Masters Program in **Geospatial Technologies**

DETERMINATION OF THE MOST SUITABLE OIL PIPELINE ROUTE USING GIS LEAST COST PATH ANALYSIS.

Case Study: Keystone XL, Nebraska State - USA

Shahin Huseynli

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NOVA IMS Information Management School

Universitat Jaume I

Westfälische Wilhelms-Universität Münster

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Dissertation supervised by

Dr.Marco Painho

Dr.Sven Casteleyn

Dr.Rauf Amanov

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Abstract

The Keystone XL 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.

Keywords

Keystone XL

Pipeline

The Ogallala Aquifer

GIS

Least Cost Analysis

Nebraska

Oil

Acronyms

GIS – Geographical Information System

KXL – Keystone eXport Limited

LCP – Least Cost Path

SCP – Straight Line Path

CSD – Conversation and Survey division

US - United States

DEM – Digital Elevation Model

USGS – United States Geological Survey

SRTM – Shuttle Radar Topography Mission

GPS – Global Positioning System

ESRI – Environmental Systems Research Institute

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1. Introduction

1.1 Overview

Nowadays natural resources are one of the key factors of developing the economic situation of any country. U.S and some other countries in North America are more famous for their natural resources more than other regions in the world. Fertile soils, plentiful freshwater, natural gas and oil, mineral deposits and forestry are the key elements of natural resources in North America which directly have influenced their economy.

Pipelines are the most efficient, cost effective and environment friendly means of fluid transport and reduce the highway congestion, pollution and spill (Dubey, 2005). Careful planning of the pipeline route can save cost, time and operating expenses to ensure longer operational life and help in preventing environmental fallouts. Proper planning and management are considered essential means of guiding and accelerating the development of an industry. It can mobilize and utilize the available resources in the best interest of the company and eliminate business fluctuation (Nasir and Hyder, 2001). 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.

Every day in our life technology is developing and it helps to develop some particular sciences which concentrated in different educational fields. The latest technology and recent researches shows that GIS is the best tool (or science) for environmental planning and regulatory conformity. Geographical Information Science in itself has a big role in various geographical areas including pipeline routing. Pipelines are one of the most expensive and very sensitive transportations type that according to their capability, they can manage really big projects. But in the other hand, even small mistakes can create huge problems. Hence, GIS in this more suitable way to protect areas from hazards and also solve problems such as oil spills, gas leak and etc.

GIS in different trends can help to understand specific fields of the pipeline and also it can help to routing process. With influence of GIS it was already possible to create route corridors for different transportation types. Special algorithm for routing first time done by Dutch scientist Edser Djikstra in 1956 and for more detailed information written in literature review part of the thesis. Later famous American geographer Michael Goodchild with using the Djikstra Algorithm have founded evaluation of lattice solution to the corridor locations in 1977. With the same methodology M. Goodchild gave new breath to the modern technology and science. But thesis more concentrated on the route analysing and that is why, study concentrated on Djikstra Algorithm.

1.2 Least Cost Analyses.

The study is converged on finding the least cost routing strategy applying GIS analysis to the geographic area where Keystone XL will pass through Nebraska State. The routing model defines the most economical and environmentally safe route through the given study area. The study is highly concerned about avoiding geological, social and environmental hazards. This study would allow working with large-scale projects in the future and it will help also to find less hazardous methodology for routing the pipeline.

The most sensitive problems in pipeline routing are geological factors, land use information, slope and some another criteria which could help researchers to determine the least cost routing. With using ArcGIS Cost Path tool, it would be easier to understand the problems in the study area and also to determine the least cost routing. All criteria were collected into the ArcGIS geodatabase and data file digitized and rasterized for specific hazard weights

1.3 Keystone XL

The Keystone Pipeline System is an oil pipeline system between Canada and the U.S which has been authorized since 2010. It starts from Alberta City which is located in the West part of Canada and it ends in the other cities in U.S (Houston, Illinois). Some parts of pipeline are done and some parts still have further constructions and some parts are proposed for the future constructions. Therefore, there are six different phases of this project (Figure 1).

Figure1. Keystone Pipeline Route. (TransCanada Corporation 2012)

Figure 1 displayed parts of the pipeline which have been already done as well as the proposed parts. The study focuses on Phase 4 which also called Keystone XL (Keystone eXport Limited), with a special interest in the second edition of pipeline extension proposed in 2008 by National Energy Board of Canada. On March 11, 2010 the Canadian National Energy Board approved the project.

Keystone XL starts from Hardesty City in Canada and it ends in Steele City in Nebraska State. The length of the proposed pipeline is 18.974 km (1.179 mile), but there is a big issue about environmental hazards. In 2011 a scientist from NASA James Hansen, mentioned that Keystone XL can make a big global warming with one small mistake, such as, oil spill. According to the State Department's review, the 830,000 barrels are going to be transformed through the Keystone pipeline daily and it means that it would add extra amount of carbon dioxide which approximately ranges from 1.3 to 27.4 million metric tons to the atmosphere. These numbers are only recorded in 2013, so it means that this hazard can be more serious than any expectations. Keystone XL is the most suitable choice for U.S government to transport oil from neighbor country. It tried to find more options for shipping Canada's oil to US but it did not work (Brad Plumer 2015).

First of all, they tried to understand if it was possible to make shipping with trains but it would cost two times more expensive than the current budget (approximately 8 billion dollars) of Keystone and it would be more dangerous for the environment compare with Keystone XL. In this way, maximum shipping capabilities can hardly reach 165.000 barrels per day. Moreover, other scientists had an idea about shipping with big boats but it was not good idea because they even did not pay attention to what had happened in "Gulf of Mexico" in 2010.

1.4 Geo-political and Economic issues.

U.S House of Representatives, Committee on Energy and Commerce proponents made a lot of debates about Keystone XL. In their opinion, Keystone XL would allow U.S to increase energy security in the region and reduce its dependence on foreign oil. U.S is on the top of oil importing country, it imports oil almost from all continents (Figure 2).

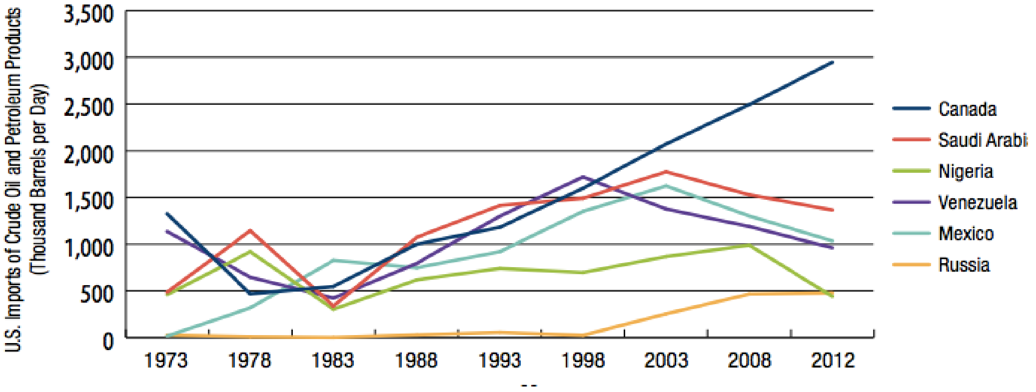

Figure 2. Top Oil Exports to the United States .1973-2013 (U.S. Energy Information Agency).

American authorities have another idea about a project that KXL can help to increase the price of the oil in Midwestern United States. It can help to partially solve their dept. The Keystone XL would also create approximately 42,000 job opportunities during the next few years and 3900 temporary constructions (The State Department, 2015). The project would push approximately 3.4 billion dollars to the economy which represents 0.02% of US GDP (Brad Plumer 2015, www.vox.com).

There is another key issue that some part of thesis concentrated aquifer where is the one of the biggest groundwater basin located in central U.S that proposed Keystone XL passing through the this area. The idea of the study to create suitable route which is not passing through the area. The Ogallala Aquifer is the one of the hugest aquifer which underlies approximately 450.000km^2. The Aquifer is part of the high plains aquifer system which is the principal geologic unit covering 80% of the high plains. It has really big role in agricultural and environmental trends. Therefore, 70% of the aquifer protecting by U.S government and other 30% using as a water resource for the agriculture and for environmental issues.

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1.5 Objectives

The objectives of the study is about to understanding the suitable route for the Nebraska State. Using the least cost path analyses it will be possible to find out what is the beneficial route or least hazardous route which cannot damage region environmentally, agriculturally and understand which route is suitable to prevent the area from expecting natural hazards from the study area. Nebraska State more famous with their agricultural issues and it is because of the agricultural zones located on high plains which has direct connection with the Ogallala Aquifer. Hence, proposed Keystone XL from TransCanada Corporation rejected by U.S government in 2014 after long period research. This pipeline rejected because of the most part of the pipeline was passing through aquifer area and also it will be second issue for the thesis, how to least cost path analyses will behave for following groundwater area. It was not possible to get exact data with more information about proposed pipeline and that is why, during the project there will be Euclidean path route which will help to understand effectiveness of each routes. Euclidean path chosen as prototype of proposed Keystone XL and this kind of path works only between two points (source and destination). In the thesis source point take into account Key Paha city which Nebraska part of the pipeline starting from there and destination chosen as Steele City in the South of the Nebraska State.

2. Literature Review

Large-scale linear projects, such as natural gas and oil pipelines, are planned and designed about a short route to limit the costs and materials of production. The most effective process to determine this route is through the use of GIS and a least-cost routing model (Aissi, Chakhar, and Mousseau 2012; Rees 2004; Feldman et al. 1995).The latest GIS techniques helps us for large amounts of cost-analysis data to be collected, stored and analyzed and improve the route accuracy for large-scale projects (Luettinger and Clark 2005). During the research of some studies as an example in previous studies, the methodology formulated to create least cost model for specific and various criteria evaluations and corporate simple criteria into one of least cost model. The complications of least cost models have limited with different categories of criteria and also they have been examined during studies. Most of criteria have been examined with physical characteristics of geographic area during the straightforward point of view to weighting the alteration of special factors. (Chakhar, and Mousseau 2012). In general there are not enough studies which have included impacts when to find the unique route selections of a pipeline and in included these criteria inside of model. Only one, (Lovett 1997) and one theses about least cost path analyses to route risky waste through study area and specific paths and both of this research provided a risk assessment due to biological hazards as an example population and environmental risk. (Lovett, Parfitt, and Brainard 1997; Kelly 2014)

Special ways to how to develop a process to determine the shortest, the lowest hazardous and least costly routes have had academic analyzing different techniques for many years. One of the first academic Edsger Dijkstra has founded way to solve problem. He developed an algorithm to determine the shortest path between two points connected in a network (Dijkstra 1959). This algorithm is one of the key elements that is included in many least cost routing models. In conjunction with a cost accumulated surface the algorithm is able to choose the least cost route across a given area. This kind of analyzes related on the neighborhood of cells around the proposed starting point and moves external from starting point to finally encompass the given study area. There are a lot of types of model that the algorithm can create cost accumulated surface with different patterns offering a different approach to solve the problem (Iqbal, Sattar, and Nawaz 2006; Luettinger and Clark 2005). The algorithm of Dijkstra is one of the commonly used tools to determine the least cost route through a surface and one of the simplest methods. That is already one fact that only with that algorithm can analyze various criteria and complied together into a cost accumulated surface and need only analyze knot across the surface. Only one restriction; however to using this type of algorithm is that it is computationally demanding and produces large amounts of data (Saha 2005).

