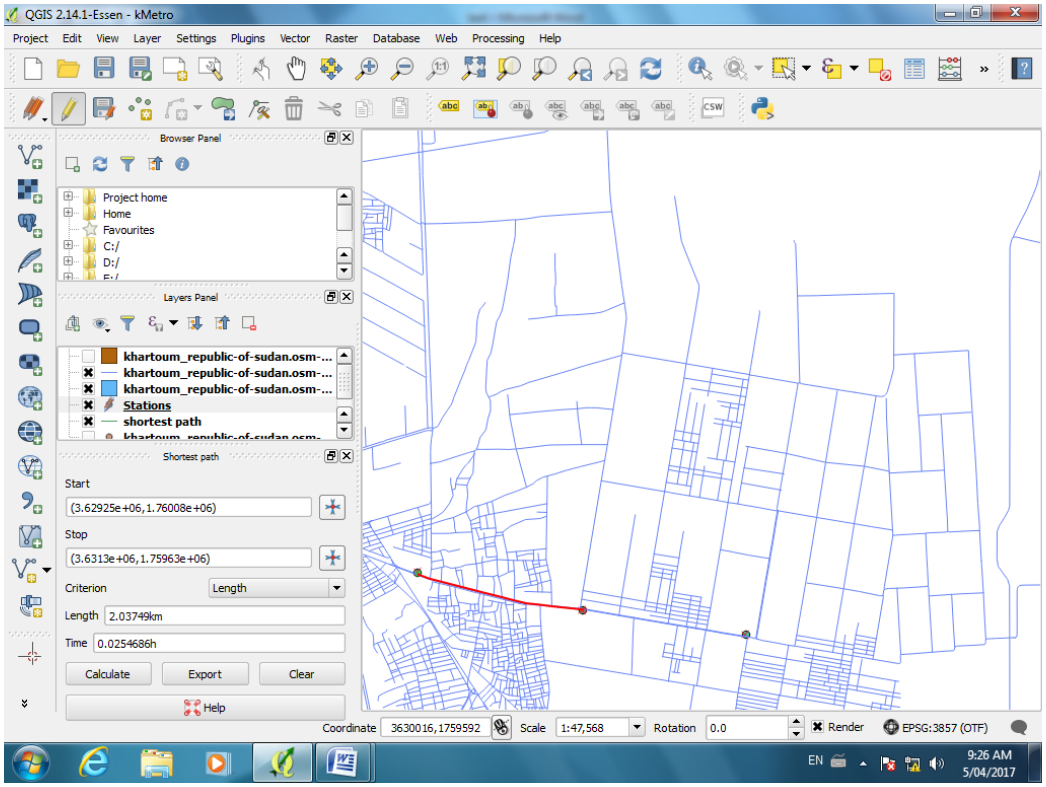

Figure 5.6 Shortest path in QGIS 2.14

5.2.4.2 Buffer Zone

Buffer zones are similar to the services area, but with a specific factor showing a zone with a circle around it, and without considering the roads network. In this study we use buffer zones for Metro stations in distances up to 2km, as shown in the fig. 5.7 and 5.8 below.

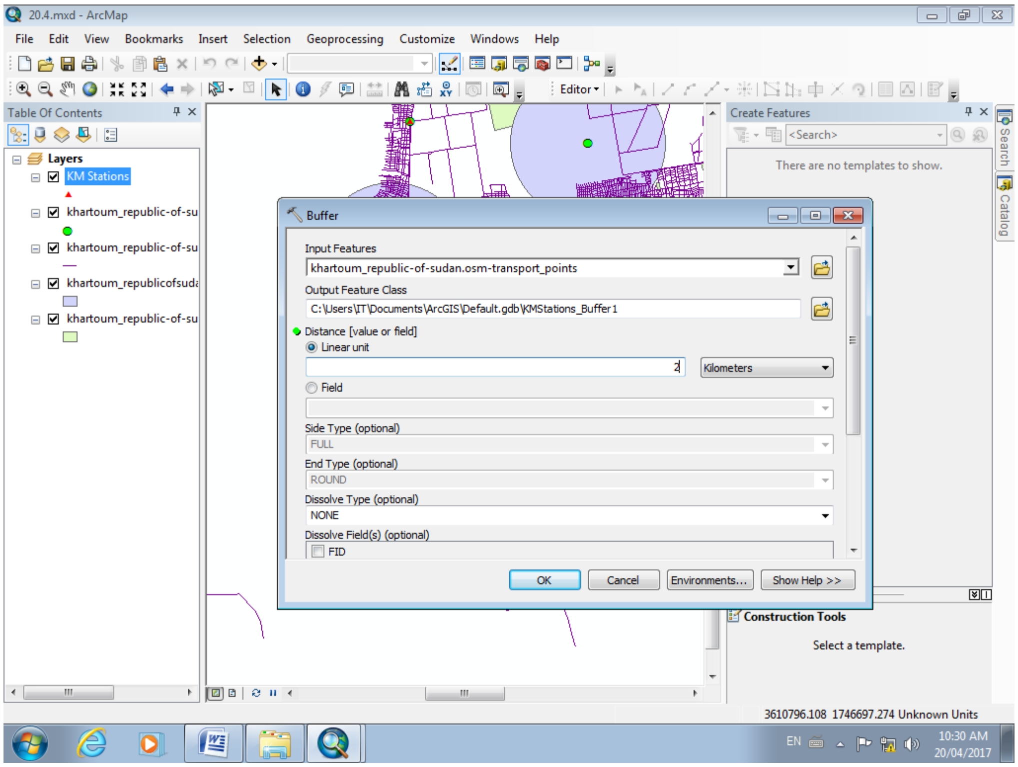

Figure 5.7Buffer zone factor (2Km)

