Sudan University of Sciences and Technology

Collage of Post Graduate Studies

SELECTION OF OPTIMAL PIPELINE ROUTE USING GEOGRRAPHIC INFORMATION SYSTEMS

Study Area -South Kordofan

إختيار أفضل مسار لخط أنابيب بإستخدام نظم المعلومات الجغرافية

منطقة الدراسة - جنوب كردفان

A Thesis Submitted for the partial Fulfillment Degree of Master of Science in Geodesy and GIS

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الآيـــــــــة

(يَا أَيُّهَا الَّذِينَ آَمَنُوا إِذَا قِيلَ لَكُمْ تَفَسَّحُوا فِي الْمَجَالِسِ فَافْسَحُوا يَفْسَحِ اللَّهُ لَكُمْ وَإِذَا قِيلَ انْشُزُوا فَانْشُزُوا يَرْفَعِ اللَّهُ الَّذِينَ آَمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ)

صدق الله العظيم

سورة المجادلة الآية (11)

Dedication

I dedicate this project to God Almighty creator, my strong pillar my source of inspiration, wisdom, knowledge and understanding, and I dedicate to my parents, my family and my friends.

Abstract

The process of selecting pipeline route is very complicated, selection of the optimal path is based on a verity of considerations (environmental and technical considerations) such as topography, geology, land use, population distribution and soil of the study area. The study area of this research is the South Kordofan. The least cost path was used to select the optimal path from the oilfield using Geographic Information System (GIS) technique.

The adopted technique, i.e. building a model, successfully resulted in the least cost route for constructing the required pipeline from the oilfield (coordinates29° 19′27" E 10°36′23" N) to the destination (coordinates 29°59′43.8"E 12°42′15.4" N) which is 251 km long.

This method is very useful for the performance such a task of route selection and it is recommended for implementation in other areas in Sudan where the optimal route selection is required.

التجريدة

أختيار مسار خط الأنابيب عملية معقدة جدا حيث ان اختيار افضل مسار يعتمد علي عدة معايير (معايير هندسية و بيئية) مثل طبوغرافيا و جيولوجيا و جيومورفلوجيا و إستخدامات الارض و التوزيع السكاني و نوع التربة لمنطقة الدراسة ، منطقة الدراسة هي جنوب كردفان تم استخدام المسار الاقل تكلفة لتحديد افضل مسار من حقل البترول ، بواسطة تقنية نظم المعلومات الجغرافية.

التقنية المبتعة، أي بناء نموزج، انتجت بنجاح المسار الاقل تكلفة لتشييد خط الانابيب المطلوب من حقل البترول (الإحدتثيات "29°19′27 شرق "10°36′23 شمال)الي نقطة المنتهى(الإحداثيات "29°59′43.8 شرق "12°42′15.4 شمال) بطول 251 كلم.

إن هذه الطريقة مفيدة للغاية لأداء مثل هذه المهمة الخاصة بإختيار مسار و يوصى بتطبيقها في مناطق أخرى في السودان حيثما يكون مطلوبا إختيار المسار الأمثل.

Acknowledgement

I would like to express my appreciation to my supervisor Dr. Mohammed Elamein Ahmed who has willingly answered my queries , assisted me in a several ways while writing the thesis and helpfully commented on earlier drafts of this thesis, also I am very grateful to my friends and family for support me.

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Abbreviations

AHP Analytical Hierarchy Process

ASTER Advanced Space borne Thermal Emission and Reflection Radiometer

DEM Digital Elevation Model

GIS Geographic Information System

IDW Inverse Distance Weighted

LES Linear Engineering Structures

MCDA Multi-Criteria Decision

SRTM Shuttle Radar Topography Mission

Chapter One

Introduction

1.1. Background

Linear Engineering Structures (LES) such as roads, natural gas-oil pipelines, irrigation-drying channels, power lines and railways cover larger areas than other technical infrastructure facilities. The operations to choose optimum route depends on the effective collection, processing, storing and analysis of spatial data such as topography, vegetation, geology, soil type, land use, and landslide areas. This situation requires the use of Geographical Information Systems (GIS) which enables effective data management.

In LES information management, spatial data of large study areas are especially collected via Remote Sensing (RS) easily. In this context, using raster network analysis has some advantages for route selection operations with the assistance of these data.

In literature, it is seen that, route selection operations of LES are determined optimally with the minimum cost. But, in some developing countries, route selections of linear engineering structures are determined via classical methods on medium scale topographic maps and only slope data is taken into consideration. In this route selection operation, because of spatial data of land use is not used in many points route is changed this causes an increase in the cost. Consequently, in these situations it is necessary that GIS based dynamic models have to be designed for LES information management.

GIS based route determination processes using raster or vector data models are named as network analysis. Traditionally, network analysis, path finding and route planning have been densely used in graph theory and vector GIS, in which there are many algorithms of this application.

Raster applications are more likely to be based on movement across a surface than movement along a network, since the general idea of finding the least cost path is linked to movement from cell to cell, and not along a finite line.

Many researchers have already sought to improve the shortcomings of the raster approach and have developed various solutions and proposals.

The conventional route planning has solely been based on topographical considerations, gradient and curvature in developing countries. Usual practice involves manually marking segments of permissible gradients for route alignment on large-scale topographical maps. Such an approach is cumbersome and tedious, and it may not be feasible when variety of factors such as landslides, geology, soil type, vegetation, landuse, and land cover are considered (Saha et al. 2005) .

1.2. Problem Statement

Different concerns of stakeholders in pipeline projects, land use/cover, soil type, slope and gradients, and socio economic considerations Cause conflicts in the decision making in planning path .

GIS is based on Multi-criteria analysis to reduce the complexity in decision making in the planning process and achieve the accuracy requirements of the different stakeholders.

1.3. Objectives of the study

1.3.1. General objective

The general objective of this study to select optimal path of pipeline route using GIS multi-criteria analysis.

1.3.2 Specific objectives

1- To apply multi-criteria Decision Analysis technology to help decision makers to select the optimal path .

2- To apply GIS technology in path of pipeline planning to achieve the satisfaction of the concerns of the different stakeholders.

1.4 Previous studies

Americo Gamarra (2014) was used GIS suitability modeling to support a pipeline route selection. The purpose of the study was to select the optimal route of pipeline in the amazon region. The pipeline was built to transport product to the coast facilities throughout the Andes mountains ,in this study use the GIS technologies to support the engineering to identify the best route for a future pipeline in the south of Peru , which start in a known location in the Amazon forest and would arrive at another known location on the coast ,the data required to select the best route of pipeline in this study its depends on the engineering and environmental constraints , the result of this study is calculate the least cost path by using the cost distance surface.

Determination Of The Most Suitable Oil Pipeline Route Using GIS Least Cost Path Analysis , by Shahin Huseynli (2015) Case Study is Keystone XL, Nebraska State – USA The Keystone XL(is export Limited)has a big role for transforming Canadian oil to the USA. The function of the pipeline is decreasing the dependency of the American oil industry on other countries and it will help to limit external debt. The proposed pipeline seeks the most suitable route which cannot damage agricultural and natural water recourses such as the Ogallala Aquifer, using the Geographic Information System (GIS) techniques, the suggested path in this study got extremely high correct results that will help in the future to use the least cost analysis for similar studies. The route analysis contains different weighted overlay surfaces, each, was influenced by various criteria (slope, geology, population and land use). The resulted least cost path routes for each weighted overlay surface were compared with the original proposed pipeline and each displayed surface was more effective than the proposed Keystone XL pipeline.

Using GIS Spatial analysis for selecting the least route between Khartoum and kassala , by M. Ahmed (2017)The operation of highway road planning tack into account many technical and environment consideration such as topography, geology, geomorphology, land use, population distribution .These different considerations and interest make the planning process complex and as such there might be confusion of interest in the decision making .This study conducted to develop a least-cost path to link Khartoum and kassala town in Sudan country by using Geographic Information System (GIS) and multi-criteria tools The final path resulted start from Khartoum north and end in kassala passing through new_halfa The length of path from Khartoum to new_halfa 325 Km and 88 Km from new_halfa to kassala while direct straight distance are 320 Km and 85 Km respectively which means that this path resulted is closer to being the shortest possible distance .

1.5. Thesis Layout

This thesis was structured into five chapters. Chapter one introduces the main topic of the study and presents the objectives and problem statement of the study.

Chapter two discusses the definition of GIS and Multi-criteria Decision analysis and The Analytical Hierarchy Process (which were used to select the optimal path) and the definition of least cost path. This chapter also contains the environmental and engineering considerations to select the best route.

Chapter three introduces the study area and the data used to determine the optimal path based on the criteria, and also contains the methodology and the software used.

Chapter four contains the results and final results and discussion.

Chapter five discusses the conclusion of the study and future recommendations.

Chapter Two

Literature Review

2.1. Definition of GIS

A geographic information system (GIS) is a system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to the earth. In the strictest sense, it is a computer system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically-referenced information In a more generic sense, GIS is a tool that allows users to create interactive queries, analyze and edit data maps, and present the results of all these operations.

With a geographic information system (GIS), you can link information (attributes) to location data, such as people to addresses, buildings to parcels or streets within a network. You can then overlay those information layers to give you a better understanding of how they all work together. You choose what layers to combine based on what questions you need to answer.

2.2. Multi-criteria Decision Analysis

In planning a suitable path for a pipeline planners take into account these different considerations and interest which make the planning process complex and as such there might be conflicts of interest in the decision making.

Example of different considerations and factors are slope of the study area, land-use and soil types, community or national landmarks and governmental interest.

The use of GIS and **Multi-criteria Decision Analysis** has helped planners to achieve desired and more accurate results and as such has reduced the complex nature of the planning process and thus enabled different stakeholders to reach a general conclusion.

The application of geographic information system (GIS) and **Multi-Criteria Decision Analysis (MCDA)** as a decision making tool for complex planning in different sectors has superseded the traditional method of planning.

Multi-criteria Decision Analysis (MCDA) 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.

The main role of the MCDA technique is to deal (with difficulties that human decision makers have encounter when handling large amounts of complex information) in a consistent way.

MCDA can be used to identify a single most preferred options, to rank option, to short-list a limited number of options for subsequent detailed appraisal or simply to distinguish acceptable from unacceptable possibilities.

A key feature of MCDA is its emphasis on the judgment of the decision making team in establishing objectives and criteria, establishing relative importance weights and to some extent in judging the contribution of each option performance criterion. An MCDA foundation in principle is the decision maker's own choice of objectives, criteria, weights and assessments of achieving the objectives (Malczewki , 1999).

2.3 The Analytical Hierarchy Process (AHP)

AHP was developed in the late 1970s. Today it is the most widely used MCDA method. AHP generates all criteria weighting and alternative preference within each criteria group by eliciting these values from the decision maker through a series of pair wise comparisons, as opposed to utilizing numerical values directly.

Thus, a complex decision is reduced to a series of simpler ones, between pairs of alternative values within criteria or between pairs of criteria. The decision maker's preference is always explicit. However, the decision maker may be asked to make very many small decisions. Hence, it becomes important to generate an optimized hierarchy of criteria and alternatives, to reduce the number of pair wise decisions.

2.3.1. Steps of Analytical Hierarchy Process (AHP)

The general steps of Analytical Hierarchy Process are the following:

Step 1: Construct the problem hierarchy Model, usually visually, and identify the problem while identifying the relationships between criteria and alternatives.

Step 2: Pairwise comparison of criteria Undertake pairwise comparison between criteria, identifying decision maker preference for criteria on which alternatives are evaluated.