To improve on this computationally demanding process has been used more and more companies began to develop new GIS packages to restrict computation time and accelerate results. The Environmental Systems Research Institute (ESRI) made a tool which called "Pathdistance" and it uses a smaller scale neighborhood analysis in order to try and control the effects of the model and make the path more realistic (Saha 2005). In effect to use of this smaller scale would help to make the compiled path less irregular and sleeker. This is a key when planning pipeline route due to the fact that a pipeline is connected together much more rigidly than a road. That is why "Pathdistance" tool became more prominent in studies due to their accessibility and this option to create much smoother designs. Downside of studies was that the limitation of the neighborhood. Analysis meant they could not accurately predict points in mountainous areas. (Saha 2005). The rapidly changing topography would be generalized too much in the cost accumulated surface for an accurate assessment of the route to be determined. Recent years ESRI developed more complex cost path extensions and made them together inside of the ArcGIS products. One of these extensions such as Cost Path tool has a significant rule about routing pipeline or to determine such more suitable routing place. This tools allows for the creation of both a Cost Distance surface and a Backlink surface that are then used alongside the main Cost surface to determine a more accurate and precise Cost Path from a source point to a destination point, all of these methods calculate the cost that path acquires across the surface (Collischonn and Pilar 2000; Rees 2004).

Current case studies have been performed to determine the least cost routes of major pipelines are mainly founded by major operators in the study. In the study researchers utilize both remote sensing and GIS data develop necessary criteria for analysis, For example: Bechtel Corporation in its analysis to develop a route a proposed pipeline in the Caspian Sea region provided one such case study. The researchers made a factors from the terrain, land use, geology and etc. through the use of geospatial data sets (Saha 2005; Feldman 1995).Using the remotely sensed data allows for areas all over the globe to be examined and evaluated without the physically travelling to the specific locations. The cost associated with the construction in each specific criterion was determined from previous study that was not published by Bechtel, permitting the researchers to obtain a greater accuracy on the real world costs. There were some factors that costs were also environmental and future liability costs should the pipeline to faults, river crossings (Feldman 1995). Feldman is one of the first studies actively and effectively integrate these types of criteria into the least cost routing model during the availability of remotely sensed and previously researched cost data. Due to researching time the use of ArcGIS software, the route that was proposed was 9 km longer than the straight line path but 14% less costly to construct (Feldman 1995). This kind of research helped to us determine the study area for less costly amount and with the available works which could help to researchers to examined the studies through the use of geospatial data.

There was some another methods to determine the least costly routes through study area and it called “View-shed analysis” (Lee and Stucky 1998). The general methodology almost the same with thesis’s methodology that is discussed previous chapters in this thesis is used to create a cost accumulated surface and a least cost algorithm. In using the view-shed analysis by Lee and Stucky 1998 a digital elevation model (DEM) selected in 4 types of paths in study area. But this analysis more useful for environmental planning and civil engineering for testing the pipeline construction, the analysis returns to results (Lee and Stucky 1998). And also in the methodology do not need some factors which have a big role in routing pipeline. For analysis there were no factors such as geology, terrain or land use etc. (Saha 2005; Lee and Stucky 1998). Therefore for pipeline routing and the focus of this thesis, view- shed did not use into the methodology.

There were some studies which have been done more currently focused on the costs of crossing water bodies and the built environmental (roads, bridge, etc) and on the slopes (Iqbal, Sattar and Nawaz 2006). The areas analyzed by researcher Iqbal in 2006, was more focused on the mountainous region of the North part of India, where the changes of grades of the terrain in short distances played a key role for determining where pipeline could be located. The criteria that were analyzed were first reclassified through a Spatial Decision Support System (SDSS) to make the system more result oriented and simpler to process (Iqbal, Sattar and Nawaz 2006). As a result of this least cost route was 1 km longer than existing pipeline in area but it was 29% less costly compare with existing pipeline. The use of the least cost model accurately displayed a more economical route and can be integrated into many other fields such as the planning water pipelines which also require more economical routing plans (Iqbal, Sattar and Nawaz 2006).

Other linear features which were similar to natural gas and oil pipelines that have used least cost routing models to more accurately plan the economic routes are roads and canals. Because, usually those kinds of works which related with water bodies and sources costs to more expensive and need more works to be sure with done as long as in the possible time period. And for understanding routes, especially in canals, features impacts of topography more important and influences the cost accumulated surface by making the weight values direction. With specific requirement the algorithms used to process the cost accumulated surface must be adapted to accommodate restriction (Collischon and Pilar 2000).

3. Study Area

The proposed Keystone XL pipeline passes through three states in US (Montana, South Dakota and Nebraska). It is more likely to cause some hazardous problems in Nebraska. That is why, Nebraska was considered as the study area of the thesis. Until the beginning of the Keystone XL project, there were not pipelines which could naturally or economically affect the region. The total study area is 200,520 square kilometers and the economic income mostly depends on wind power and solar power. The capital city of the state is Lincoln and the estimated population was 1.800.000 capita in 2014. Keystone XL would be the first and largest pipeline which passes through eastern part of Nebraska. After first proposed pipeline, there were wide oppositions inside Nebraska regarding declining the project because of the expected pollution and global warming. The proposed Keystone XL was passing through the middle of the Ogallala Aquifer and could make dangerous hazard problem to the region (Figure 3).

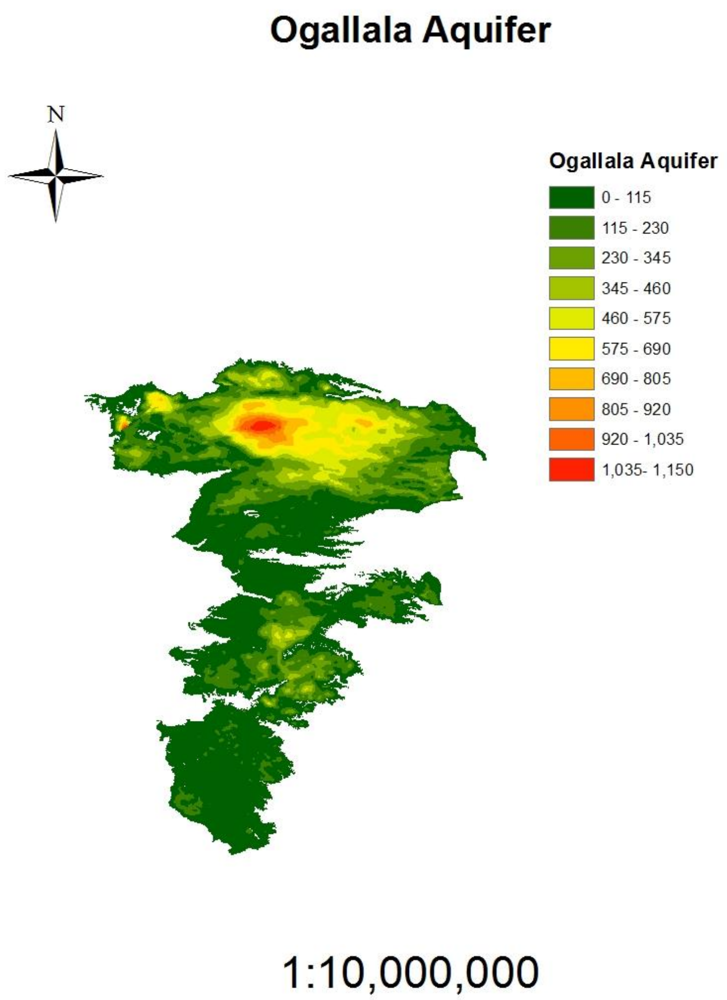

Figure 3. Ogallala Aquifer. (Map applies to 1997)

Another key element of study area is located in the Ogallala Aquifer (Figure 3). This aquifer is one of the biggest water bodies in the world and also it has a significant influence on importing water to Nebraska and other neighbor states.

Initial steps about Keystone XL were proposed to pass through the East part of aquifer. But this issue could be more dangerous for following study area. Dr Jim Goeke, a research hydrologist and professor said that the Ogallala Aquifer providing more million's people with quality water and it is necessary to try find more suitable routing way for Keystone XL. Small incident can make big problems and even there were some parts of aquifer deepest parts changes between 50 and 300 feet (Figure 4) and also this shows us first proposed pipeline was not good enough for routing process. Keystone XL's path is east of more than 80% of the Ogallala Aquifer. Impact modeling conducted by the State Department and the Nebraska Department of Environmental Quality has shown that in the very unlikely event of an incident, impacts would be localized to as little as tens of feet (Keystone-xl.com).

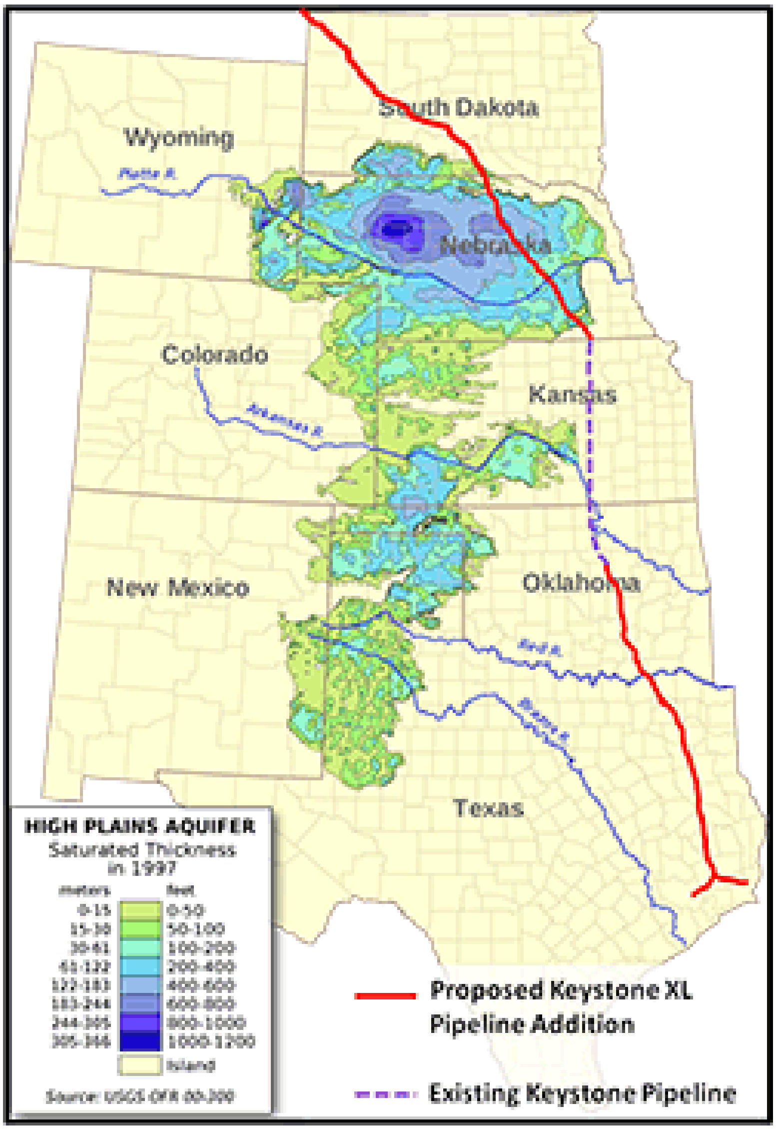

Figure 4. The first Keystone XL proposed pipeline. (Keystone-XL.com)

4. Methodology and Data

4.1 Methodology

Long distance gas and oil pipelines are complex systems in the specific GIS fields. For determining the more appropriate routing way, it is needed to find a geographic location closer to the study area; also, it is needed to filter geological condition and many other factors that can effect defining the proper way for pipeline. There will be many different data, diagrams, schemas, figures and different data files, which are difficult to use and update together effectively on each step of planning and pipeline construction (Xaoge and Wentong 2005). These parts of the study are more inexplicit and more difficult for determination. Hence, the experiment period of the data files study is divided into four essential criterion. Some of them are downloaded in a vector format, also converted from vector to raster. Because, vector data is not appropriate for least cost path analyses and at the end cannot help to solve the same problem. For this point of view, for routing model it is mandatory to create geodatabase and include different raster files for each specific criterion (Figure 5).

