Determination of Optimal Road Alignment Using GIS Least Cost Path Analysis: A Case Study of Situm - Gagidu Station, Morobe Province-PNG.

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Abstract

An access route linking the people of Finschhafen and surrounding villages to Lae City would be life changing. The route would stimulate socio-economic development and help bring in much needed goods and services by road rather than depending on sea and air transportation, which is costly and time consuming. The proposed road seeks the most suitable route, taking into consideration agricultural and environmental factors. Using Geographic Information System (GIS) techniques, the Least Cost Path Analysis method was applied to achieve viable results that were useful in determining a feasible road corridor. The route analysis parameters contained different weighted overlay surfaces; each surface is influenced by various criteria (slope, geology, population, and land use-land cover). The least cost route was then calculated based on the weighted overlay of each criterion. The criterion with the highest influence was used as benchmark for selecting the least cost route. Least cost path analysis (LCPA) has the ability to reduce the overall cost of road construction and minimize the negative impacts of such projects on both the macro and micro environments.

***Keywords**: least cost path analysis, weighted overlay, cost distance, cost line, Morobe Province, PN*

1. Introduction

Efficient roads are increasingly vital in facilitating the smooth flow of goods and services to people living in remote communities. A road can be defined as the passage way connecting two different locations within a spatial context. However, constructing a proper road requires considerable time and effort. Roads bring basic services to communities; alter the demographic pattern of an area, and impact the environment positively (Environmental Science.org, 2017). To construct an actual road requires an extensive pre-feasibility route analysis over the proposed site; hence, this paper investigates the use of Geographic Information System (GIS) techniques to accomplish that purpose, while taking into consideration the importance of ground truth data. Geographic Information System is a technological tool that is used to collect, store, control, manipulate and help users visualize geographic data in a digital format (Longley et al. 2005).

Finding the optimal route between two locations has been a spatial problem encountered by engineers and road designers over the years. However, the application of GIS has had a positive impact on selection of the best possible techniques for solving such geospatial problems. Least cost path because of its routine and standardised processes allows the output to be shown in a quantitative manner. The concept behind least cost analysis is to determine a route that is cheap and would have a less detrimental impact on the surrounding environment. It is a spatial analysis function that employs raster data sets rather than vector data.

1.1. Nature of the Problem

In 2013, PNG's national budget highlighted the impact of proper road management as one of its key infrastructure policy issues of concern. In Morobe Province, specifically between Situm (Nawaeb) and Gagidu Station (Finschaffen), development in terms of water supply, road accessibility, rural electrification, livestock farming, aquaculture and telecommunication services are yet to reach some isolated areas in Morobe Province. The problem is aggravated when the road alignment is influenced by the location of services, existing settlements and buildings, and the implications of financial, social and political costs of land resumption by which privately held lands are acquired through a compulsory acquisition process by the government.

The recent downturn of the economy may also be a factor in delaying of implementation of proposed road projects in terms of funding, engagement of experienced and qualified contractors, carrying out feasibility studies for route selection and best practices in road design to implement actual road projects. The purpose of this paper is to determine an optimal route connecting the two locations (Situm to Gagidu) within Morobe Province, which is the cheapest and least damaging to the environment. GIS, in terms of its spatial context, has the capability of identifying optimal routes linking Situm to Gagidu Station, provided the required parameters are identified and given appropriate weighting factors.

In view the above, this paper seeks to answer three research questions as a means of contributing to the knowledge of the subject, namely:

i) *What is the least cost route to link Situm to Gagidu Station by incorporating Euclidean Distance?;*

ii) *Can we establish a least cost path for an optimal road alignment from Situm in Nawaeb to Gagidu Station in Finschaffen, by identifying pixels that have least cost (cheapest) route values and that is economical and least hazardous?; and*

iii) *Do thematic maps of environmental features, such as geological structures, land use-land cover (LULC), digital elevation model, river networks, slopes and topography have any influence on identification of the Least Cost Path?*

1.2 Study Area

The area of study lies between Situm in the Nawaeb district and Gagidu station in Finschaffen district. Nawaeb is located 6°26' South and 146°49' east; and has a total land area of 3,219 km^2 (1,243 sq miles). According to the PNG 2011 census, the total population of the Nawaeb district is 44,556 people with a population density of 14 people per km^2. Finschaffen is a district on the north-east coast of Morobe Province. It can be accessed via sea transport from Lae. It is located 6°36'South and 147°51' East and has a total area of 2,642 km^2 with an estimated population of 54,672 people. The population density is 21 people per km^2. Gagidu Station is selected as the destination point of this study because it is the district's administrative centre.