Step 3: Pair wise comparison of alternatives within each criterion Undertake pairwise comparison between alternatives based on their performance within each criterion.

Step 4: Compute the vector of criteria weights from a matrix of pairwise comparison results AHP utilises a variety of matrix transformations to calculate criteria weight vectors representing normalized criteria weightings.

Step 5: Compute the matrix of alternative scores from the results of the pairwise comparisons on alternatives within each criterion nxm (where n is the number of criteria and m is the number of alternatives) matrix is constructed representing the normalized performance (score) of each alternative for each criteria.

Step 6: Rank the alternatives utilizing the vectors of criteria weights and the matrix of alternative scores cores a global score and hence ranking for each alternative is calculated using:

$$G_a = \sum_{c=0}^{n} W_c \times S_{a,c} \qquad (1)$$

Where:

'a' is the alternative, 'c' is the criteria, 'G' is the global score of the alternative, 'W' is the criteria weight and 'S' is the alternative score.

A function of the ranking equation, aggregating across each criteria, means that trade-offs between criteria is fundamental to the final ranking. (Saaty, T.L ,1980).

2.3.2 Problem Hierarchy

The problem hierarchy provides a structured, usually visual, means of modeling the decision being processed. As the first step in the analytical hierarchy process the creation of a hierarchy that models the decision problem enables decision makers to increase their understanding of the problem, its context and, in the case of group decision making, see alternative approaches to the problem across different stakeholders.

The AHP problem hierarchy consists of a goal (the decision), a number of alternatives for reaching that goal, and a number of criteria on which the alternatives can be judged that relate to the goal.

2.3.3 Pair wise Comparisons in AHP

Within AHP pair wise comparison is the process of comparing entities in pairs so as to judge which is preferred and by how much. Comparisons are undertaken to determine criteria weighting and also assess the value or score of different alternatives within each criteria. Calibration are in accordance with the scale follows:

1 when it is showing no preference

3 when it is showing moderate preference

5 when it is showing strong preference

7 when it is showing very strong preference

9 when it is showing extreme preference.

Less preferable entity within the pair scores the inverse, for example the less preferable entity where the more preferable entity shows very strong preference would score 1/7.

Groups of pair wise comparisons are undertaken between every alternative value within a single criteria, and every criteria within the goal. For each group a matrix is completed with the results of the pairwise comparison, such as that shown the table (2.1).

Table 2.1 Matrix of Pairwise Comparison

	Criteria A_1	Criteria A_2	Criteria A_3	Criteria A_4
Criteria A_1	1	5	3	7
Criteria A_2	1/5	1	1/3	3
Criteria A_3	1/3	3	1	7
Criteria A_4	1/7	1/3	1/7	1

The results of the matrix would provide the normalized criteria weights for criteria A1 to A4. Similar matrices would be completed for criteria B1 to B4, for C1 to C4 and also one comparing criteria A, B and C.

Finally, pair wise comparisons would be undertaken to fill matrices for each criteria comparing the performance of each alternative within that criteria.

(Saaty, T.L ,1980).

2.3.4. Consistency across pair wise comparisons

The consistency of the decision maker across a number of pairwise comparisons is a significant complexity. Consider the very simple comparison of three criteria: A, B and C. If the decision maker judges A to be more preferable than B, and A to be less preferable than C then the decision maker must not judge B to be more preferable than C.

In a group that contains a large number of pairwise comparisons or where the difference is between moderate and very strong preference it can be seen that lack of consistency is a largely inevitable consequence of complex decision processes within AHP.

The AHP method attempts to address the issue of consistency by implementing a consistency index that is a function of opposing comparisons. Above a threshold, a lack of consistency is highlighted and no analysis results are presented. An unfortunate consequence is that decision makers begin to fulfill pair wise comparisons not on their actual judgments but rather in order to maintain acceptable consistency.

An effective approach to limit the issue of consistency is to utilise a multi-criteria hierarchy thereby reducing the number of pairwise comparisons undertaken within each group.

2.3.5. Rank reversal

If the inclusion or exclusion of a non-outperforming alternative, or duplicate alternative alters the ranking of the remaining alternatives a rank reversal occurs.

AHP method and other MCDA methods are susceptible to rank reversal and experienced users must be aware of this. Recording the decision making process and decision makers subjectivity It is useful to have a record of decision making process. This gives some idea of how the decision was reached. The problem hierarchy gives insight into how the decision was structured.

Most AHP tools allow to view the pair wise comparison matrices showing the preference values applied to each pair. However, this does not make explicit the subjectivity inherent in the judgments made by the decision maker, the reasoning and understanding behind those simple judgements is lost (F. Mehrdoust M. Ghamgosar, M. Haghyghy and N. Arshad (2011)).

2.4. Least Cost Path (LCP)

The role of GIS is to select the optimal path in Linear Engineering Structures (LES). We use the least cost path technology. Least cost path analysis is a distance analysis tool within GIS that uses the least cost path between two locations that costs the least to those travelling along it to determine the most cost effective route between a source and destination. Cost path analysis is a tool in GIS used to select an optimal path between two points through continuous space that minimizes costs. Cost in this sense can have a number of connotations, including actual monetary expenditure in construction, time and effort required to travel, and negative environmental impacts. Any path through space will accumulate these costs, and routes with higher associated costs are less favorable than routes with a lower cost associated with it. Cost path algorithms are designed to efficiently find the path with the minimum total cost.

Cost path is one of a series of algorithms and tools that analyze such costs, collectively known as cost distance analysis. Its most common application is for planning corridors for constructing linear infrastructure such as roads and utilities.

Determining an optimal path cost typically requires three steps, which in most GIS software is implemented in separate tools.

1. Cost surface: the various types of cost are combined into one comprehensive measure that could be measured anywhere in the space , then modeled in GIS to create a raster grid known as a cost surface .
2. Cost distance: given a source location, a new raster grid called a cost distance raster is created that calculates the accumulated cost to travel to each cell from the source, this is created by radiating out from the source, determining the cost of each cell by indentifying the neighbor with the lowest accumulated cost and adding its cost to the total simultaneously, a separate grid called a back link raster encoding the direction from each cell to its lowest cost neighbor.
3. Least- cost path: given a destination location, this algorithm finds the corresponding cell in the back link raster, then traces a path from the destination back to the source by following the direction of each cell to the lowest cost neighbor. The corresponding cell in the cost distance raster gives the total cost accumulated by following this optimal path.

2.4.1. Discrete Cost Map

The first and critical step establishes the relative (goodness) for locating a pipeline at any grid cell in a project area (figure 1). In turn, the calibrated maps are weight-averaged to form logical groups of criteria (see figure 1)

Finally, the group maps are weight-averaged to derive a Discrete Cost Map.

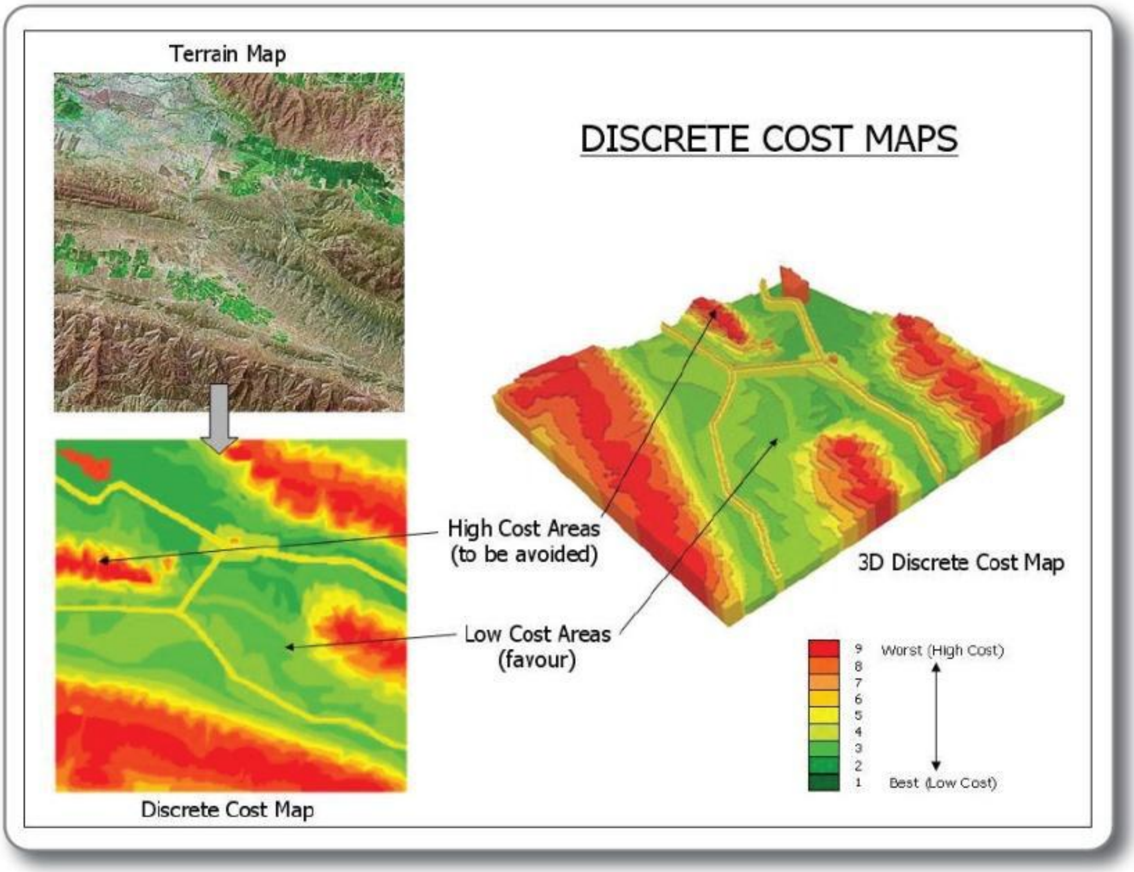

Figure 2.1: Discrete cost map

(Google Earth in Pipeline Design and Route Selection, Appendix 5.1.2)

2.4.2. Calibrating and Weighting

Calibrating: refers to establishing a consistent scale from 1 (most preferred) to 9 (least preferred) for rating each map layer used in the solution.

Weighting: Weighting of the map layers is achieved using a portion of the Analytical Hierarchy Process developed in the early 1980s as a systematic method for comparing decision criteria.

The procedure involves mathematically summarizing paired comparisons of the relative importance of the map layers.

The result is a set map layer weights that serves as input to a GIS model. In the routing example, If there are four map layers that define the six direct comparison statements :

pairs $(N \times (N-1)/2) = 4 \times 3/2 = 6$ statement ———(2)

The members of the group independently order the statements so they are true, then record the relative level of importance implied in each statement. The importance scale is from 1 (equally important) to 9 (extremely more important) . (Joseph K. Berry,2003)

2.4.3 Accumulated Cost Map

The second step of the LCP (least cost path) procedure uses propagating wave-front from a starting location to determine the least (cost) to access every location in the project area. It is analogous to tossing a rock or stick into a pond with the expanding ripples indicating the distance away. In this case however, the computer moves one ripple away from the start and incurs the cost indicated on the discrete cost map. As the expanding ripples move across the discrete cost map an Accumulated Cost Map is developed by recording the lowest accumulated cost for each grid cell. In this manner the total (cost) to construct the preferred road from the starting location to everywhere in the project area is quickly calculated (Joseph K. Berry,2003).