The biggest issue of the study is about defining the implementation of each criterion with each raster datasets. Due to the methodology part, some were downloaded as a shape file and other kinds of datasets. As previously mentioned, it was necessary to convert data files to a spesific raster format. Another key element was remote sensing techniques which helped to use land use map and elevetion models in certain criterion. The study criterion was divided into four different parts: Slope criterion, Geology criterion, Land Use criterion and Population criterion.

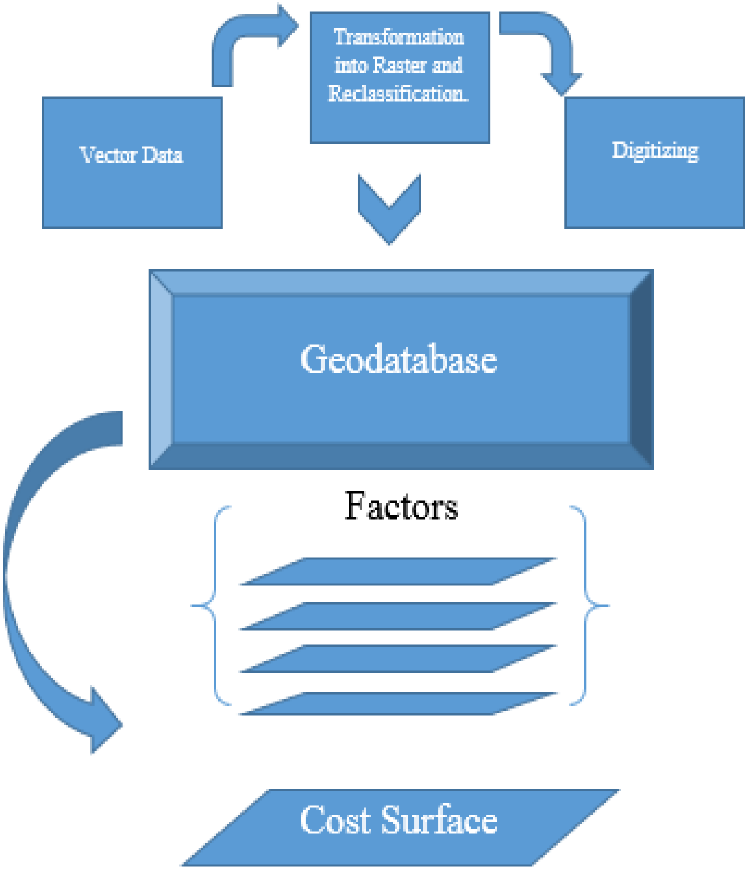

Figure 5. Data proccesing and factor rasters shown as a criterion datasets.

The principle of these criteria rasters were to reclassify and make distinction among the different costs associated with each specific criterion. The reclassifying and ranking of the criterion rasters created scales from 0 to 10. According to the scale 10, was the highest cost value and 0 was the lowest one. It helped to study to recognize which part of cost was high or low for accumulating cost value all together. It is possible to route the pipeline from the lowest to the highest cost or reverse, but it would be more expensive compared with normal way. Another example is that, vertical slopes are much more dangerous and difficult to consturct large pipelines. That is why, it is better to put highest values for the particular area and after planing it would be more suitable to create large linear fetures through the area (Rees 2004).

In case of the study determinations of the certain rankings, the same techniques were used (Feldman 1995).

The created routes were compared to one another and also a straight-line path through the study area to determine the cost benefits of the analysis and to make sure that the routes were realistic. Multiple routes were created with differing weights for each criterion in order to see what geographic locations are most affected by each specific factor. The unit calculations that were derived from the tool were also compared to one another to identify if the weighting system increased the costs associated with the pipeline or decreased them.

4.2 Data Sets

For the least cost path analyses, it is needed more detailed and accurate datasets, especially for geological criterion. The reason is that, implementation of less hazardous ways need more comprehensibile datasets for area. Geological criterion in thesis was downloaded with full detailed information, while some parts which were not good enough for routing were ereased from ArcGIS and digitized for the study area. The data was downloaded as a vector file and with the help of ArcGIS, was converted from the vector to the raster file in order to display the continous surface. At the same time, the geological raster that was created to display the highest cost values contain geologically young and the lowest contain geologically old, due to their higher stability or load bearing proporties (Paige and Green 2011).

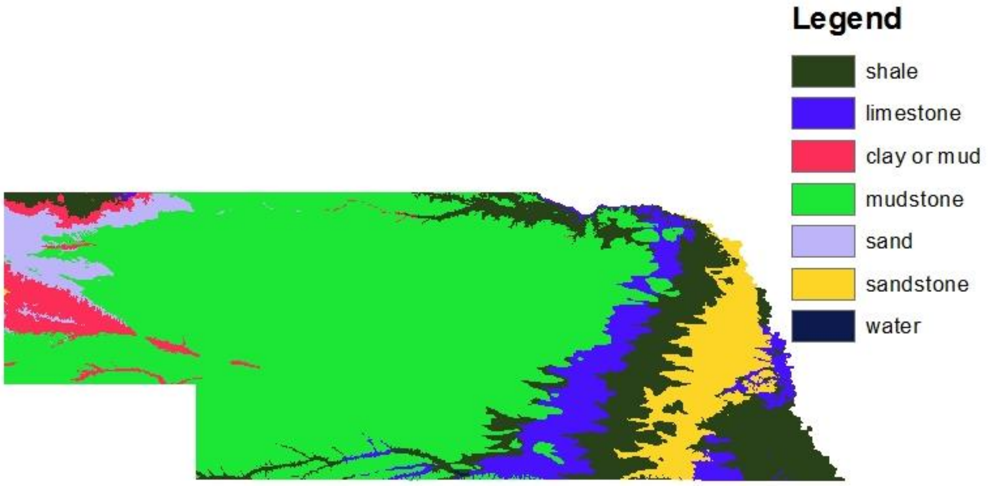

Figure 6. Geological map data for Geology criterion of Nebraska. (USGS)

The geological map of the Nebraska included different kinds of geological surveys, such as, hidrology, soils, oil shales, different kinds of rocks, water recources and etc. From that point of view, this map was perfect choice for using in the study. The geological data of Nebraska was downloaded and extracted from United States Geological Survey (USGS). Fur more detailed information possible o see in the following link. (http://mrdata.usgs.gov/catalog/lithclass-color.php). Table 1 in the Annex displays data processing for geology criterion and how effectiveness can effect to each weighted overlay surface.

Another key data element of the study area is determining the slopes for the specific study area and define the most suitable corridor for the pipeline. To use the slope it is needed to get Digital Elevation Model (DEM) dataset with high resolution to accurately display the changing topographic and geologic features in the area. There is no need for the DEM dataset of full area, so the data for thesis gets just half of the Nebraska state**,** therefore it is needed to understand the source and destination point given by the data. The data was providen by official website of NASA JPL and chosen only Shuttle Radar Topography Mission (SRTM). Since, SRTM data set had a 90m cell size and it helped to implement the pipeline with high accuracy. The coordinate system was North American Datum of 1983 and all datasets were digitized and the scales were chosen in this coordinate system. The creation of these criteria rasters were completed in order to reclassify and rank the different costs associated with each specific criterion. When reclassifying and ranking the created criteria rasters the scale from 0-10 was used where 10 would indicate the highest cost value and 0 the lowest. This scale was used both for simplicity and for the ability to easily recognize high/low cost areas visually on the cost accumulated surface when all of the criteria rasters were combined together. For example, steeper slopes are much more hazardous and difficult to construct large linear features; therefore, the areas encompassing the steepest slopes were assigned the highest values in the output raster (Rees 2004). The determinants for the specific rankings for each criterion was done arbitrarily but referenced specific case studies such as Feldman et al. (1995)Data processing calculated by “Reclassified” tools in ArcMAP and after reclassfied data criterion using for the each weighted overlay (Annex A. Table 4).

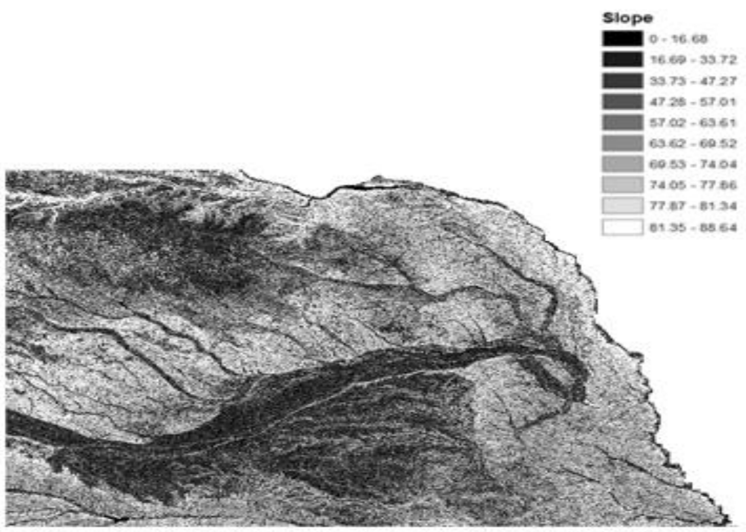

Figure 7. Elevation data for Slope criterion of Nebraska (NASA JPL).

Other compulsive option of the routing pipeline through the study is to determine the acqiution of the accurate location, thus there is a need for a very exact data to define the area. It is almost impossible to find this kind of data in available data storages. At the same time, to understand the accurate area it is needed to make new land use classification for the routing system. In this study it was not possible to create a precise data for the study area. Therefore, just simple classsifaction method was carried out and compared with the data, which was downloaded from the official website of University of Nebraska. The data was rasterized and digitized for the study area. During the digitizing period, there was not any changes and almost nothing changed from 2005 till 2014. Besides, land use criterion would permit the least cost paths to take into account the types of surface that are most comfortable for the construction and less hazardous (Kelly 2014).