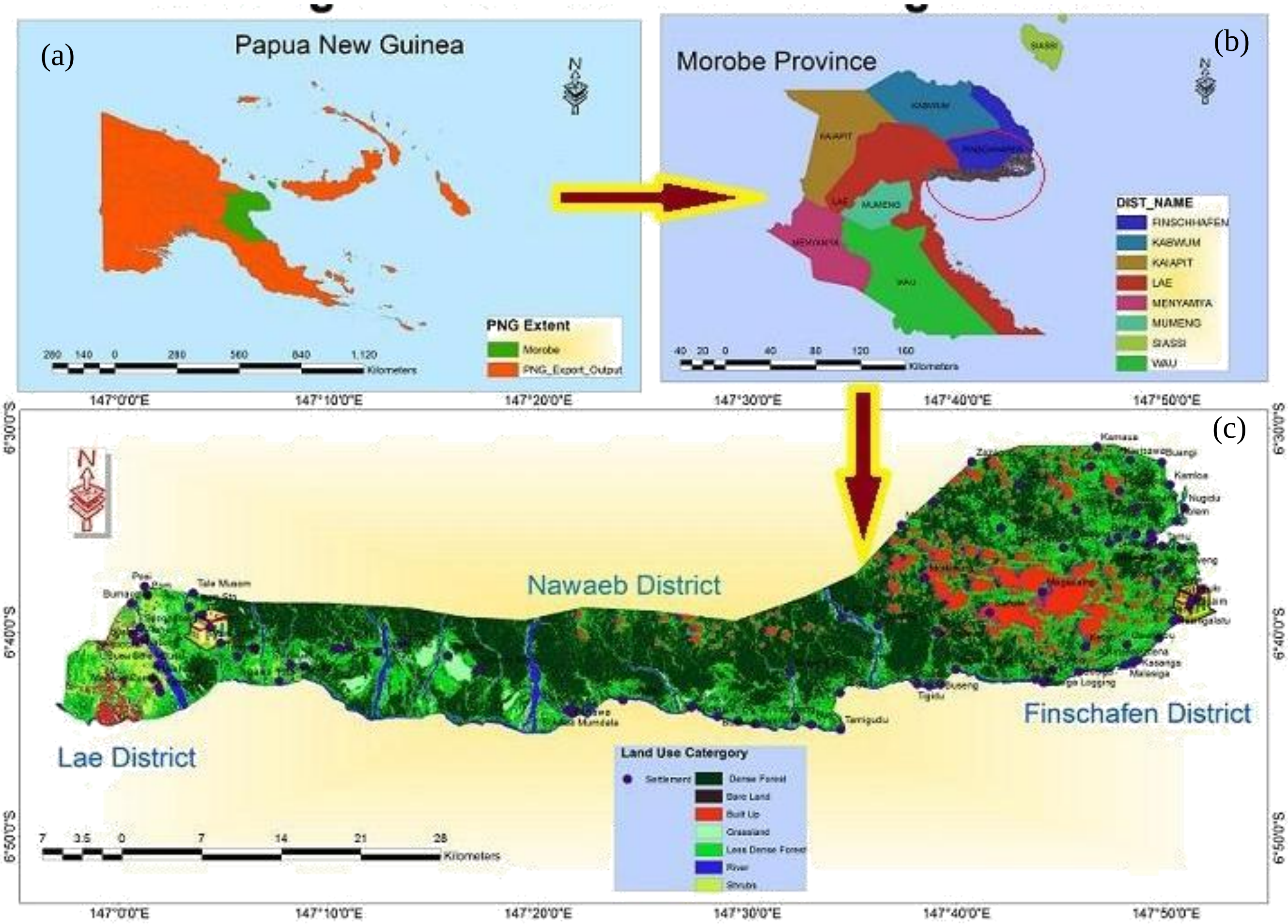

Fig. 1**:** Maps showing the study area: (a) PNG Map (b) Morobe Province Map (c) Locality Map

2. Method and Database

2.1 Method

The study criterion was divided into four sections: slope criterion, geology criterion, land use-land cover (LULC) criterion and population criterion. The primary stages of the project were identified and are shown in the flowchart in Figure 2. Starting from data collection to digitizing, all the datasets were stored in ArcGIS geo-database where each dataset was used in computing the total cost surface of the route**.** The datasets were used as parameters/factors in the weighted overlay process.