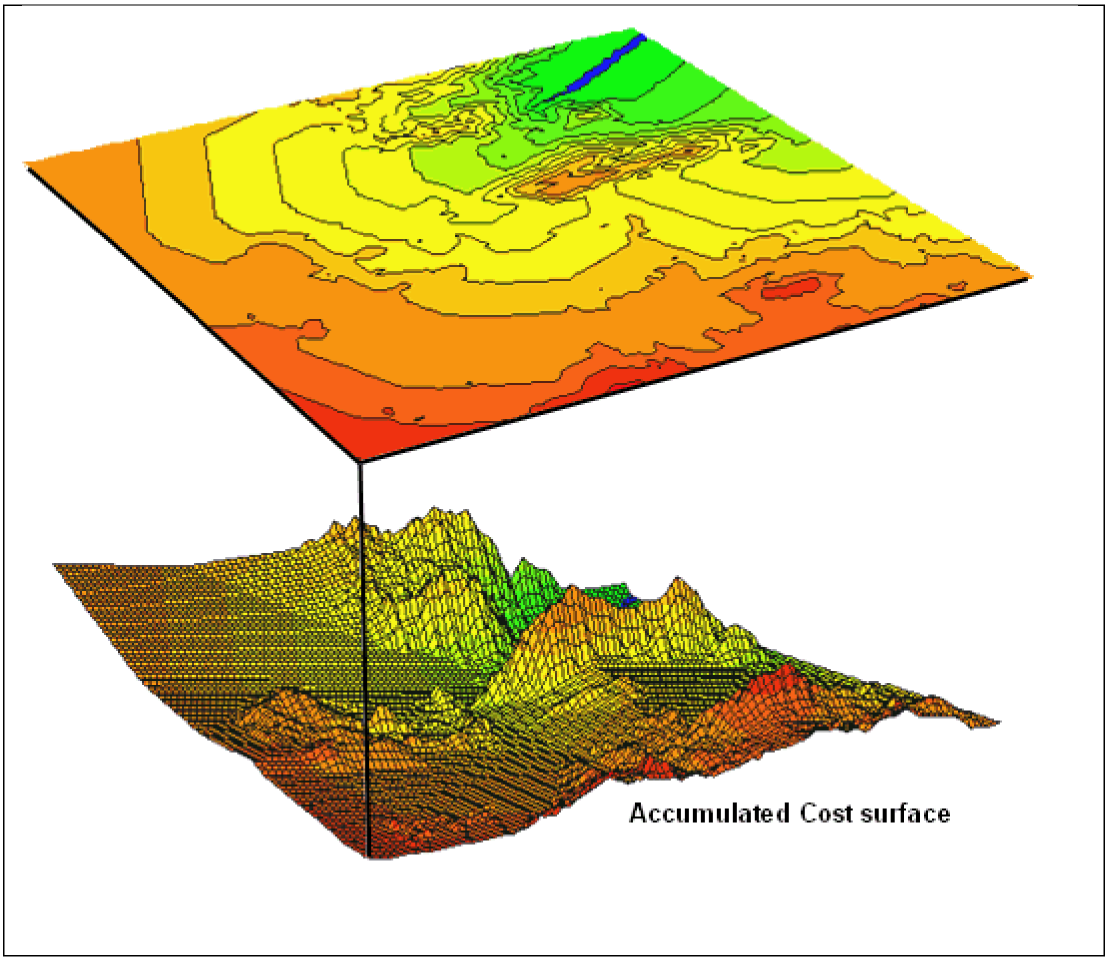

Figure 2.2: Accumulated Cost Map

(Beyond Mapping III, Topic 19: Routing and Optimal Paths)

2.4.4. Optimal Route

The third step of the LCP Optimal Route: By simply choosing the steepest downhill path over the surface, the path that the wave-front took to reach the end location is retraced.

By mathematical fact this route will be the line having the lowest total cost connecting the start and end locations. Note that the route goes through the two important paths that were apparent in both the discrete and accumulated cost maps (Joseph K. Berry,2003).

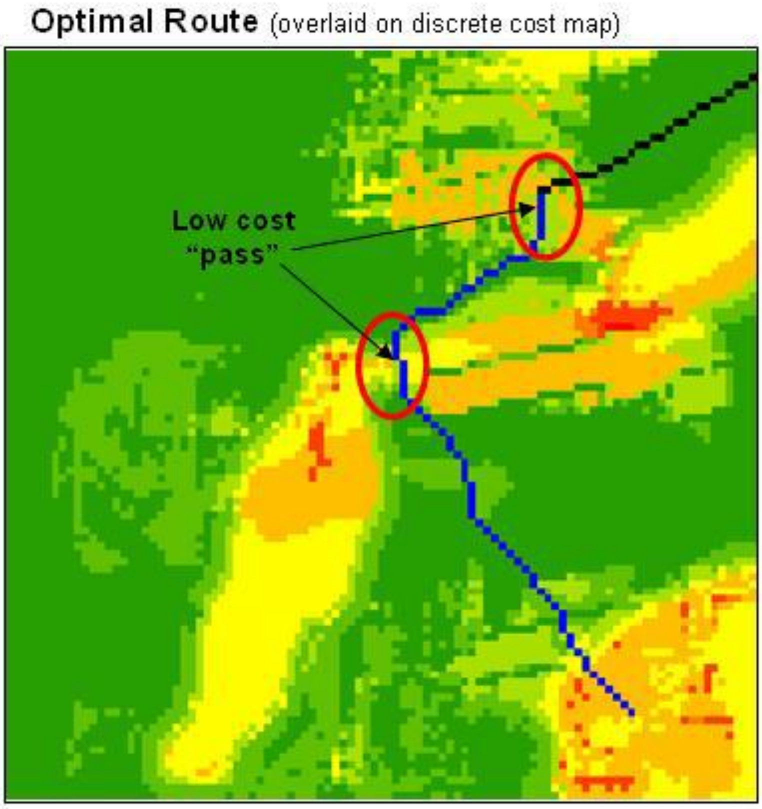

Figure 2.3: Optimal Route

(Beyond Mapping III,Topic 19: Routing and Optimal Paths)

2.4.5. Optimal corridor

The optimal corridor identifies the Nth best route. These form a set of nearly optimal alternative routes that a siting team might want to investigate. In addition, optimal corridors are useful in delineating boundaries for detailed data collection, such as high resolution aerial photography and ownership records.

The Optimal Corridor Map is created by calculating an accumulation cost map from the starting and the end locations. The two surfaces are added together to indicate the effective cost distance from any location along its optimal path connecting the start to the end locations.

(Joseph K.Berry 2003).

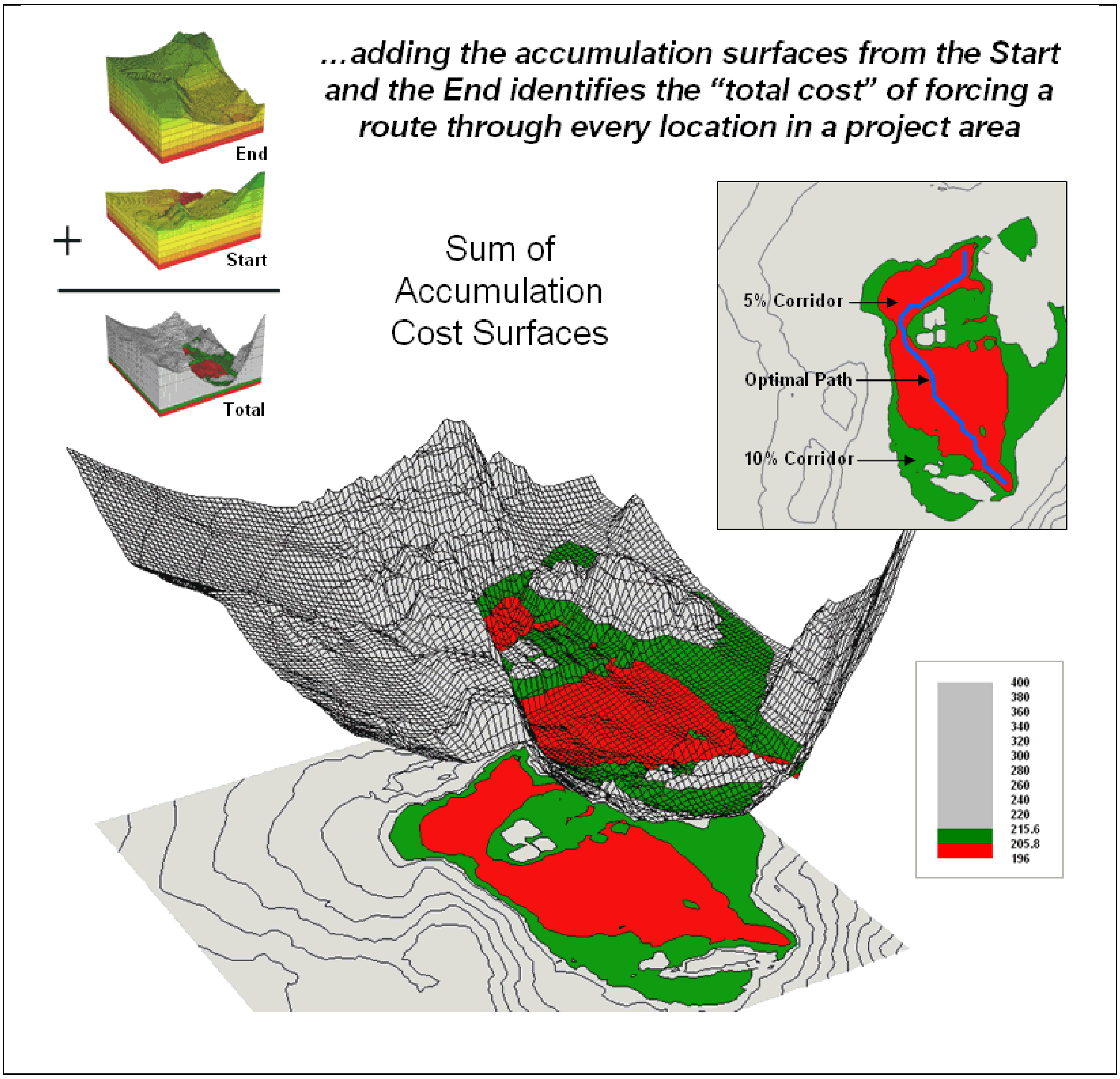

Figure 2.4 Optimal Corridor

(*www.innovativegis.com/basis)*

2.4.6. Straightening Conversions Improve Optimal Paths

This approach modifies the discrete cost map by making disproportional increases to the lower map values This has the effect of straightening the characteristic minor swings in routing in the more favorable areas (low values) while continuing to avoid unsuitable areas.

2.4.7. Spatial Sensitivity Analysis

The study of how the variation (uncertainty) in the output of a mathematical model can be apportioned to different sources of variation in the input of a model. In its simplest form, sensitivity analysis is applied to a static equation to determine the effect of input factors, termed scalar parameters, by executing the equation repeatedly for different parameter combinations that are randomly sampled from the range of possible values. The result is a series of model outputs that can be summarized to:

1) Identify factors that most strongly contribute to output variability, and

2) Identify minimally contributing factors.

As one might suspect, spatial sensitivity analysis is a lot more complicated as the geographic arrangement of values within and among the set of map variables comes into play. The unique spatial patterns and resulting coincidence of map layers can dramatically influence their relative importance a spatially dynamic situation that is radically different from a static equation.