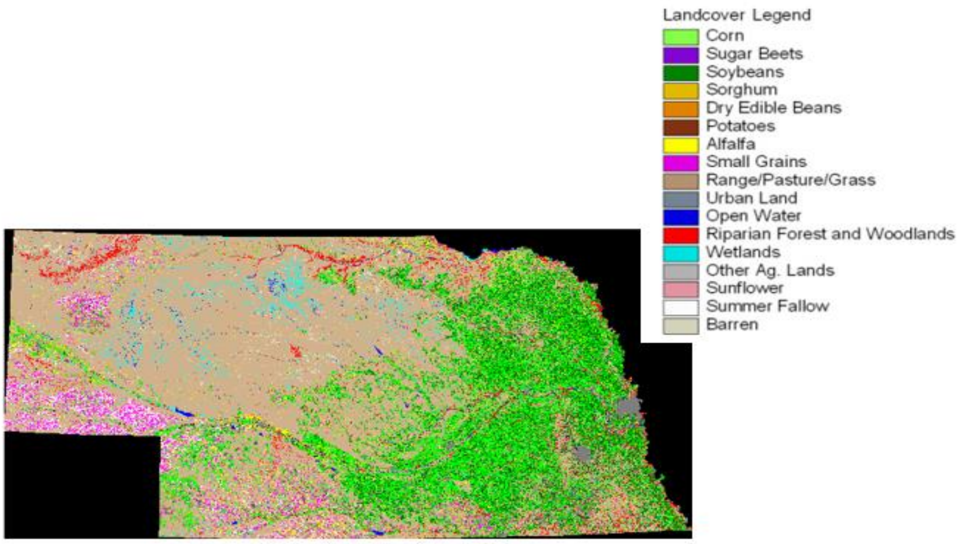

Figure 8. Land Use data for land use critertion of Nebraska (University of Nebraska).

The data file is downloaded as a .TIFF file format from the offical website of the Univeristy of Nebraska-Lincoln and in Figure 8 shows all attributes of the data in legend type.

The values were changed only for computation of the landcover. Because, each class had a different values which is not good for routing. The lowest values were used with 1, such as agriculutre, other lands and etc; while the highest values mostly were about water parts and urban places. Since, exploring the study area mentioned that Keystone XL passed through area mostly covered water recources (The Ogallala Aquifer) and also there were some small lakes and rivers. Routing the pipeline through water areas is dangerous and it would cost the construction lots of money. Given this fact, before planning the routing, it is better to calculate each classes of the land use just for insurance not to get any problem in the future. Table 3 in the Annex A displayes how data proccesing prepared for the each weighted overlay surfaces.

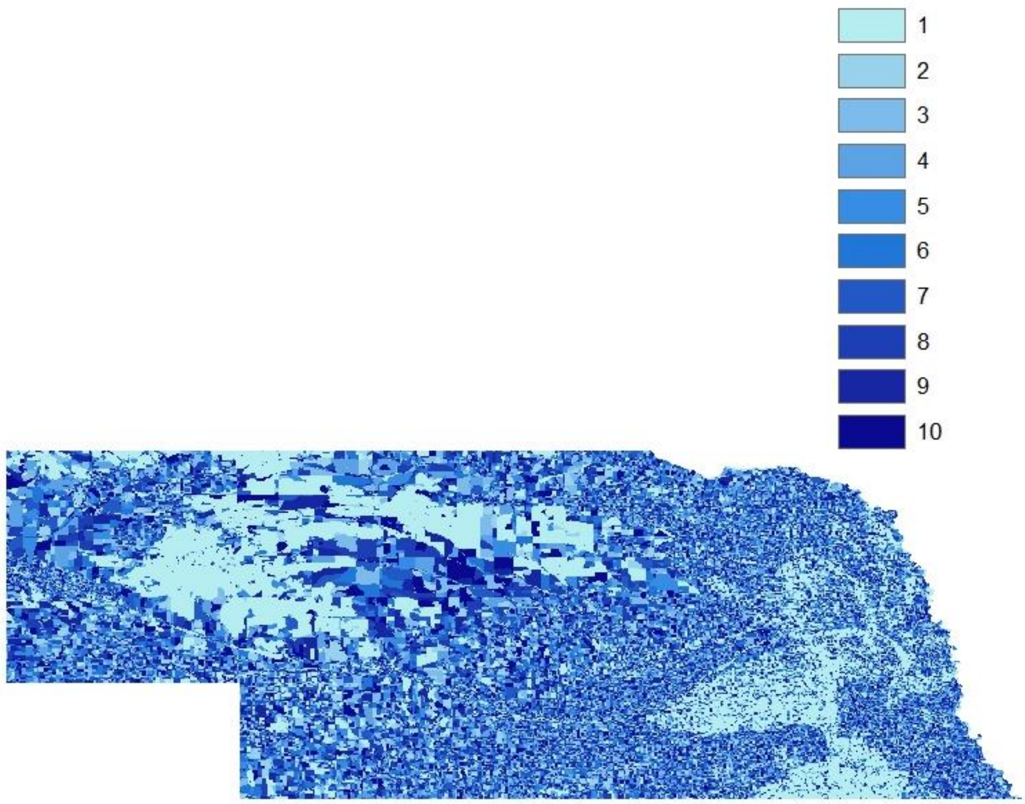

Figure 9. Envirnonmental data map for environmental criterion(Census).

The last data facor is about different environmental issues which more concentrated on the population, houses, block, and etc. The data map have collected by using the U.S Census TIGER Data Resources and using the ArcMap tools data have been created for one main data factor. The main goal of the using the environmental criterion is because to protect state from different kinds of the hazards. Each year in different states of the U.S some hazards calculated arround 1-2 billion dollars because of the various hazards (oil spills, gas leaks or natural hazards such as hurricane). Hence, data try choosed to protecting the study area from hazards and during routing period to not make some cunstructural affects to the environments. The spatial resolution was set to the same as the slope and lithology rasters and the raster was clipped to the extent of the study area. The water bodies' raster was then reclassified in the same 1-10 but much differently from the other criteria rasters. Figure 8 displays environmental data converted to raster file and following figure also displays result after reclassfying. About data values more detailed information shown in the Annex A. Table 1.

4.3 Accumulative Cost Surface

The combination of the each criterion rasters in order to create least cost path was separated into two different techniques. First of all, criterion resters combined together with equal weighting, where each of the 4 factors calculated with 25 percent of the influence for routing procedure. In this case each criterion was ranked in a similar scale and clipped only for the same geographical location. The second technique generally was divided into four different weighted overlay criterions. Each overlay was accounted with a different effectiveness percentage. All those processes were taken from varios studies and from some reports which related exactly the same topic and also relevant studies discussed in literature review part (Saha 2005; Geneletti and Orsi 2011). Consequently, each criterion was weighted with specific amount of percentage and then combined together for creating a cost accumaltve surface using the map algebra. All of the weighted criterions of the four criteria were collected inside of 100%.

Except the equal weighting overlay, other weighted overlays accounted for each specific criterions in order to determine and understand the difference between propoesed pipeline and least cost pathes.

For the first weighted overlay is mostly about the elevation model of the region. With accurate slope criterion it would help to define the heavy slopes and topographical partiality of the region. The terrain which includes vertical slopes are more acceptable to fail.

The second weighted overlay more is about geological stability and geology of the area. The geological segment has a big role for the routing pipeline. It would help to predict the area about natural hazards and protect from future hazards. The geological overlay part is determined from USGS that provides compositions and age.

The third overlay adopts the land use charasteristics of the study area. The land use had a more detailed information about the study area. Almost all natural and agricultural criteria are combined insde of this criterion. It could help constructors to determine more suitable places and protect agricultural areas from future hazards such as oil spills and etc.

The study area limited in each specific criterion and also other limitations were about to figure out the resolution of the each raster datasets and making them more suitable for applied study area. Resolutions of each cell were different in each raster format, also other datasets such as population and geology datasets were converted to raster and cell of each of raster formats modified as a resolution of the elevation data and in order to get effective costs it was very useful to understand that.

During analyzing of the weighted overlay surface and reclassifyng period there were some necessery issues such as “NO DATA” values. In each category (except land use criterion) there were values which displayed as “NO DATA” value. It was displaying in the map some how it can make confusion with error of the cell. Note that 'No Data' cells are excluded from the possibility of travel. The procedure described "ensures that the lowest accumulative cost is guaranteed for each cell". Therefore, cost assigned to every link reflects a resistance value of moving over one geographic distance unit (ESRI Desktop Help and Belka 2005). More formation about data processing for each criterion detailed in Annex A.

4.4 Least Cost Routing Tool

After the creation of cost accumulative surfaces using the ArcGIS, least cost tool and cost path were handled to define the least cost rout through the study area. The source and destionation points were appointed to the accumulated cost surface based on the proposed pipeline. The source point was located in the North-West part of a city which was called Key Paha and the destination point was located in the South part of Steele city. It was not possible to get point by downloading or searching, so the special vector data inside Keyston XL geodatabase was made. The starting and ending points were used due to the accumulated cost surfaces and had the role to control them as an input and output location inside of the model. Afterward, next stages were to understand roles of cost distance tool and backling rasters, while these rasters were used in conjuction inside of cost path tool to create a linear feature between source and destination point.

The created routes were compared with proposed linear feature and helped to determine suitable route for weighted overlays. The routes were created with different weights for each criterion, in order to identify which geographic locations had more influence and which were most effected by each criterion. All those methods were taken from different GIS recources and studies which related to the same topic, such as Kelly 2014 and Saha 2005.

5. Result

5.1 Equal Weighted Overlay

The initial cost surface that was generated combined all 4 criteria (slope, geology, population, and land use) for pipeline routing equally where each criterion accounted for 25% of the total cost value per cell. The four factors as stated in previous sections generated a continuous cost surface across the study area that is displayed in Figure 9.

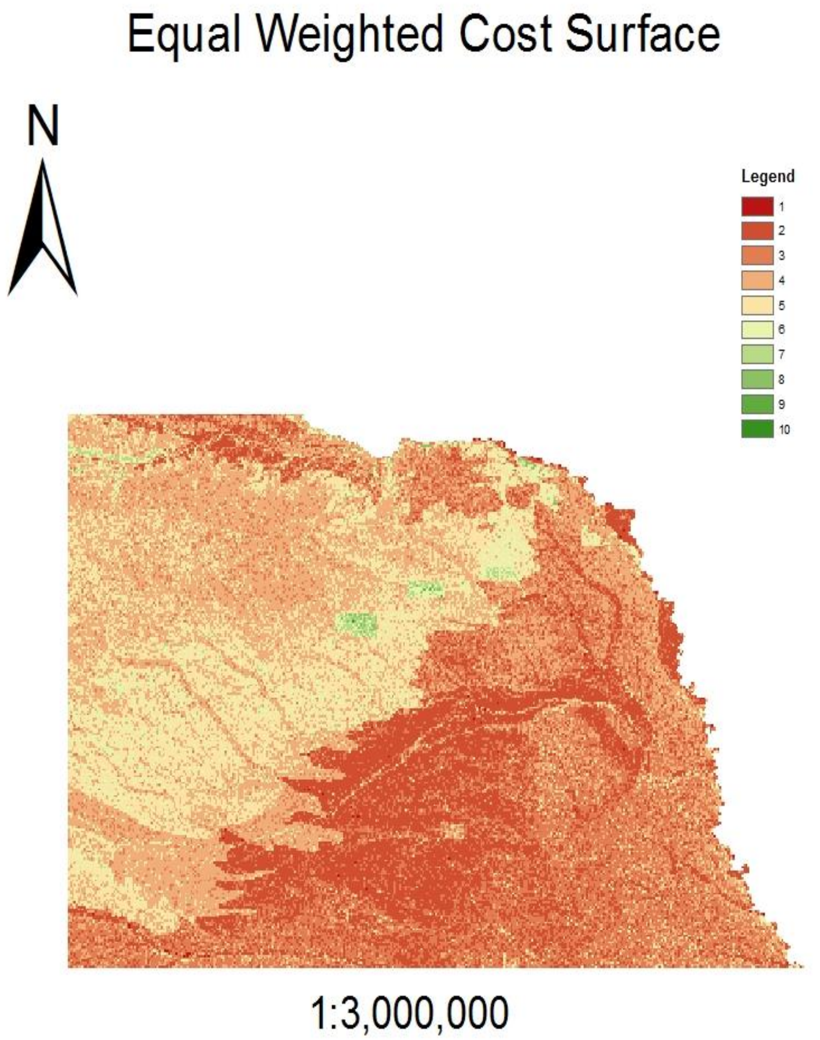

Figure 10. Equal Weight cost surface that was formed for the study area.