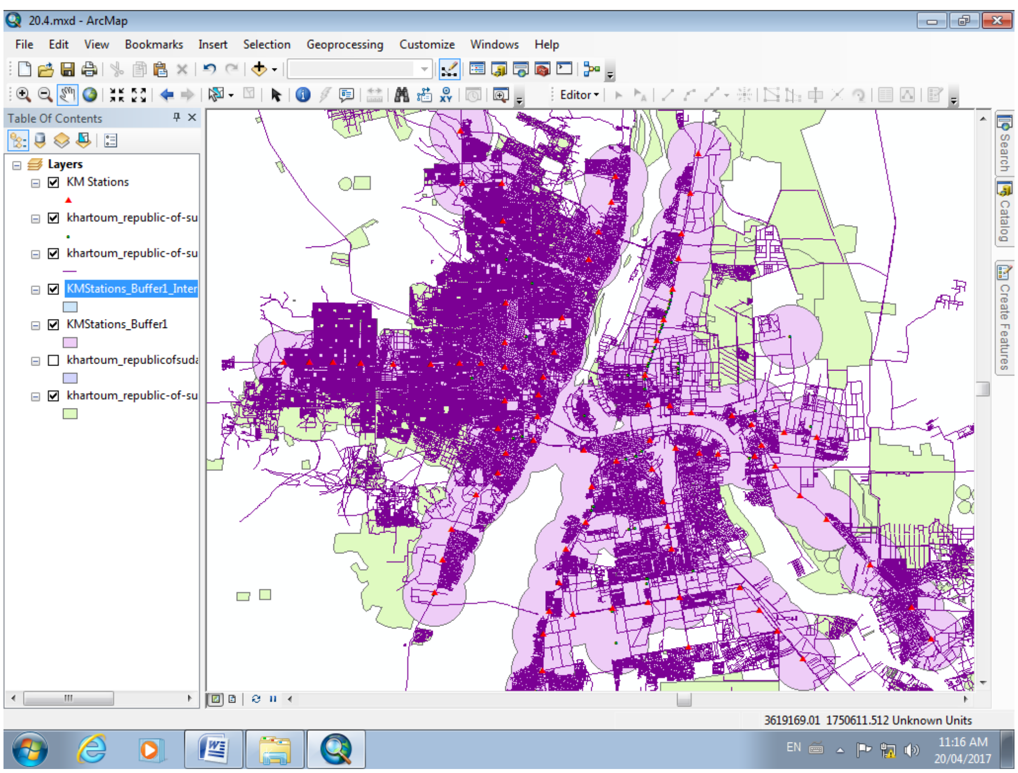

Figure 5.8Khartoum Metro Services area using a buffer zone of 2km

5.2.4.3 Service Area

By using a network analyst in GIS we can specify a serving area around any point in a network. Service areas are places that are located inside the boundaries of the area in a specific distance (1km, 5km.) or time (10 minutes, 4 hours...).

5.2.4.4 Accessibility

By using the GIS Network analyst we can classify the accessability for any services. This study used this function to classify the Khartoum Metro Service maps.

5.2.4.5 Closest facility

Finding the nearest station and specifying the shortest path for this station is providing by using the GIS Network analyst. This study used this function to determine the closest station for any point in Khartoum map.

6. Chapter Sex Conclusions and Recommundations

6.1 Conclusions

6.2 Recommendations

6.1 Conclusions

GIS have come to stay and there is no doubt that is a an efficient and effective tool in the Transportation Infrastructure Planning, it provides the tool for a planner in transportation field to convey ideas and present implications of planning decision.

In this study we deal with a map and all the processes using Arc GIS V10.2 and QGIS V2.14.1 software to get the final results and a geo-database for the study area (Khartoum state), which contains road network, the suggested Metro network schema with its stations and paths as well as producing a number of thematic maps like the metro services area, accessibility, closest facility and shortest path for Metro Stations.

We found that by using a geo-database in Khartoum State will support decision-making processes reducing the risks of taking the wrong decisions based on incomplete information.

6.1 Recommendations

1. By using geo database of khartoum Metro will support decision-making processes reducing the risks of taking the wrong decisions based on incomplete , database includes
    a. Roads ID, Name, Type, Tunnel, bridge, one way and class
    b. Land usage ID, Name, Type and area.
    c. Metro Stations ID, Name, Type and description
    d. Metro Lines ID, Name, Type and description
2. Using GIS application in all departments and agencies of Ministry infra structure and Transportation.

3. Also it is important for data to be available for researchers to solve and integrates the transport systems.
4. A study on modeling criteria in transportation network design can be done to evaluate adopted criteria via others. Different transportation zoning methods can be tested to find the best for each type of problems.
5. Using scientific techniques to analyze road network jointly with professionals in the fields of computer software development. This will reduce the laborious steps involved in graph theoretic analysis.

7 Chapter Seven References and Resources

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