Hence a less robust but commonly used approach systematically changes each factor one-at-a time to see what effect this has on the output. While this approach fails to fully investigate the interaction among the driving variables it provides a practical assessment of the relative influence of each of the map layers comprising a spatial model (Joseph K.Berry, 2003).

2.5. Pipeline's route considerations (optimal path)

Pipelines are needed to transport the oil over long distances to meet the demand for refining and distribution. They are the most efficient, cost effective and environmentally friendly means of fluid transport. The evaluation of the best route is a complex multi-criteria problem with conflicting objectives that need balancing. This research used spatial modeling and GIS analysis to derive an optimal route together with deriving a weighting criterion using AHP and modeling using the derived weightings.

Routing a pipeline is an important task, thus proper planning is essential in order to maximize the benefits derivable from the use of pipelines. With the scientific planning of a route, cost, time, and operating expenses can be saved, ensuring longer operational life and minimizing environmental fallouts. The use of pipelines reduces the probability of oil spillage and eases traffic congestion caused road transport.

The inefficient and traditional methods of optimal routing of pipelines are mainly based on expensive and protracted methods. These methods utilize static paper maps which are huge and bulky, furthermore, they are not precise and the role of all effective parameters in pipeline routings cannot be easily considered. Technical, economic and environmental concerns are not observed in designed paths as a result of these outdated methods. GIS tools bring new approaches to routing enabling all factors affecting the route be considered and weighted under one umbrella. GIS includes scientific tools that enable the integration of data from different sources into a centralized database from which the data is modeled and analyzed. GIS-based tools and processes address the challenges of optimizing routes based on the collection, processing and analysis of spatial data. It’s an approach routing that is systematic and effective.

The GIS approach to pipeline routing optimization is based on relative rankings and weights assigned to project specific factors that affect the potential route. This results in an optimal path between the start and the destination point. The factors influencing pipeline route selection are technical and engineering requirements, environmental considerations, and population density. The Optimal path based on the criteria which includes engineering and environmental constraints.

2.5.1. The engineering constraints include

- Avoid area elevation that is more than 5,000 m
- Avoid terrain slopes that are more than 35 degrees (preferred less than 5 degrees).
- Avoid areas which are 20km away from road (preferred area within 5 km existing roads)
- Minimize roads crossings and rivers crossings.
- Avoid areas with high risk of land slides, sand dunes, and movement of tectonic faults.
- Avoid areas where rain is historically more than 500mm per year.

2.5.2 The environmental constraints

- Avoid environmentally sensitive areas like national parks, reserves, sanctuaries, lakes, and minimize river crossings.
- Avoid any urban or populated areas, but areas within 5 km are preferred.
- Avoid national projects, non-permit, national defense, ports and airports.
- Minimize crossing areas with active mining concessions.
- Avoid national archaeological zones and areas with high risk of social conflicts

  (A. Gamarra , 2014) ,(Yildirim, 2007)

Chapter Three

Materials and Methods

3.1. Overview

The main objective of this study is to use GIS multi-criteria analysis to select the optimum route for pipeline. Figure (3.1) shows the flow chart of method followed in study.

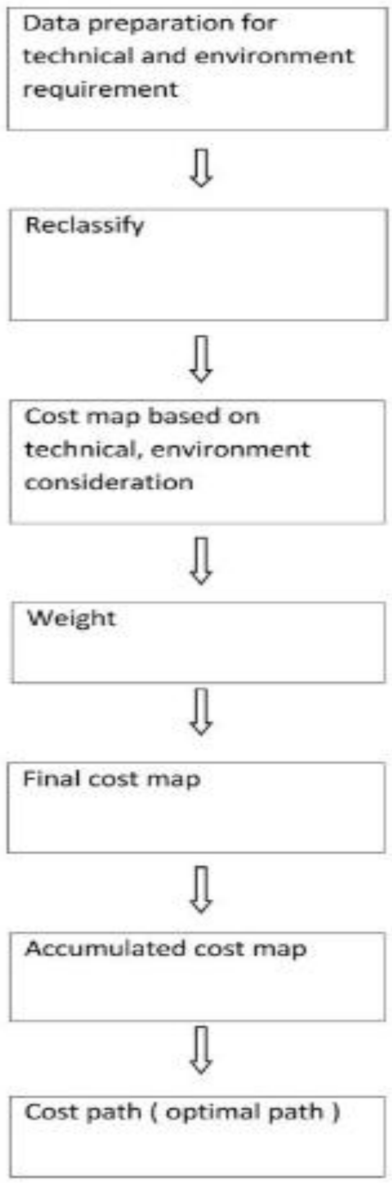

Figure 3.1.The Flow Chart of the Method

3.2. Study Area

The study area of this research located within the South Korodfan state in west of Sudan. It has an area of 158,355km^2 and an estimated population of approximately 1,100,000 people (central Bureau of Statistics).

Kaduqli is the capital of the state .it is centered on the Nuba mountains. It covers 79470km^2 and it is population is 1,066,117 people (central Bureau of Statistics), the most important crops are cotton sesame millet and hibiscus. Animal number is 17,025,000 (camels, sheep and caws) .

The location of study is South Krodofan, between 12 degrees latitude and 9 degrees latitude north and longitude 32 degrees and 27 degrees east. The starting point for the route was 29° 19′27" E 10°36′23" N while the end point of the route was coordinates 29°59′43.8"E 12°42′15.4" N.

South Kordofan is one of the coldest regions in Sudan with an average daily temperature of only 35 degree centigrade. It is year long warm and hot.

Districts of south Kordofan is Dilling District, Rashad, Abu jubaiah , Talodi, Kadugli, Alsalam, Lagawa and Algoze.

The most important cities of South kordofan are Dilling or Dalang, in 2008 it is population 59,089 people (central Bureau of Statistics), the coordinates 12.049441N degree and 29.51048E degree .

Talodi is a small town in the Nuba mountains. The town is nearly 650 km (406 miles) south west of Khartoum .

Kadugli is located 240 km (150 miles) south of EL Obeid at the northern edge of the White Nile plain in the Nuba mountains .Figure (3.2) shows the South kordofan state.

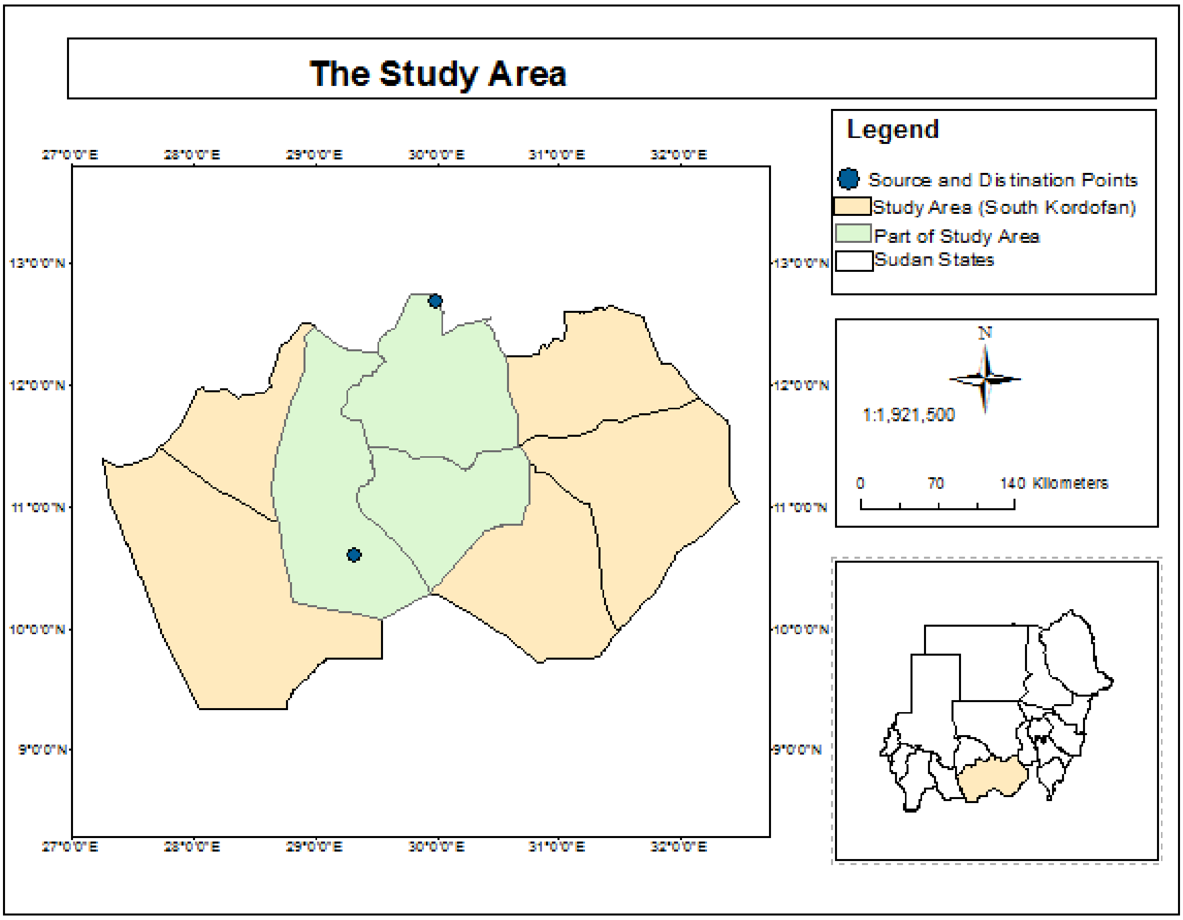

Figure 3.2: The Study Area

(Sudan National Survey Authority)

3.3. Data Acquisition

In order to perform the selection of pipeline route using the GIS analysis techniques the following data were acquired.

3.3.1. DEM

Advanced space borne thermal emission and reflection radiometer (ASTER) has been used to produce single-scene (60- x 60-kilometer (km)). Digital Elevation Models (DEM) having vertical (root-mean-squared-error) accuracies generally between 10- and 25-meters (m).

This data was used to produce layers that are useful for the technical analysis. The DEM used to create slope and stream layers. Figure (3.3) represents the DEM of the study area.

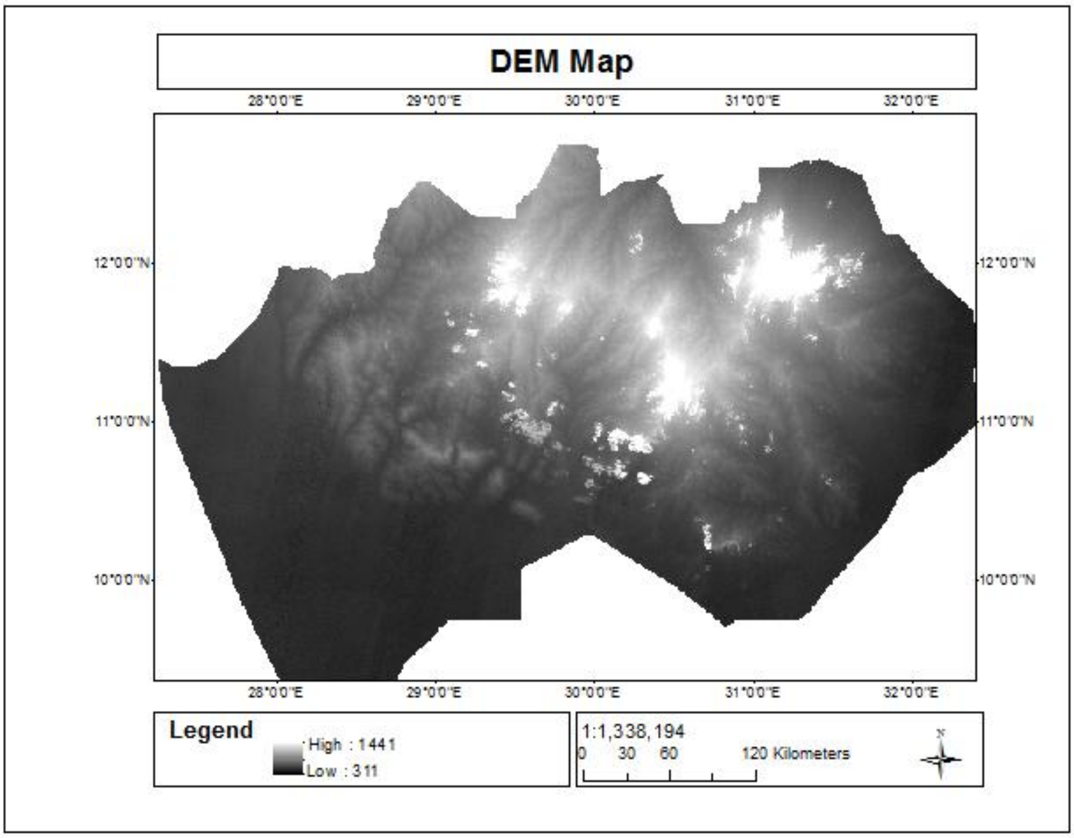

Figure 3.3: DEM (Digital Elevation Model).