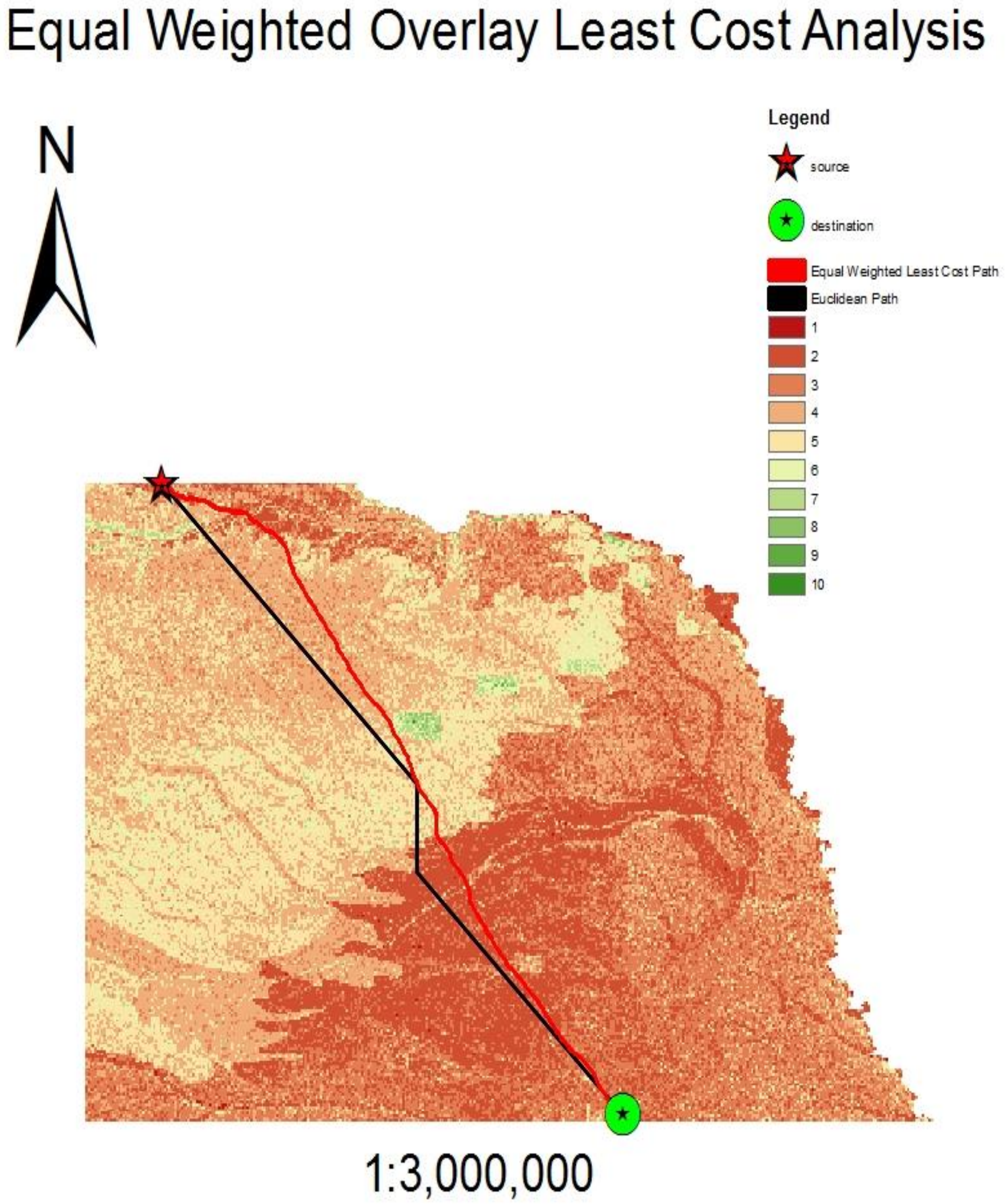

Figure 11. Equal Weighted LCP and straight-line route, which achieved for cost surface Equal Weights overlay.

In the Figure 10, the green areas define the highest values which this places are not suitable for routing. Moreover, the map shows the less risky areas that contributed with the dark brown color. For the reason that the percentage and route corridor would be more proficient for the overlay, which classified with the equal percentage effectiveness.

Route	Length (km)	Units per path	Influence by percentage
Least Cost Path	423.18	2052	17.1%
Euclidean Path	400.25	2476	

Table 1. Least Cost route lengths and Euclidean Path route length, which based on Equal Weighted Cost surface.

This study has different values from the different lengths of the routes. The relative cost was impossible to use as a quantitative measurement of the cost of the pipeline (Kelly 2014). In addition, straight-line path cost was used as a prototype of the original pipeline. It was not possible to get GPS points from the original Keystone XL, as there was no chance to get the relative cost of the Euclidean Path to compare the effectiveness between both paths. The following Table 1 shows that the LCP is 23.18 km longer than STP. Table 1 displays the units that are associated with each route and also the percent effectiveness that the least-cost path obtains when compared to the straight-line path across the same cost surface. The least-cost path is almost 23 km longer than the straight-line path but is 424 units less indicating that the least-cost path is 17% more effective

5.2 Weighted Overlays

This part of the study is more about Weighted Overlay surface that had big effective influences for each specific study field. Multiple cost surfaces were created using the Weighted Overlay tool in the ArcMap software that designated specific weights to each criterion. Table 2 below displays the weight amounts for each of the weighted cost surfaces that were created. Each Weighted Overlay surface that was created highlighted a specific criterion or criteria more than others to detail the impact that they had on the least-cost path.

Surfaces	**Criterion**	**Percentage**
Weighted Overlay 1	Environment	15%
	Land Use	10%
	Slope	45%
	Geology	30%
Weighted Overlay 2	Environment	30%
	Land Use	40%
	Slope	20%
	Geology	10%

Weighted Overlay 3	Environment	10%
	Land Use	10%
	Slope	35%
	Geology	45%

Table 2. All three Weighted Overlays with specific weighted percentage for each criterion.

All criterions were explored, digitized and reclassified with the help of "Reclassify" tool in ArcMap and divided into 10 classes. There was one simple and main reason for the land use criterion that criterion was not reclassified. This is because, the land use had 25 basis classes in itself that were given special values just to determine least hazardous routing through agricultural areas of the study area. In order to define the routing areas, it is necessary to have digitized values for each class. For instance, water land, wetland and other similar classes were exploited with high value such as 10, according to methodology part it can be explained that it would be very costly for construction after planning (constructing bridges, hanging bridges or etc.). The others were mostly computed between 3 and 4, the values which were taken as standard class values for land use (Annex B).

In order to get the essential results, it is needed to understand which criteria could be more effective or least hazardous. The following figures (Figure 13, Figure 14 and Figure 15) demonstrates the results that are acquired after long way exploring, digitizing. It is also displayed all the three least cost path routes for each overlay cost.

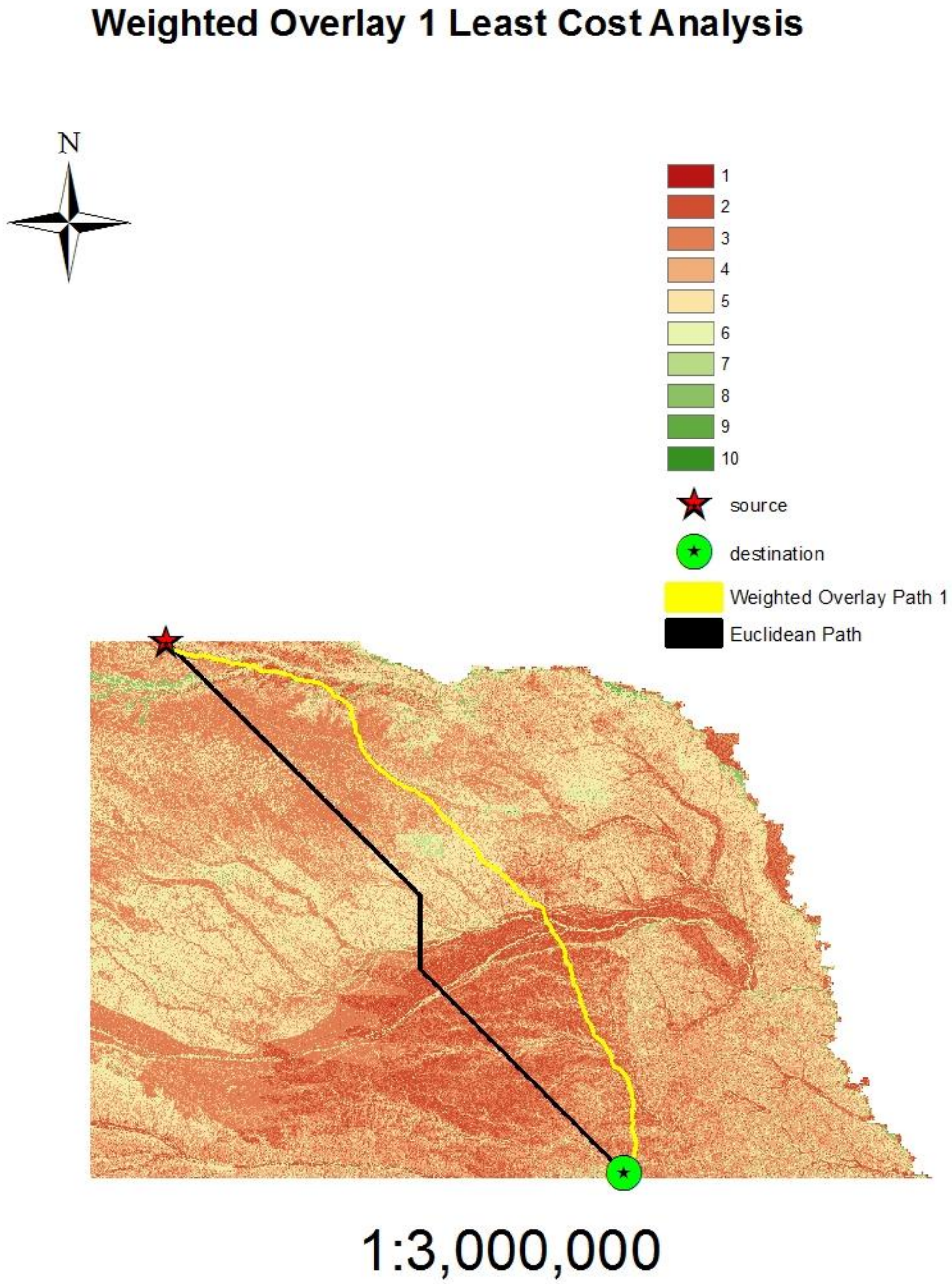

Figure 12. Least Cost Route and Euclidean Path for Weighted Overlay Surface 1.