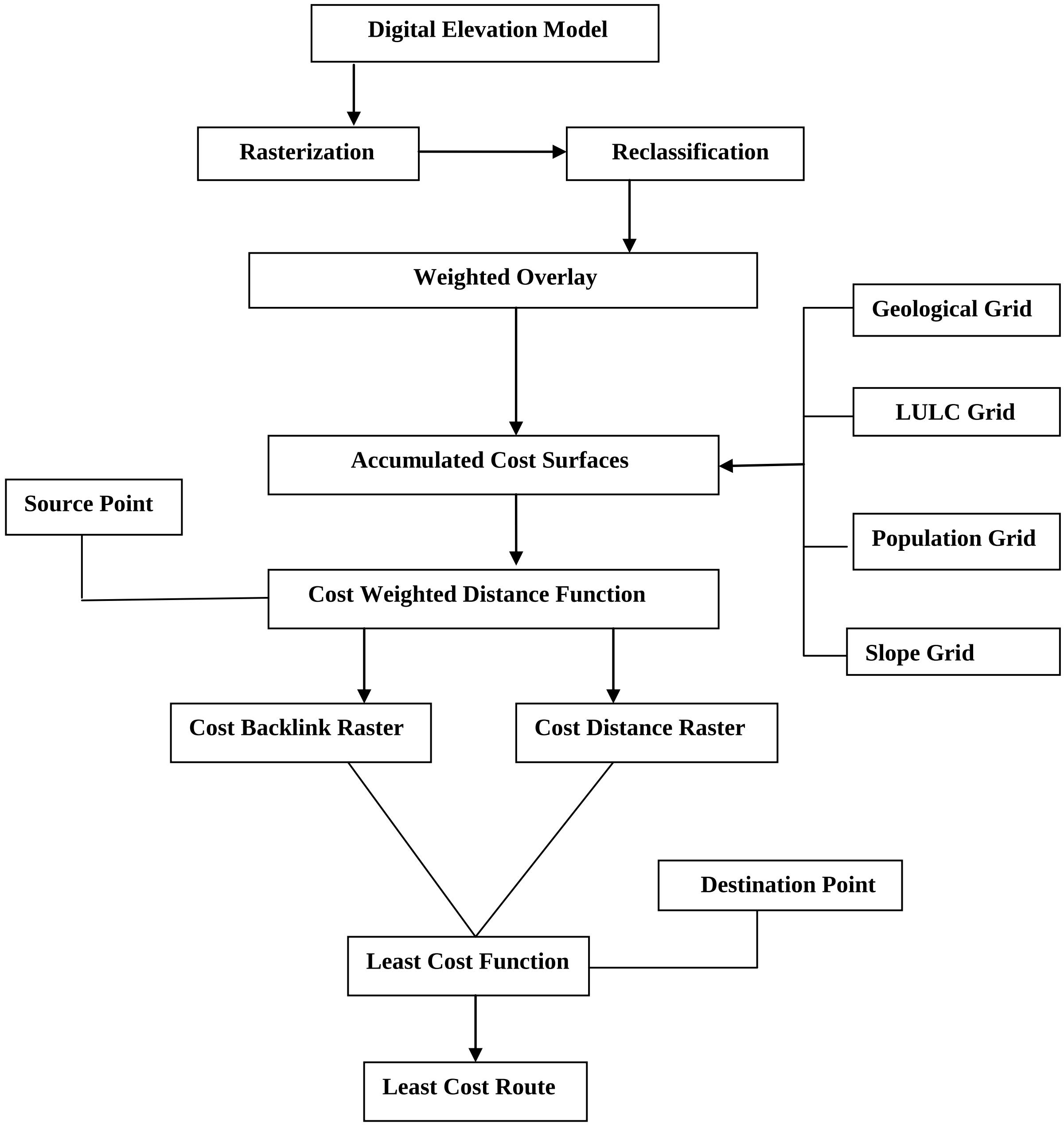

Figure 2: Flowchart of the process used in determining the least cost route.

2.2 Database

2.2.1 Land Use - Land Cover (LULC)

Two landsat level-1 quality band images of 30-metre spatial resolution were used to provide a quick view of the quality of the pixels within the scene to determine if a particular scene would work best for the user's application, such as representing land use - land cover (LULC) regions, atmosphere and vegetation. The two images were mosaicked to cover the study area. Supervised classification was carried out on the mosaicked image and compared with the satellite image downloaded from Google earth that encompassed the study area. Since the Google earth image contained less percentage of cloud cover, it helped justify the accuracy when making assessment. The LULC criterion permitted the least cost path to take into account the type of surface that was most optimal and less hazardous (Austin 2014).