(https://earthexplorer.usgs.gov)

3.3.2. Soil Map

Soil map of study area was used for analysis to produce a layer showing suitable soil of the study area.

3.3.3. Land-use of the Study Area

Type of land use including bare land, forest, agriculture, urban and urban associated. This data was used for environment analysis.

3.3.4. Population

Excel sheet data from central statistic organization shows result of census in 2008. This data was used to produce population map to meet the social environmental requirements of serving the largest possible number of population.

3.3.5. Geological Map

Geological map shows the rock compositions, the risk areas and earthquake area. This data was used to produce geological map to satisfy the environmental requirement.

3.3.6. Existing pipeline route

The existing pipeline route was needed to identify the source and destination points of the rout. Figure 3.4 represent the existing rout.

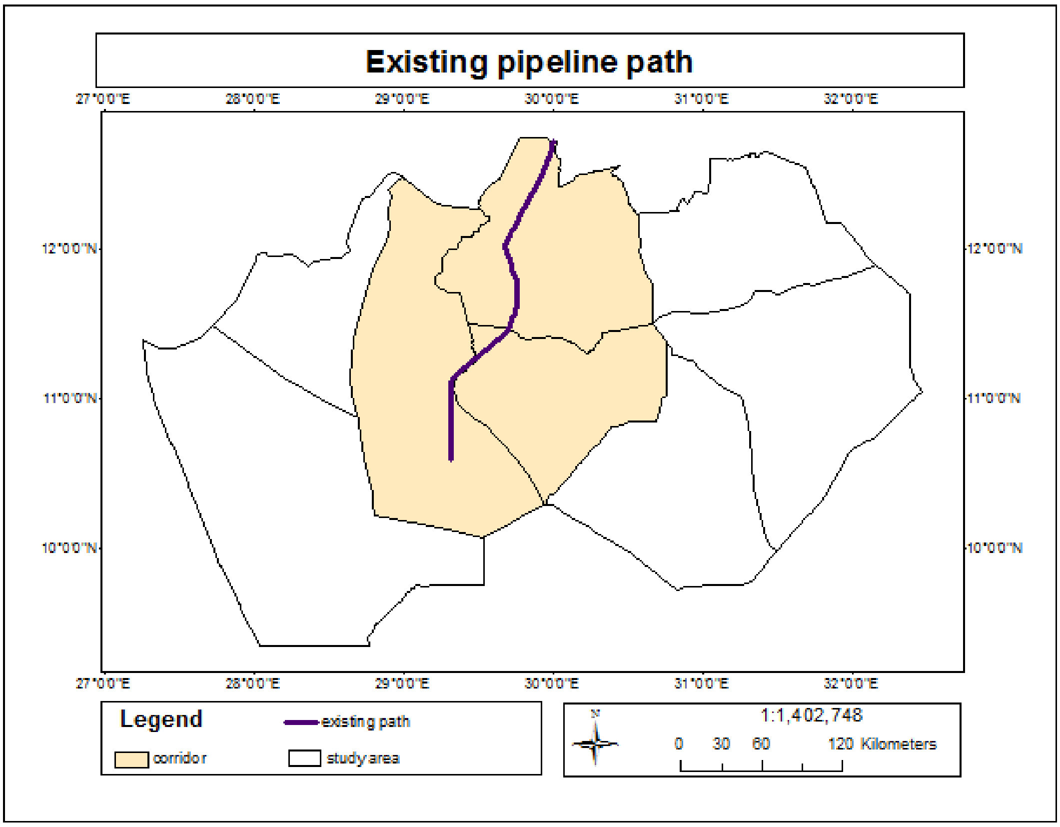

Figure 3.4:The existing path

(Sudan National Survey Authority)

3.4. Software used

Arc GIS 10.2.2 software has been used in this study to be able to work with maps and geographic information. It is used for: creating and using maps; compiling geographic data; analyzing mapped information; sharing and discovering geographic information; using maps and geographic information in a range of applications; and managing geographic information in a database .

3.5. Model Builder

The figure 3.4 shown the Model-Builder Diagram.

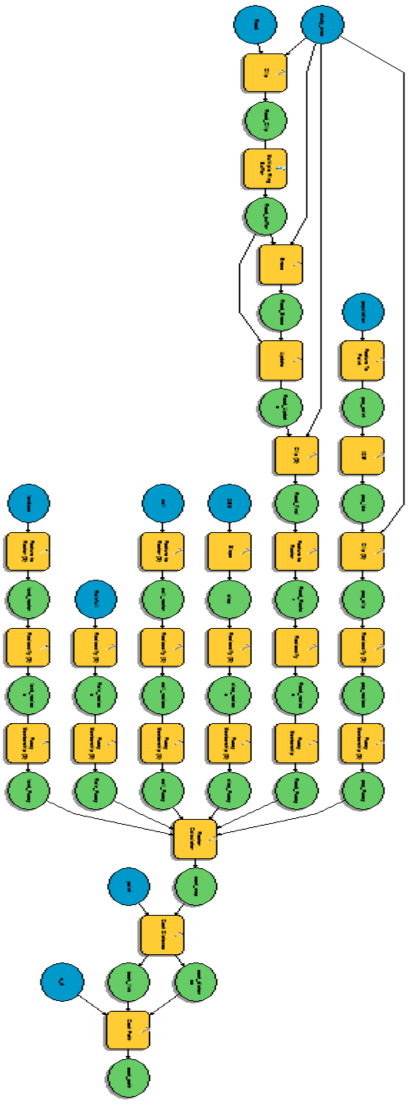

Figure 3.4Model-Builder Diagram

Chapter Four

Results and Discussion

4.1. Results

4.1.1. Soil Layer

The soil layer was classified into four groups (from A-l through A-4) based on the criteria to select the best route. Construction cost increases towards group A-4 and decreases towards group A-1. The soil vector layer was converted into raster dataset and reclassified into sand, loamy sand, medium loamy, and heavy clay, figure (4.1) represents the soil map of study area.

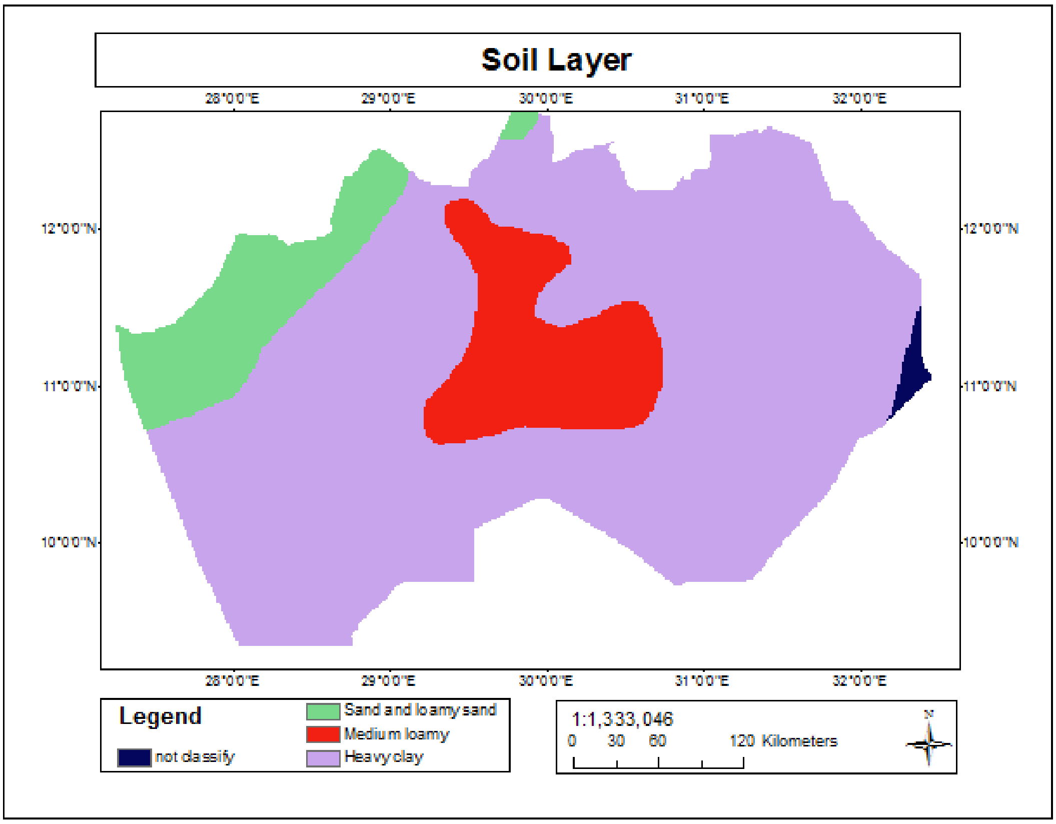

Figure 4.1: Soil Map

4.1.2. Roads layer

This layer shows the existing roads in the study area, were buffered roads every 5 Km because this distance is appropriate as a buffer to protect the roads, then the roads vector layer was converted into raster and reclassified, figure (4.2) represents the road map of the study area.