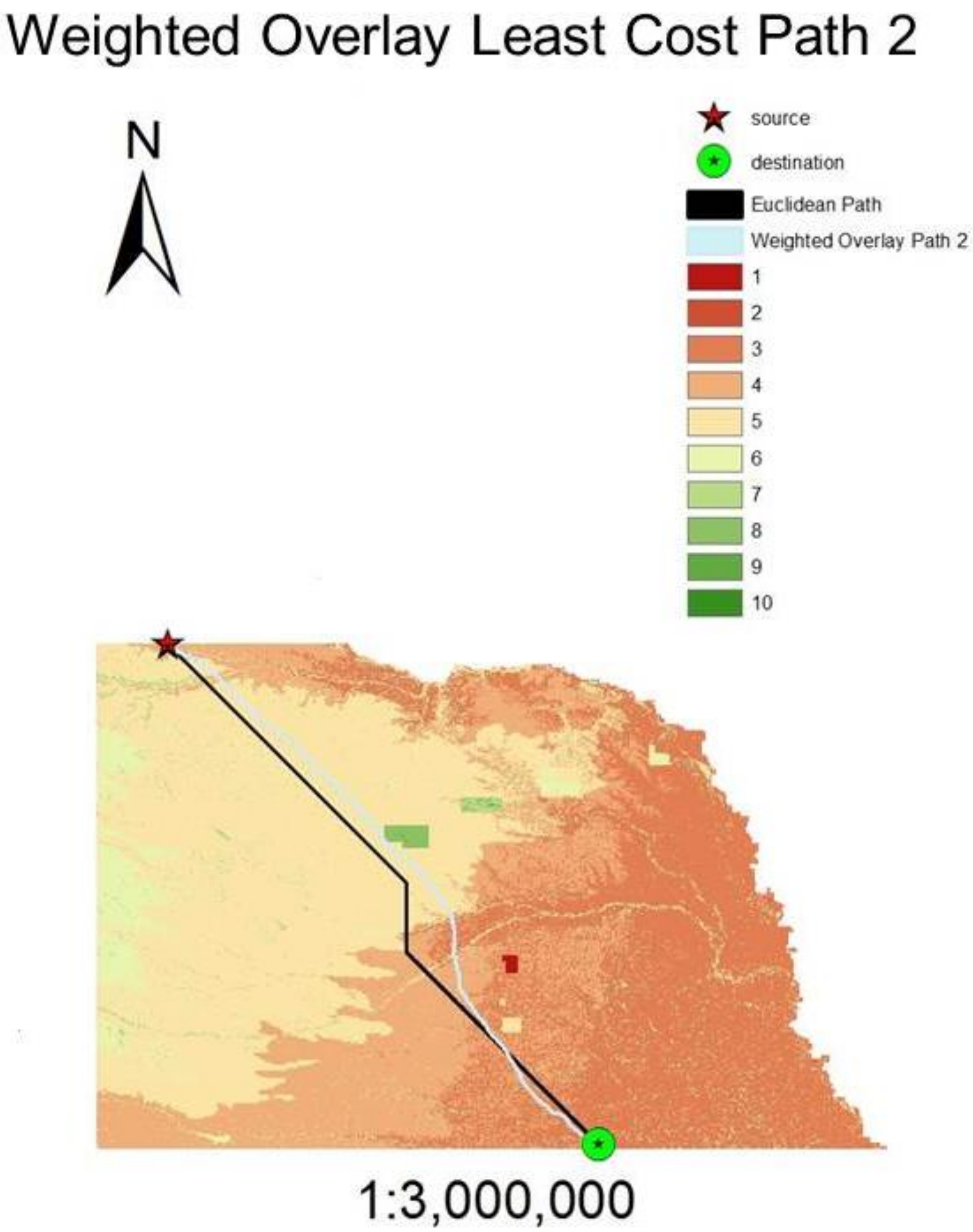

Figure 13. Least Cost Route and Euclidean Path for Weighted Overlay Surface 2.

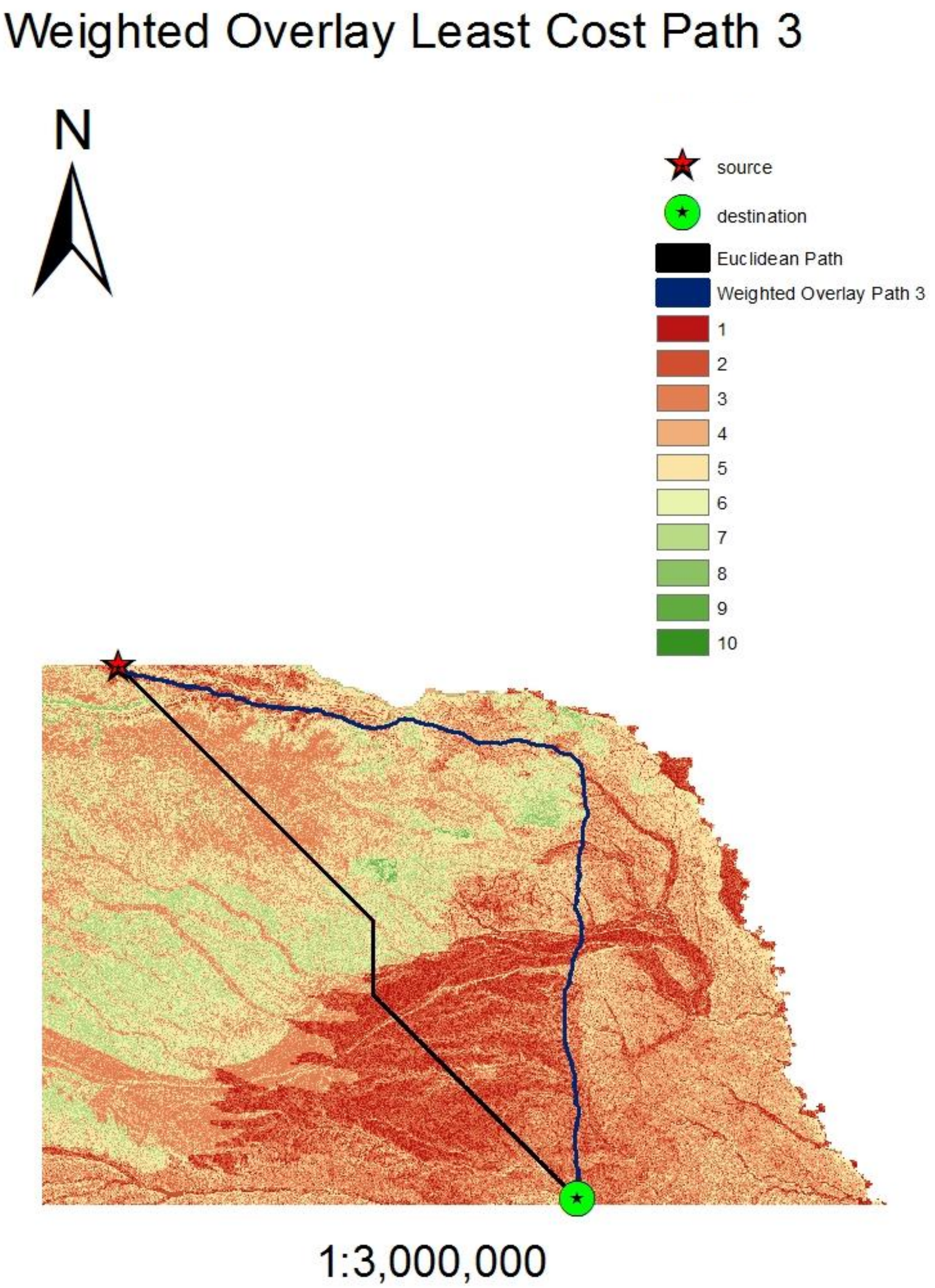

Figure 14. Least Cost Route and Euclidean Path for Weighted Overlay Surface 3.

Route	Surface	Length (km)	Units per path	Influence Percentage
Least Cost Path	Weighted Overlay 1	447.28	1867	27.1%
Euclidean Path	Weighted Overlay 1	400.25	2561	
Euclidean Path	Weighted Overlay 2	421.04	2048	14.7%
Euclidean Path	Weighted Overlay 2	400.25	2401	
Least Cost Path	Weighted Overlay 3	515.56	1404	37.0%
Euclidean Path	Weighted Overlay 3	400.25	2236	

Table 3. Least Cost route lengths and Euclidean Path routes length, which based on Weighted Overlay 1, Weighted Overlay 2 and Weighted Overlay 3 cost surfaces.

The costs for the straight-line paths through each of these cost surfaces are higher than the costs for the least-cost paths, although the lengths of the least-cost paths are longer. By examining each Weighted Overlay surface one can see that the highest percent effectiveness was calculated from the third weighted overlay surface with its value of 37% The third weighted overlay surface placed emphasis on the geological hazards within the area more so than any of the other criteria. This indicated that the major criteria for the routing in this study region were the geological hazards that are present. The Least Cost Path 2 concentrated on the Weighted Overlay which has more influences from Environmental and Land Use criterion. It is because of the most environments and agriculture located on the middle part of the study area. Location of this both criterion is in the high plains area which is very useful for agriculture and that is why, result displayed 14.7% (less than compare other results). LCP 1 displayed average result compare Weighted Overlay 1 and 2. Because, more slopes of the area more upper in the middle and west part of the East part of Nebraska but effectiveness of geology criterion effect cannot let to analyses to route path from the East part it is therefore, LCP 1 displayed 27.1% more effective compare with Euclidean Path.

There can be some confusion about LCP 2 that route passing through area where there is no data calculated. In the Annex B. Figure 1 displays more details about this issue. All analyses behaved perfectly and more accurately according to the data sets.

5.3 The Ogallala Aquifer and Proposed Keystone XL Route.

The Keystone XL pipeline was proposed by Trans Canadian Corporation and the available data can be taken from ESRI. As previously mentioned, the following details about the data was not with special GPS points or with essential details and it was not possible to determine main differences between proposed pipeline and least cost path routes. It is because of the fact that the construction and surveying part of the project has not started yet. As a result, it is not possible to get further information about the data. The proposed pipeline and least cost route features are shown in Figure 15 with reclassified slope surface. In this slope surface, the legend is a little bit different from the previous figure legends. The white parts of surface display the lowest slopes in the study area.