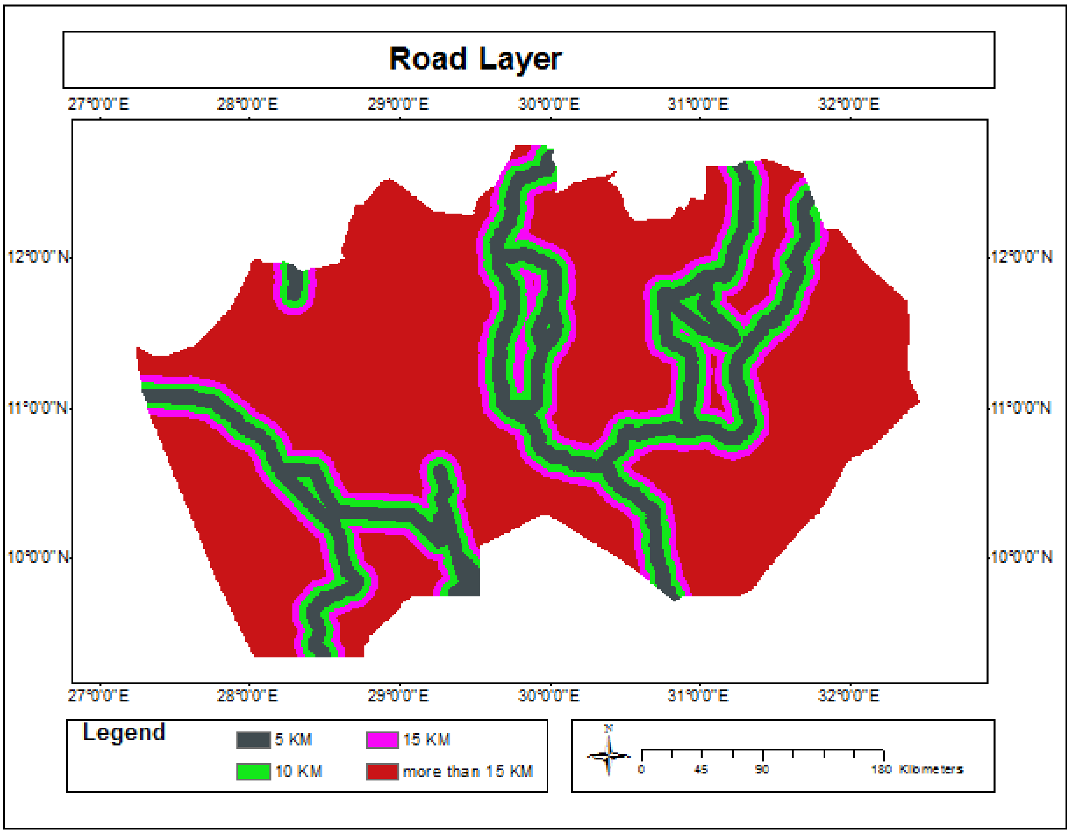

Figure 4.2: Road Map

4.1.3. Land use Layer

The land use layer has been divided into four classes based on environmental criteria, staying away from urban and urban associated areas and preserving the environment of forest and agricultural land, bare land is the most appropriate area for the pipeline. This layer was reclassified into four groups and bare land was selected as the most suitable followed by forest, agriculture and urban land, figure (4.3) shows the land use map of the study area.

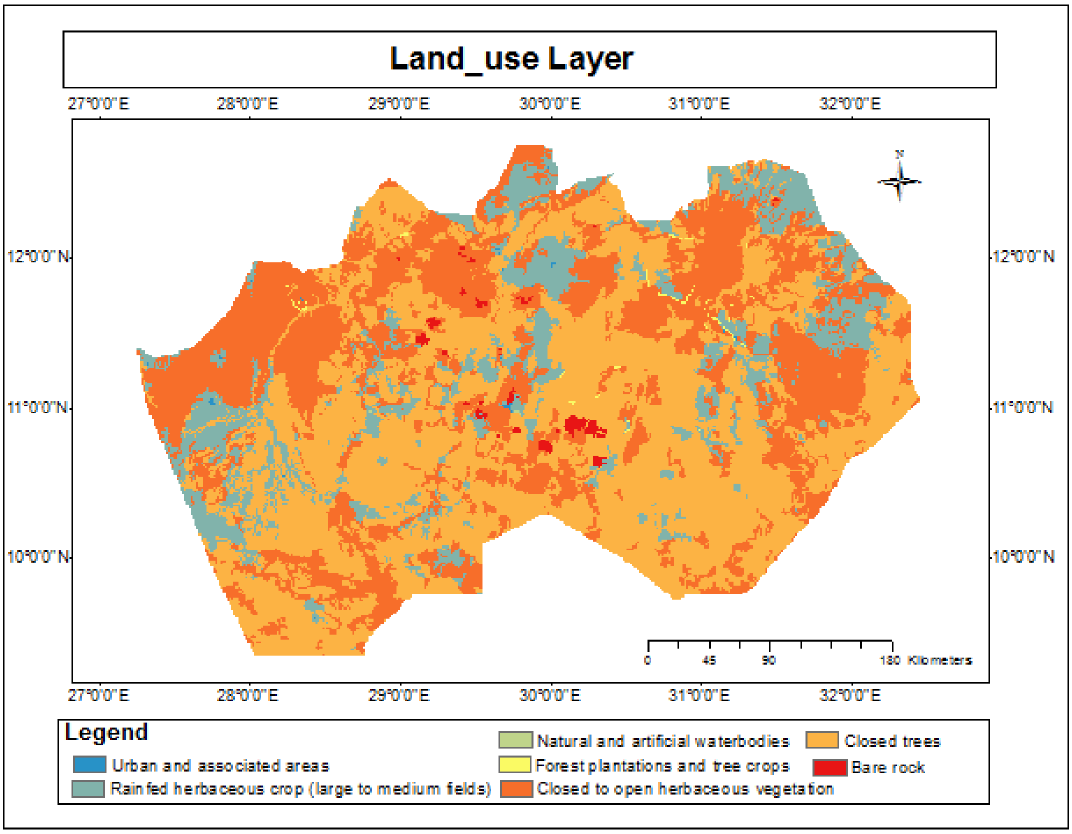

Figure 4.3: Land Use Map

4.1.4. Population Layer

The population data was used to create a point shape file, then the population density surface created and reclassified. The layer the highest population density is the least suitable for the pipeline route and the lowest population density is the most suitable for the route, figure (4.4) shows the population map of the study area.

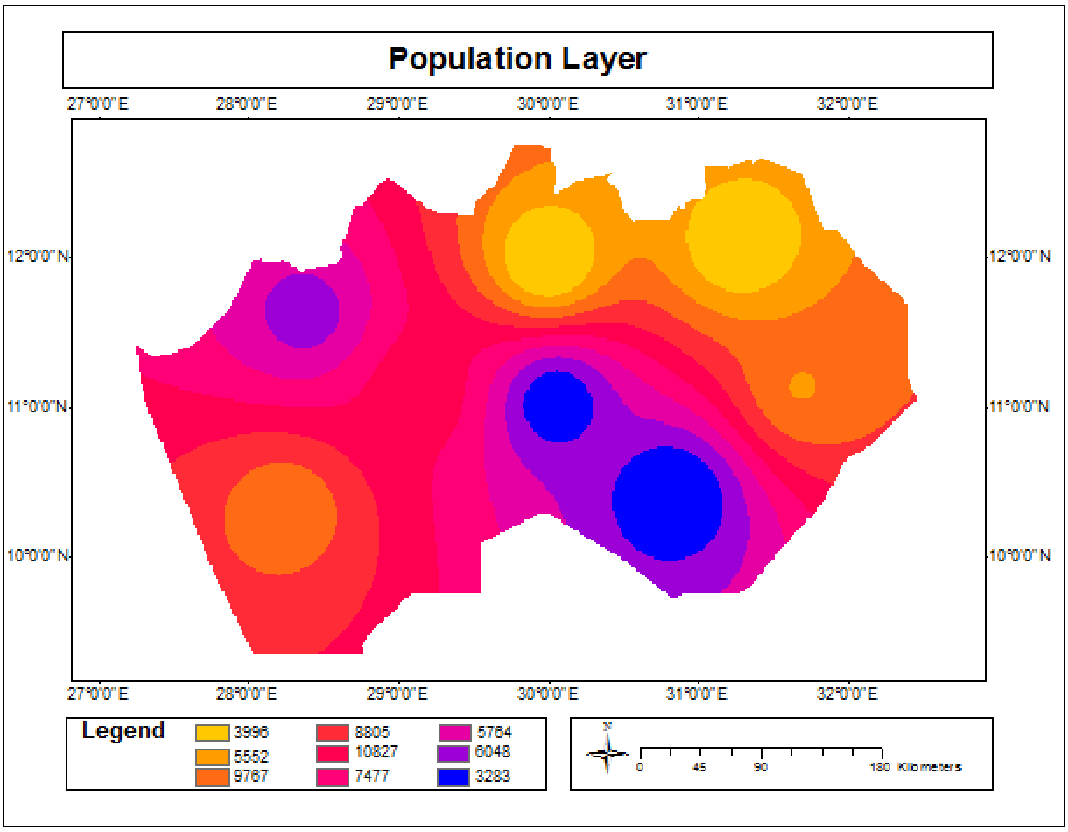

Figure 4.4 Population Map

4.1.5. Rainfall Layer

The rainfall map was classified based on the rainfall average which is suitable when it is less than 500 mm per year. Rainfall was classified into four groups as shown in figure (4.5).

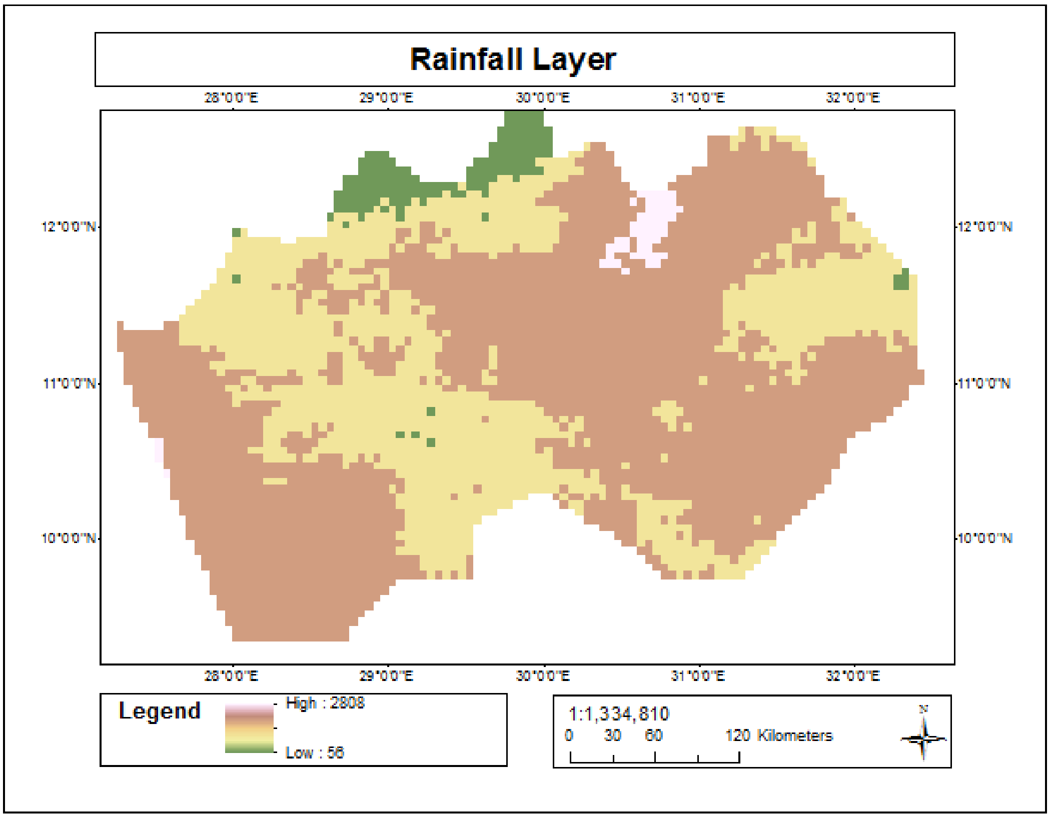

Figure 4.5: Rainfall Map

4.1.6. Slope Layer

From DEM of the study area the slope layer has been created and reclassified into 9 classes (from 1 to 9) based on the criteria, figure (4.6) represents the slope map of the study area.