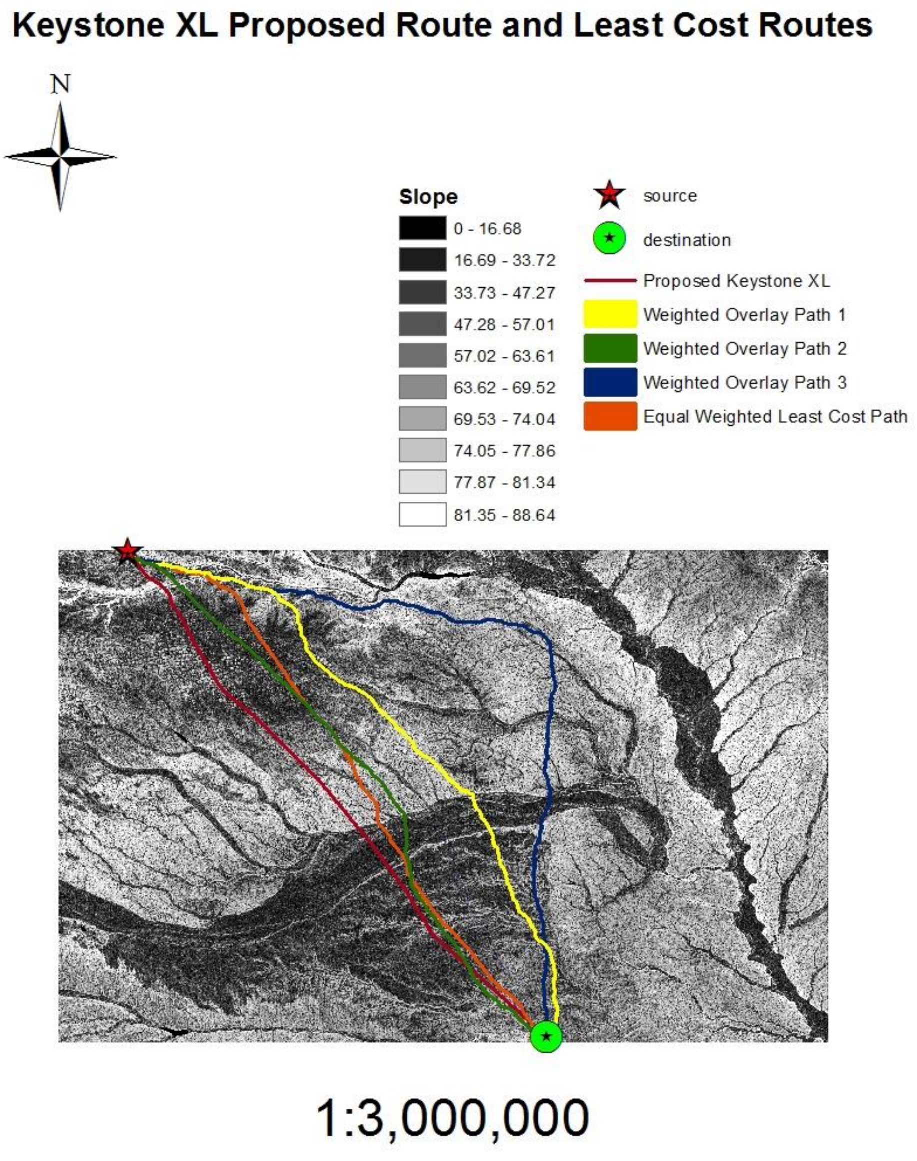

Figure 15. The proposed Keystone XL from Trans Canadian Corporation and all least cost path routes displayed on the slope surface.

Due to some problems, it was not possible to compare all pipelines with their further information. The study was about which routes are more effective and which of least cost routes pass through the Ogallala Aquifer. The results have been discussed in the discussion part of the thesis. Another issue was about the study that some of the routes passing through the area are protected by the State Department of the U.S and some other governmental organizations. The Ogallala Aquifer has been explored in the study area part and Table 4 displays that which routes passing through the aquifer and results shown with percentage of the. The results were expectable from my side of view. So, the least cost path route which was represented on the Weighted Overlay surface 3 was more effective and less hazardous compared to the other routes and proposed pipeline.

Surface	**Length of the routes, which passed through, protected area. (km)**	**Percentage**
Weighted Overlay 1 LCP route	303.54	68%
Weighted Overlay 2 LCP route	358.43	85%
Weighted Overlay 3 LCP route	210.56	40%
Equal Weighted Overlay	325.36	77%

LCP route		
Proposed Pipeline	340.13	86%

Table 4. The percentages and length of the routes, which passed through the Ogallala Aquifer.

In the Table 4, it is easy to realize that Least Cost Route 3 has less percentage compared to the other routes and it means that this route occupied only 40% of the underground water field.

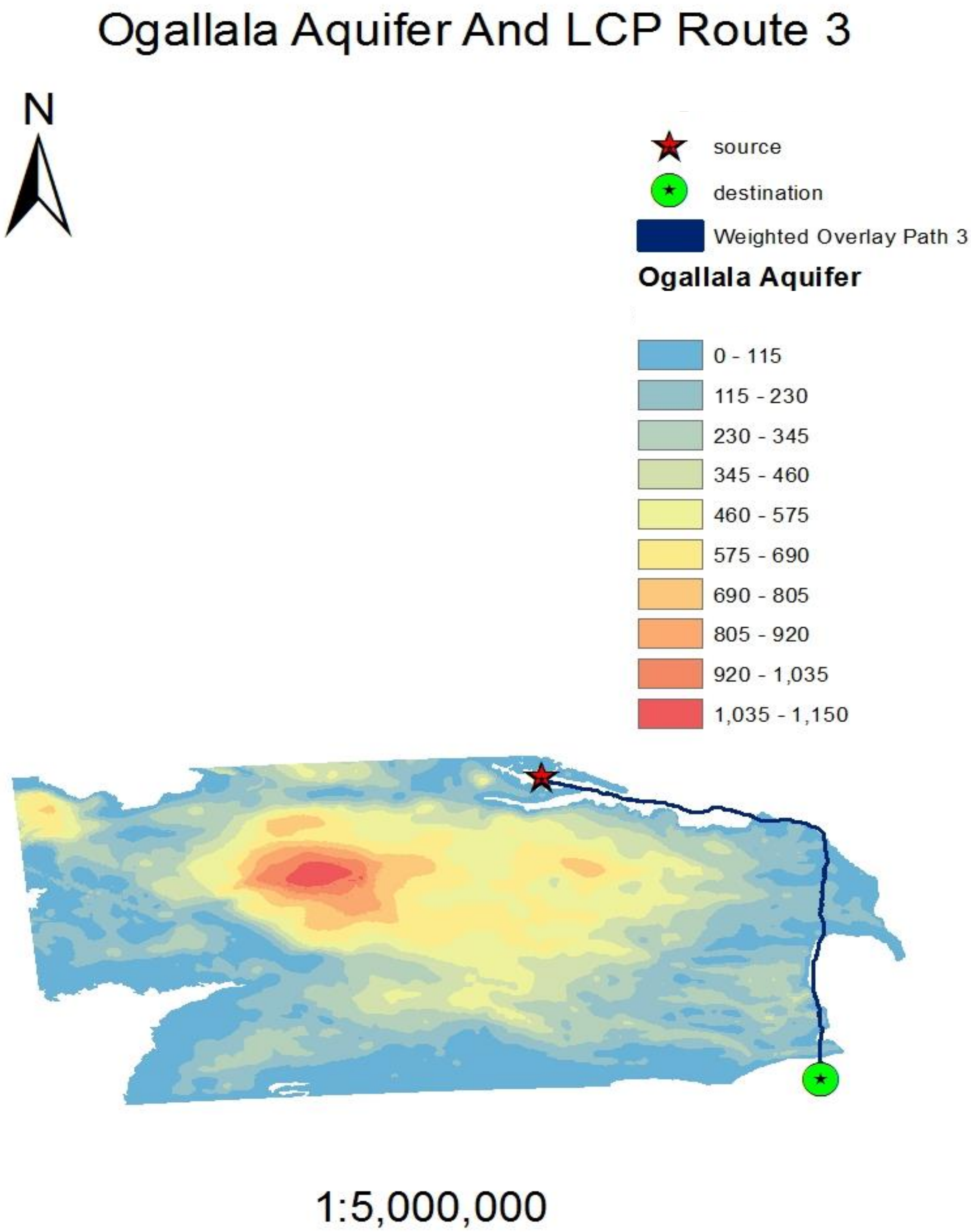

Figure 16. The Least Cost Path route, which is related to the Weighted Overlay 3 and shown with the Ogallala Aquifer geological map.

The following Table 4 and Figure 16 gives accrued results about less hazardous routes and it shows which the least cost path route based on the Weighted Overlay 3 was more effective and less hazardous. During the calculation time, the units gave almost 2 time more units than straight-line path, but effectiveness of the route 37.0%. It is also clear that the weighted overlay 3 was more concentrated on the geology criterion and it means that the data covers the quality of the high level 9 for the study area. Detailed lengths and costs were calculated by usage of the ArcMap with specific coordinate system, projection type and the scale. This criteria is one of the main purposes of the study.

6. Discussion

During the examination period the results were composed from the different four cost surfaces within the study clearly showed that the least cost tool is more effective then compare with a normal Euclidean Path. Euclidean Path chosen for as a prototype of the proposed Keystone XL and generated between two points (source and destination). It is because of during the study, it was not possible to get an available exact data about proposed pipeline which is concentrated on the usual GPS points. Starting with the Equal Weighted cost surface, least cost path route detailed units were around 17% lower than standard Euclidean Path. According to the Austin Kelly., 2014, this is not the case though due to the specific criteria that were combined together to form the cost surface. This is where the logic of the least-cost algorithm that is coded within the ArcGIS tool displays its worth in navigating the highest cost cells while traversing the cost surface from source to destination. (Kelly 2014)

The cost that are accumulated for each derived path are not numerical figures that can be used in projects. For example, in engineering methods as these values only helping to determine the units of each cost that is generated from transom of the specific cost surface. The units of the costs displayed on the Table 1 for Equal Weighted cost surface and Table 3 for following Weighted Overlays. It is also appropriate to note that the units of the each path costs that were calculated for Equal Weighted Overlay cannot be comparable with other Weighted Overlay's results. It is because of the factors of Equal Weighted Overlays divided between equal percentage effectiveness but Weighted Overlays have their own specific effectiveness values which generated on specific values. Another point that issue to according to Kelly 2014, is about different scaling of the cost units between two types of surface (Equal Overlays and Weighted Overlays).

When the effectiveness of each path routes were compared to another the higher the effectiveness of the routes, the better routes were crossing through the specific cost surfaces. In displayed table 3 the least cost path was made across Weighted Overlay 3 was the most efficient route to compare with the Euclidean Path. Actually, all of results behaved in very nice way but the thing is that each routes were dependent on their specific criterion. The percentages of the each criterion have gotten after few analyses period which have given by ArcMap. Initial steps about feedbacks of the each criterion were random and then with starting the analyses feedbacks changed according to their accumulated cost cells. In this case, Weighted Overlay 3 cost surface percentages feedbacks were getting by their cost and table 3 it is more detailed. Weighted Overlay 3 more effective by geologic values of the units which is more concentrated about lithology, rock, water resources and etc. in the study area. The Least Cost Path 3 was more effective to compare with other overlay surfaces and supposedly it is because of the data was more accurate for the region. It is already clear that in the study are there is a big aquifer which has influences for the Least Cost Path and I was one of the main goal to determine the route which is not passing through the aquifer area. The available data set downloaded from the USGS official website and Conservation and Survey Division (CSD) provided this data more beneficial. CSD provided beneficial dataset which had beneficial effect on the study. They engaged in geologic mapping, researches about soils, settlings of different rocks and etc. Studies conducted by CSD personnel provide the basis for effective resource management and use, water resource safety and security, the exploration and exploitation of industrial mineral and fuel resources, natural-hazard mitigation, and building-site evaluation (University of Nebraska 2015). The Least Cost Path which generated on the Weighted Overlay 3 cost surface and it is more effective compare with Euclidean Path and other LCP routes percentage. Secondly, only 40% of the route passing through protected the Ogallala Aquifer and in this issue also has more effective result to compare with other routes.

Another main issue were concentrated to find out the route which cannot make land slide and terrain hazards for the study area. Weighted Overlay 1 cost surface more concentrated on the slope criterion and feedback percentage about weighted overlays have same methodology which explained in previous part. From the study area part of the thesis it is almost understandable that in the following region terrains are not higher than the West part of Nebraska State and study generated on the East part that is why, level alttidue less than the Middlewest of Nebraska. The elevation data downloaded from official website of the NASA JPL and digitized for the study area. The results showed that LCP 2 was 14% cheeper and less hazardous compare with the Euclidean Path but this route connot apply for construction. Because, 68% of the least cost path route croosing through the Ogallala Aquifer. Compare it to Equal Weighted and Weighted overlay 2 it is seems more suitbale but compare it with LCP 3 that the route LCP 1 is more longer.

The latest overlay is displaying agricultural and evinormental issues for Nebraska State. The mostly agricultural issues located in the central parts of the study area and it is because of the high plain location. Ususally agricultural areas are locating on the area which is suitable for them. Following Weighted Overlay 2 more concentrated about agricultural issues and from the Figure 13 it is more visible that central areas are more about this criterion. Dataset for the this criterion downloaded from University of Nebraska-Lincoln which is providing accurate and available data sets for Nebraska state. It does not make sense to provide criterion more about population areas, it is because of the study area population calculated around 2 million and heavy population more located in the Midwest and kind of central area and environmental data is not providing exact data about population there includes houses and block into environmental critertion.

Land use criterion data just digitized only for study area but it did not pass though the reclassification period. It is because, dataset was providing small amount of atrributes and it was easy to numerized it by manually. In the Annex A Table 3 displays values which choosen manually and the goal it was about to route the pipeline thorugh the water areas. Because, water sources are more expensive and more hazardous for construction. The result from table 3 shows that the Least Cost Path which generated on Weighted Overlay 3 is 14% effective compare with staright line path which generated in the same overlay cost surface. It can be 14% cheeper that Euclidean Path but again it connot be applicable for the region. Because, only 85% of route passing through protected area and it is just 1% less than proposed Keystone XL.

A key maintenance to take into account when examining the results from the proposed
Keystone XL route and the least cost routes that were practically created was that even though these practical routes only took into account a very selected few criteria they almost simulated the proposed route. In Figure 12 shows that the eximined routes were sourced from the exact location where the proposed route inputted the study area. This is not due to the changing condition when routing large projects such as this pipeline. Although the source locations for each route were different, this did not affect the practical routes significantly enough to document.

Another key limition of this study was about the obtaining more accurate data for Nebraska State. It is not possible to understand how and which datasets used by Transcanadian Coorpoartion to propose Keystone XL but in case of the study all datasets were more accurately and they behaved from the begining which results were expecting. Only problem about original data for proposed Keystone XL. It needed because to understand atrributes and make more observations for area which is proposed Keystone XL crossed. There were “No Data” values for the each Weighted Overlays and they were locating mostly middle and right part of the study. It was not about error or some factors which cannot effected to surface to route paths through the region.According to Belka., 2005 it is normal to get “No Data” values and it is only because of the reclassification of the factors (except land use).

7. Conclusion

The created least-cost paths from this thesis provides the least hazardous pipeline routes by using the available data that covers the region of Nebraska State. When comparing the created routes to the proposed Keystone XL the least-cost paths accurately detail routes that are strikingly similar and effective in providing a path from the documented source and destination points within Nebraska. This thesis, using similar studies as background and for reference, combined the key factors in routing a large-scale pipeline project into a relevant cost surface that was then able to perform a least-cost path analysis and deliver a connected route. While the thesis had some limitations with the amount of data available and its precision, the overall result was a viable least-cost path that satisfied the main regulations with routing this type of infrastructure.

The study concentrated on the four different weighted overlays and demonstrated with different least cost paths routes which helped to determine least hazardous route for the study area. The results were more precision compare with proposed pipeline and it could be more accurately with more precision data sets. Least Cost Path analyses distributed in various criterion which last results (Table 2) of the each criterion calculated by logic of the algorithm.

Results of the thesis were behaved more proper way in true sense of the word, especially Least Cost Path analyses which related to Weighted Overlay 3 and result will help in future to determine route with more proper and least hazardous way.

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Annex A.

The annex describes data processing for each criterion after reclassifying.

№	Calculated Values	Weights
1	174196	2
2	176923	2
3	177252	2
4	178312	3
5	181538	4
6	181780	4
7	186012	4
8	190821	6
9	197257	6
10	517252	10
	No Data	No Data

Table 1. Data processing for "Environmental Criterion".

Table 1 displays data processing for "Environmental Criterion" and population, houses, blocks and etc. included into the data. During the weighted overlay analysis special numbers given to the calculated values to determine the hazardous route for environment.

№	Geologic Names	Weights
1	Shale	3
2	Limestone	3
3	Clay or Mud	2
4	Mudstone	3
5	Sand	1
6	Sandstone	3
7	Water	10
	No Data	No Data

Table 2. Data processing for “Geology” Criterion.

There were special geologic units in the study area. Data reclassified for criterion High value given to “Water” class.

№	Classes	Weights
1	Corn	3
2	Sugar Beets	3
3	Soybeans	3
4	Sorghum	3
5	Dry Edible Beans	3
6	Potatoes	3
7	Alfalfa	3
8	Small Grains	2
9	Range/Pasture/Grass	1
10	Urban Land	5
11	Open Water	10
12	Woodlands	8
13	Other Ag.Lands	3
14	Sunflower	3
15	Summer Fallow	5
16	Barren	1

Table 3. Data processing for "Land Use" criterion

Data was not reclassified for the criterion. It is because of the special units inside of the data and with changing the special unit's data can lose its effectivity. Specific numbers given according to ESRI.

№	Slope (degrees)	Wieghts
1	0 - 16.68	1
2	16.69 – 33.72	2
3	33.73 – 47.27	3
4	47.28 – 57.01	4
5	57.02 – 63.61	5
6	63.62 – 69.52	6
7	69.53 – 74.04	7
8	74.05 – 77.86	8
9	77.87 – 81.34	9
10	81.35 – 88.64	10
	No Data	No Data

Table 4. Data processing for “Slope” criterion.

Data describes values with degrees which have gotten after reclassification period. Given values applying to complance of the degrees.

Annex B.

The annex B descries the methodology and examples of the least cost algorithm. Furthermore, the appendix describes invisible part of the "Weighted Overlay 2 Least Cost Path" which can make confusion for readers.

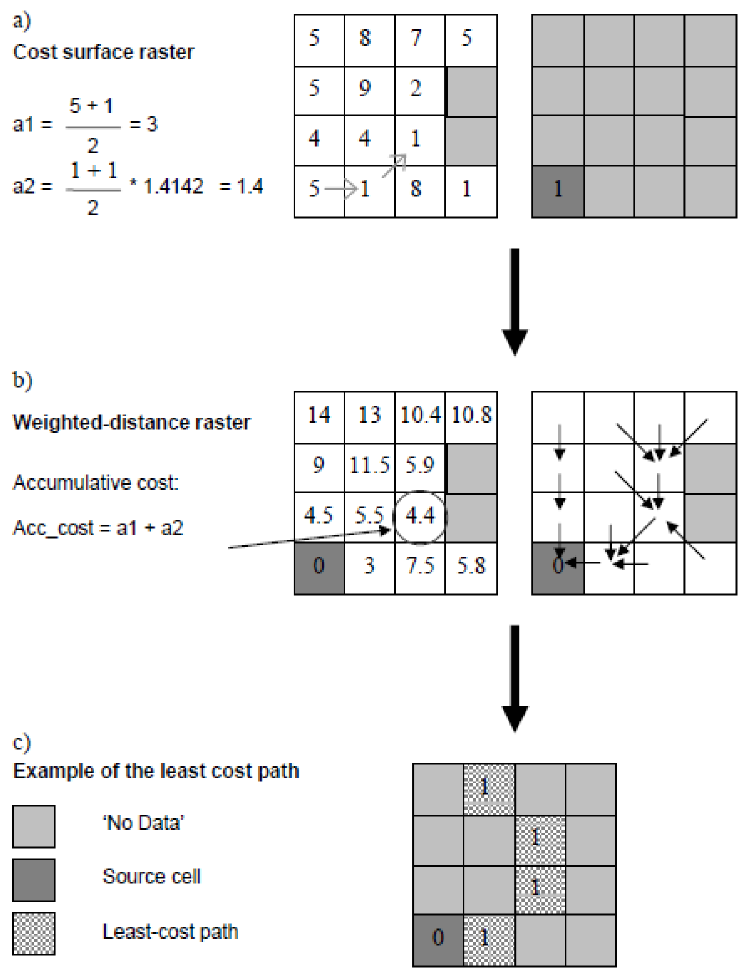

Figure 1. Displays the procedure of least cost path.

Figure 1 displays example for least-cost path algorithm which routes calculated into raster's cell. If the cost is higher than that previously calculated, it is ignored. However, if the cost value is lower, the old accumulative cost is replaced. The cells that are already assigned to the output raster are not recalculated and treated as 'permanent'. The process is repeated until the least accumulative cost is assigned to all cells and the back link raster is completed. Generation of the weighted-distance raster is based on graph theory and the shortest path is based on the Dijkstra algorithm (ESRI Desktop Help and Belka., 2005).

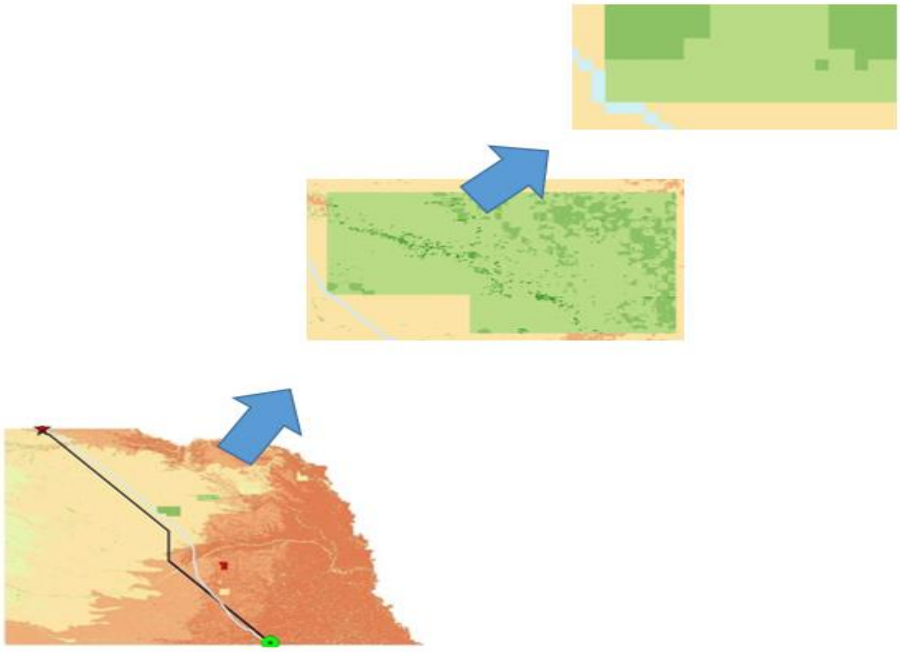

Figure 2. "Weighted Overlay 2 Least Cost Path" and not understandable part of the route.

Figure 2 displays least cost path which passes through second Weighted Overlay surface. Which in the middle part of the weighted overlay seems like a path is passing through the "NO DATA" value part. After making some zooms to area it is possible to see that route is not passing through area, it is just paring nearby "No Value" area and means that least cost path performed very accurately and the word out of the error.

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