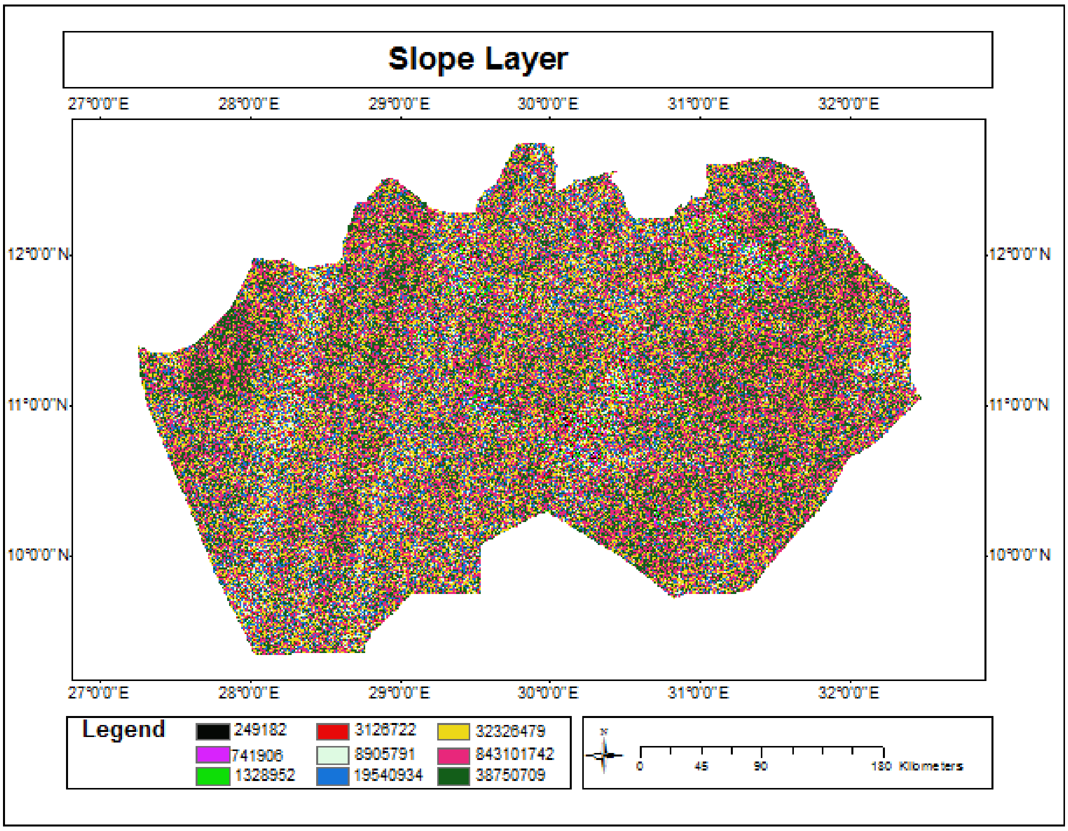

Figure 4.6: Slope Map

4.1.7. Standardization

All layers were put in standard scale using fuzzy membership tool in Arc Toolbox, this tool transforms the input raster into 0 to 1 scale, indicating the strength of a membership in a set, based on a specified fuzzification algorithm.

4.1.8. Discrete cost map

There are two steps used to create the discrete cost map. The discrete cost map is used to create the cost map into two steps by adding AHP toolbox. Step one opens all of layers to make a table of the layers. Table (4.1) represents step one.

Table 4.1 Step One: Discrete Cost Map

OBJECTID *	layername	land_fuzzy	pop_fuzzy	rain_fuzzy	road_fuzzy	slope_fuzzy	soil_fuzzy
1	land_fuzzy	1	1.2	2	1.5	6	3
2	pop_fuzzy	0.83	1	1.67	1.25	5	2.5
3	rain_fuzzy	0.5	0.6	1	0.75	3	1.5
4	road_fuzzy	0.67	0.8	1.33	1	4	2
5	slope_fuzzy	0.17	0.2	0.33	0.25	1	0.5
6	soil_fuzzy	0.33	0.4	0.67	0.5	2	1

And applying step two to the previous table to get a weight to each layer

Table 4.2 Step Two Calibrating and Weighting

OBJECTID *	layername	land_fuzzy	pop_fuzzy	rain_fuzzy	road_fuzzy	slope_fuzzy	soil_fuzzy	weight	CI	RI	CR	Notes
1	land_fuzzy	1	1.2	2	1.5	6	3	0.285714	0.000183	1.2	0.000145	The matrix is considered to be consistent enough.
2	pop_fuzzy	0.83	1	1.67	1.25	5	2.5	0.238016	0.000183	1.2	0.000145	The matrix is considered to be consistent enough.
3	rain_fuzzy	0.5	0.6	1	0.75	3	1.5	0.142857	0.000183	1.2	0.000145	The matrix is considered to be consistent enough.
4	road_fuzzy	0.67	0.8	1.33	1	4	2	0.190556	0.000183	1.2	0.000145	The matrix is considered to be consistent enough.
5	slope_fuzzy	0.17	0.2	0.33	0.25	1	0.5	0.047698	0.000183	1.2	0.000145	The matrix is considered to be consistent enough.
6	soil_fuzzy	0.33	0.4	0.67	0.5	2	1	0.095159	0.000183	1.2	0.000145	The matrix is considered to be consistent enough.

4.1.9. Hybrid Cost Map

Map algebra was used to multiply each layer by its weight and get the summation of output. Figure (4.7) represents the hybrid cost map .

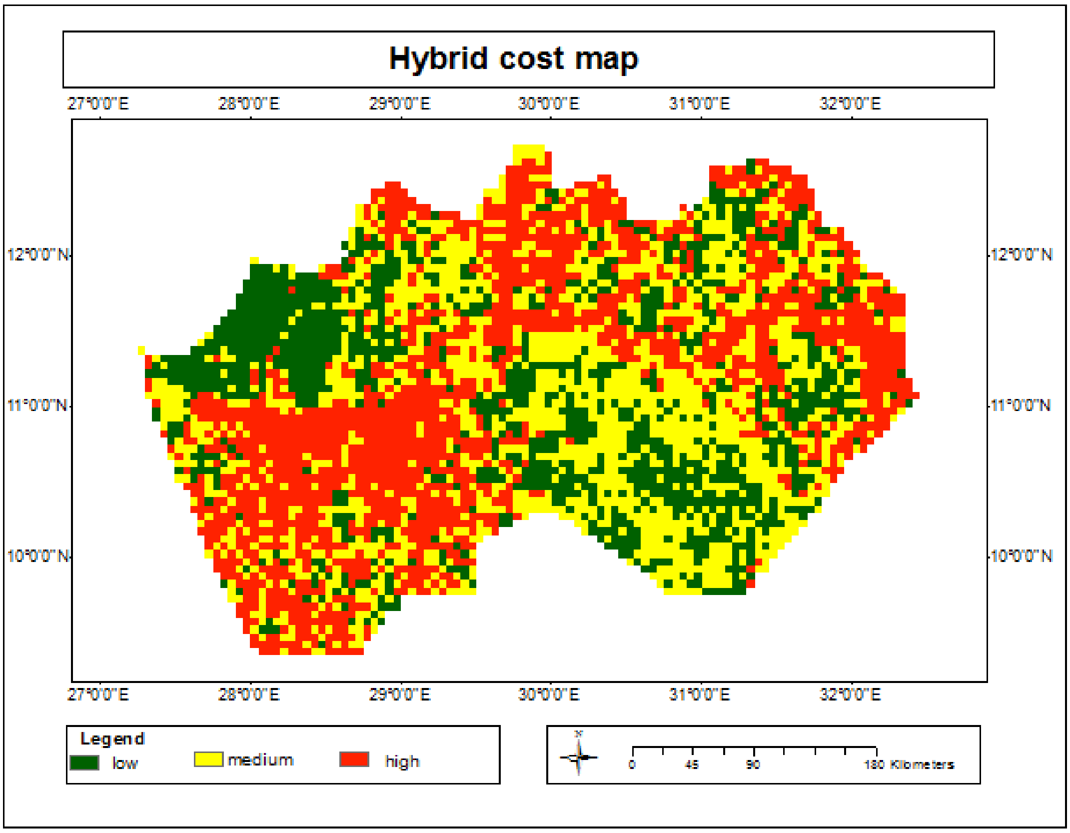

Figure 4.7 Hybrid Cost Map

4.1.10. Accumulated Cost

From Arc Tool box using distance and cost distance, the cost map in the previous step and the starting point of the project were used as inputs, the output are two layers, distance raster that represents the least accumulative cost distance for each cell to the nearest source over the cost surface, and back link distance that represents the direction from each cell to the nearest source over the cost surface. Figure (4.8) represents the cost distance map and figure (4.9) represents the back link map.

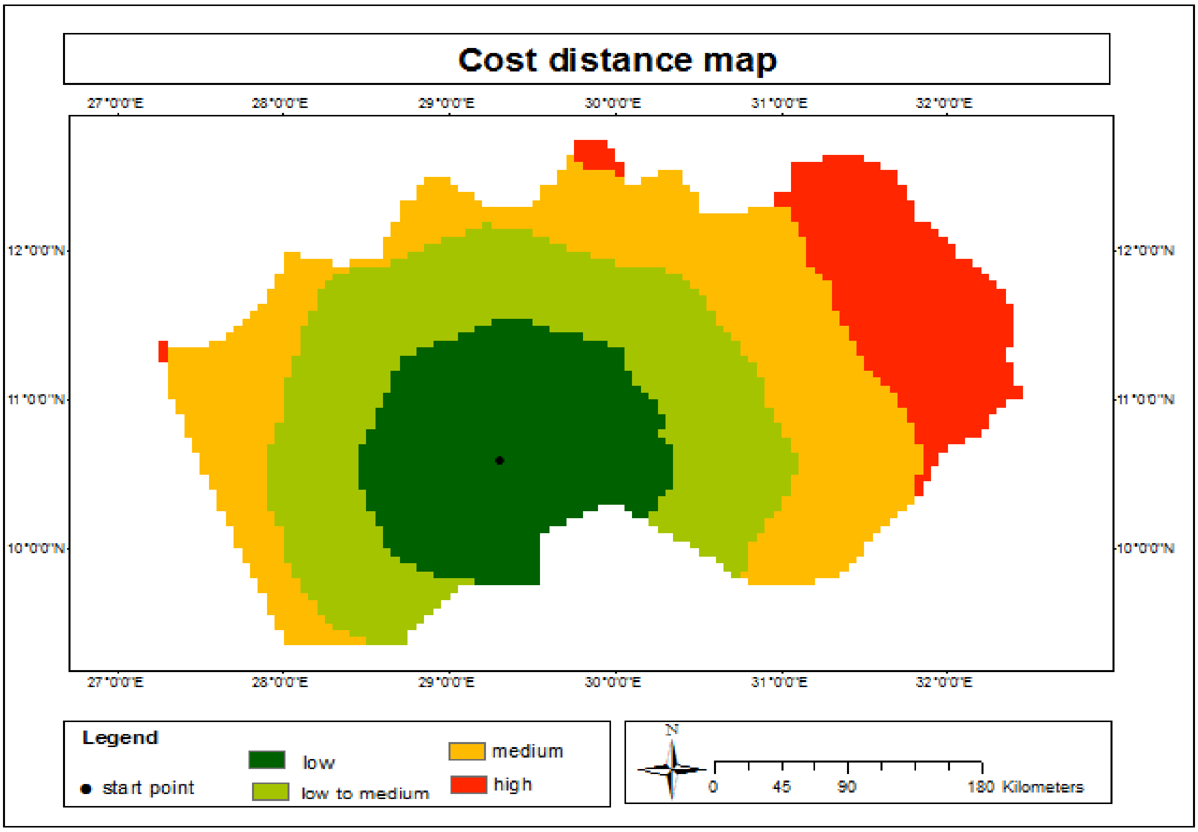

Figure 4.8: Cost Distance Map

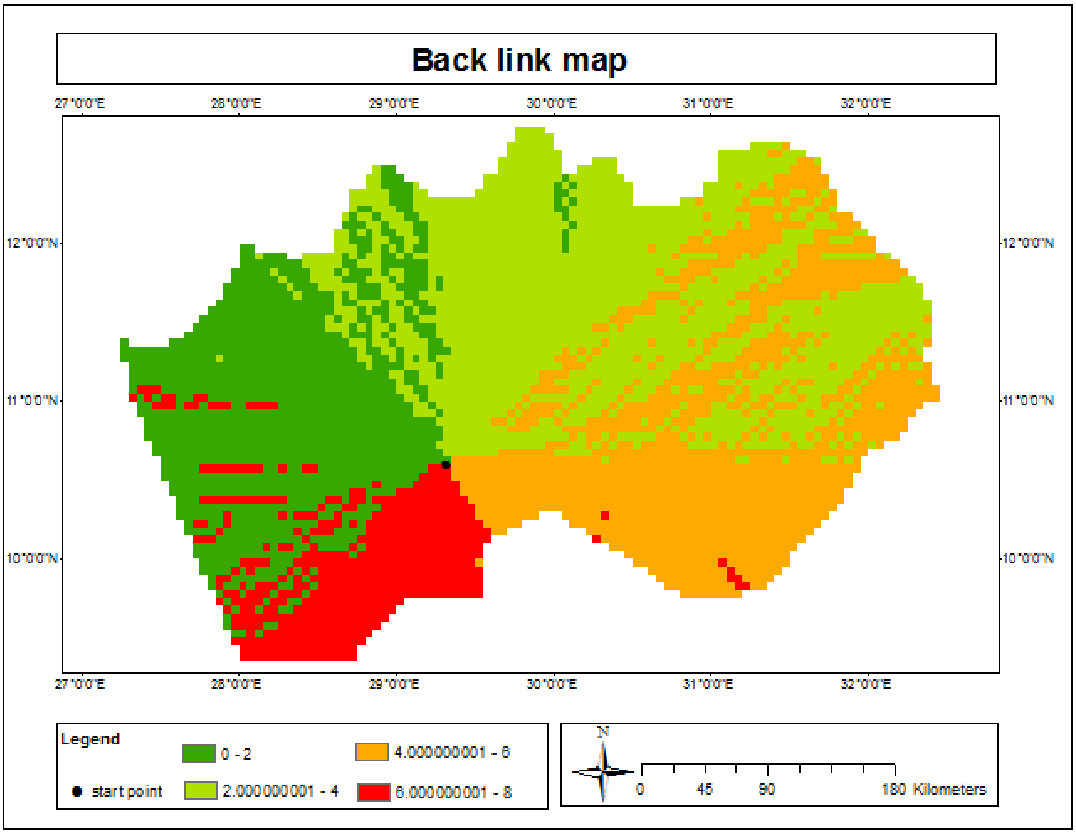

Figure 4.9: Back Link Cost Map

4.1.11. Cost Path

The least-cost path has been calculated from a source to a destination by using the cost path tool in Arc Toolbox. The input data were the two raster layer that were produced in the previous step and destination layer which is the end point. The output of the least cost path of pipeline from the oilfield to the end. The length of the path about 251 Km.

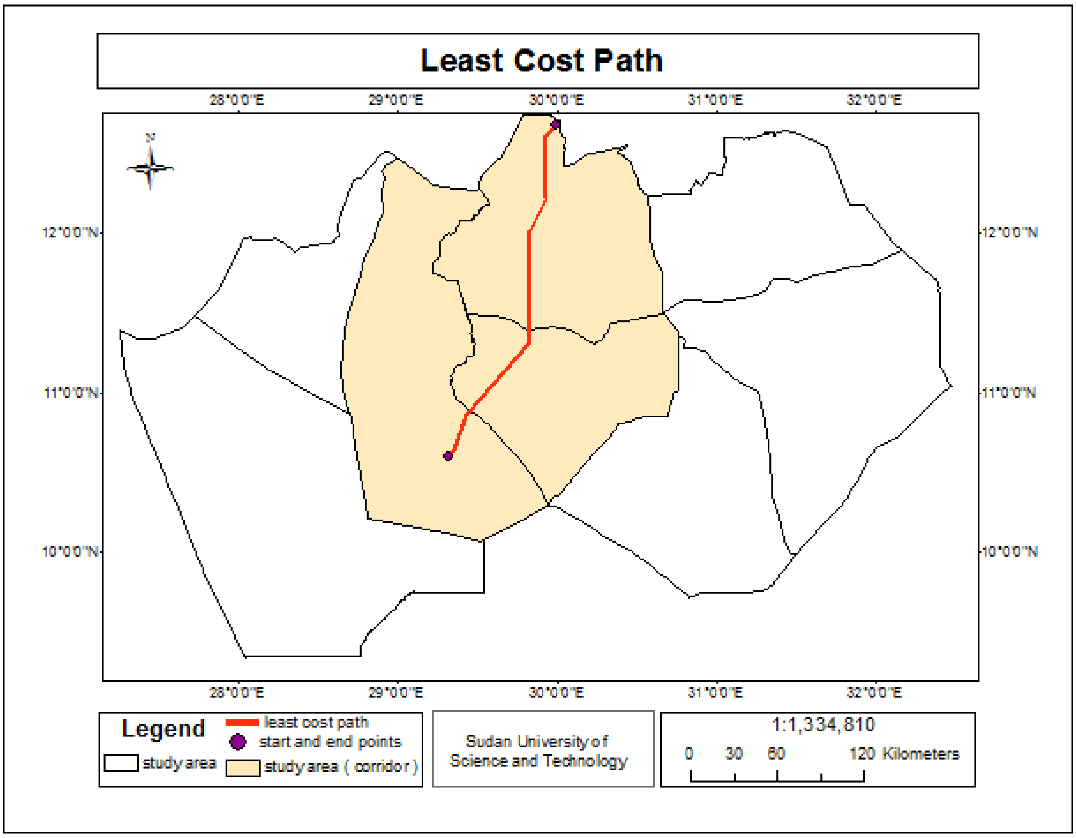

Figure 4.10 Least Cost Path

The final path through the medium loamy and loamy sand in the soil layer, in the road layer the path passes with in 5 km to 10 km, and through the rain fed herbaceous crop, closed to open herbaceous vegetation and closed tree in the land use layer, in the population layer the path through the areas with the least density of the people, in the rainfall it is passes between the 156 mm and 1562 mm, and in the slope layer the path pass through the least slope.

2.4. Discussion

The different between two paths (least path and the existing path), the length of proposed is 251 km while the length of existing path is 264km, the existing is longest that mean is the more cost. The least cost path passes through an area according to the criteria, figure (4.11) represents the comparison between two paths.

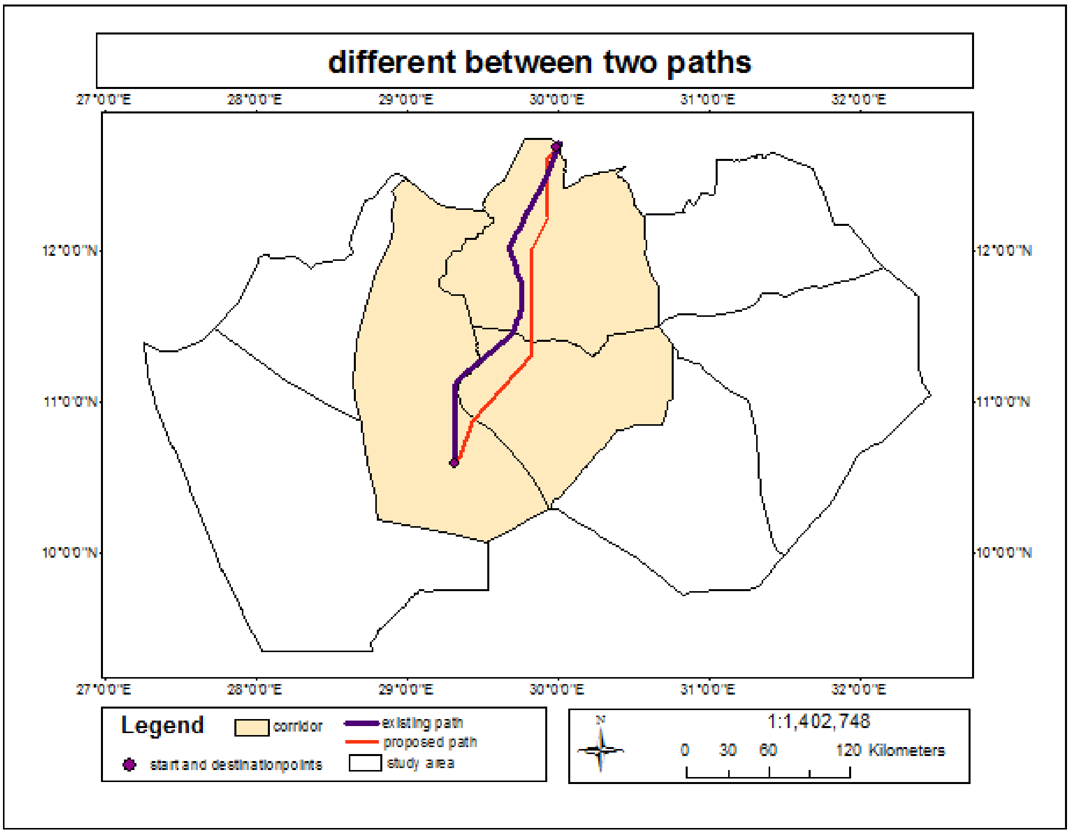

Figure 4.11: two paths

Chapter Five

Conclusion and Recommendations

5.1. Conclusion

The main goal of this study was to use geographical information system (GIS) for the selection of the optimal pipe line route. The main conclusion of this study can be summarized as follows:

- Using Arc GIS, Multi-criteria to determine the optimal path of pipeline.
- Land use, soil, slope, road, rainfall, and population can be used as criteria and classified based on the criteria into six classes to produce the weight-averaged by using the Analytical Hierarchy Process (AHP) toolbox to select the optimal path.
- The Discrete Cost Map was derived from the weight-averaged of these criteria(layers) using map algebra tool .
- The pipeline determine the least cost to access every location in the project area cost distance map and back link map were produced from the discrete cost map and the starting point of the pipeline to determine the least cost path.
- Finally, the optimal route can be determined from the source to the destination points using the cost distance and back link maps.

5.2. Recommendations

From the use of Arc GIS Multi Criteria for the selection of the optimal path of pipeline in the study area, the following topics can be recommended for consideration in the future studies:

- Adoption of this method for all route selection tasks in Sudan.
- Using the geological map which represents the rocks formations as a criteria in the study.
- Using recent images with high resolution for more accurate results.
- Using the Shuttle Radar Topography Mission Digital Elevation Model 30 (SRTMDEM 30) for higher spatial resolution.
- Involvement of other related disciplines in the task of deciding about the necessary criteria and their suitable weights and influences.

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