2.2.2 Digital Elevation Model (DEM)

The DEM was used to determine the slope for the study area. The study deemed it reasonable to have a 5 km extent in terms of width, starting from the coastline inwards. The slope was used to represent the changes in elevation of the topography within the study area. The DEM was derived from a SRTM 90m cell size, with the coordinate system in UTM Projection and WGS 84- Zone 55 Southern Hemisphere as its datum. All the datasets were digitised and projected according to that coordinate system. The slope data was then reclassified and ranked according to the different costs associated with each specific criterion in the weighted overlay function. When reclassifying and ranking the slope data, the scale factor ranged from 0-5, where 5 indicated 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 raster 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).

2.2.3 Geological Data

Geological data was used in the whole process of routing the alignment; the reason being that implementation of less hazardous routes needed more comprehensible dataset for the area. Some parts of the datasets were not located inside the study area and were masked out using ArcGIS 10. The data was captured in vector format and was later converted into its raster format as per its function to display the cost surface as contiguous. Geological structures that were estimated as young in nature were given the highest cost value, whilst old geological structures were given low cost values, due to their higher stability or load bearing properties; this is shown in Figure 3, part (d).

2.2.4 Population Census Data

The study was carried out to establish a route connecting the two locations, so that the majority of the population can have unhindered access to goods and services. Within the census region of the area, its distribution is rarely uniform. It varies depending on the allocation of resources, access to services, and availability of fertile soil. So it was compulsory to have a population data. The census data contained the population statistics for the entire area showing the distribution and density in square kilometers.

3. Results

3.1 Research Question1: What is the least cost route to link Situm to Gagidu Station by incorporating Euclidean Distance?;

The cost distance analysis relies on cost data ‘surface’, while each cell represents a unit value per distance and is based on the following criteria:

- Slope Grid
- Land Use-Land Cover Grid

- Geological Grid
- Population Census Grid

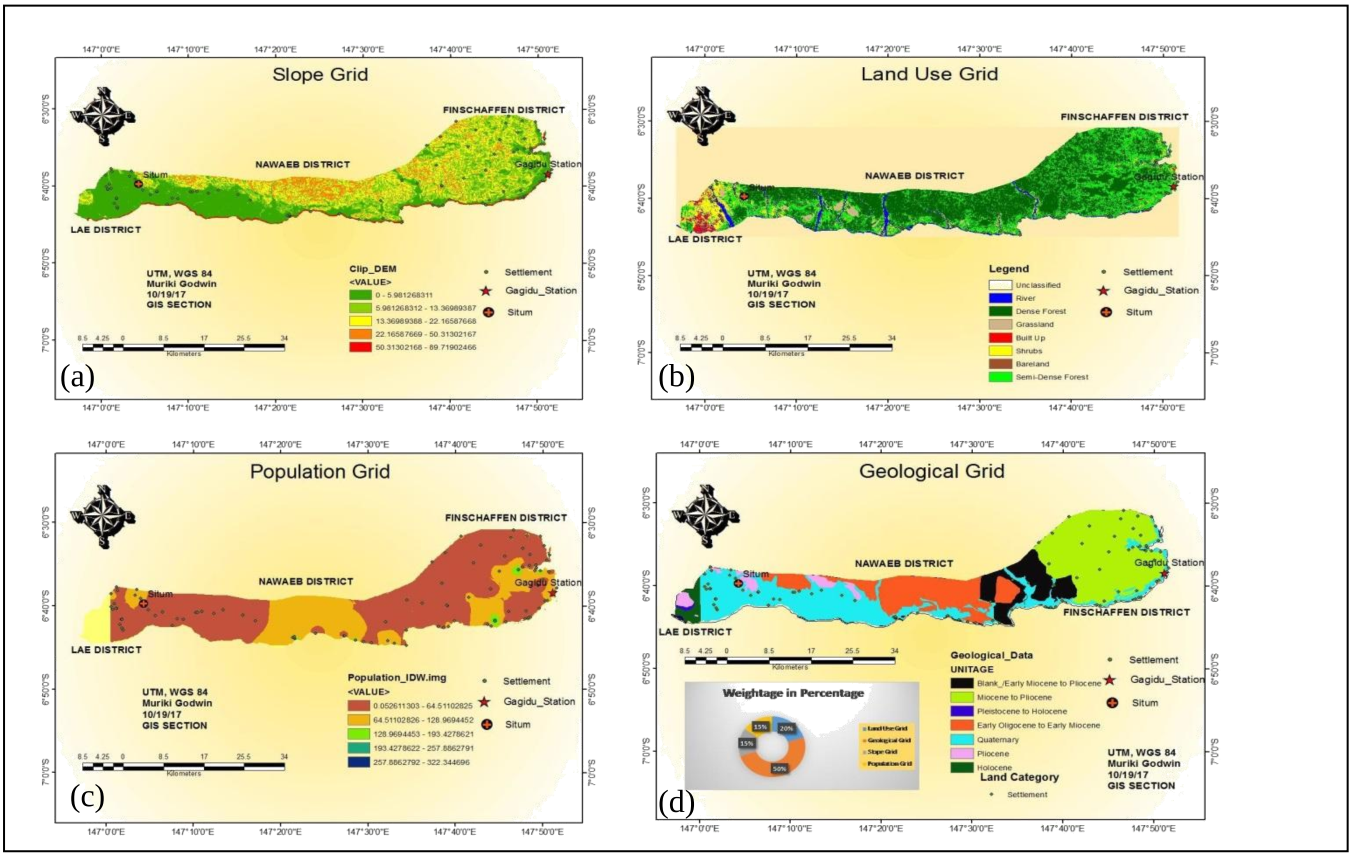

Fig 3: Criteria used in calculating the least cost data surface: (a) slope grid (b) land use grid (c) population grid (d) geological grid

The four parameters were then used to calculate the weighted overlay using Model Builder in ArcGIS. The weighted overlay function in ArcGIS was used as a tool that combines all the weights together after assigning a certain percentage to the parameters used. As shown in Table 1.

Table 1: A List of Parameters and their Rankings

Parameters	Categories	Ranks	Description
Land Use Grid	River	5	Very High Cost
	Dense Forest	3	Moderate Cost
	Grassland	1	Very Less Cost
	Built Up	5	Very High Cost
	Bareland	2	Less Cost
	Semi Dense Forest	3	Moderate Cost
Geological Grid	Early Miocene	5	Very High Cost
	Oligocene	4	High Cost
	Holocene	2	Less Cost
	Piliocene	3	Moderate Cost
	Pleistocene	2	Less Cost
	Quaternary	1	Very Less Cost
Population	0-25	5	Very High Cost
	25-49	4	High Cost
	49-90	3	Moderate Cost
	90-145	2	Less Cost
	145-345	1	Very Least Cost
Slope	Flat Land	1	Very Less Cost
	Moderate Slope	3	High Cost
	Very Steep	5	Very High Cost

__3.2 Research Question 2:__ Can we establish a least cost path for an optimal road alignment from Situm in Nawaeb to Gagidu Station in Finschaffen, by identifying pixels that have least cost (cheapest) route values and that is economical and least hazardous?

Two weighted overlay techniques were applied to combine the criteria to influence the routing. The first technique involved evenly distributing the percentage of the criteria to add up to 100 percent which resulted in the map in Figure 5.

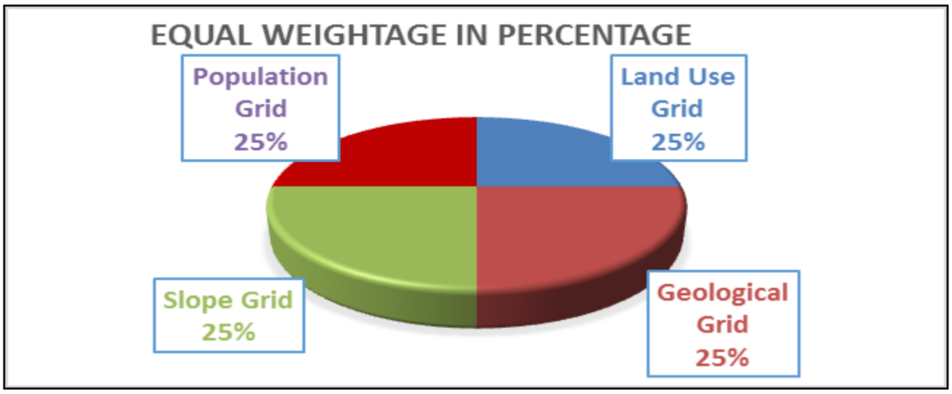

Fig 4: Pie chart showing equal weighting assigned to the four different parameters.

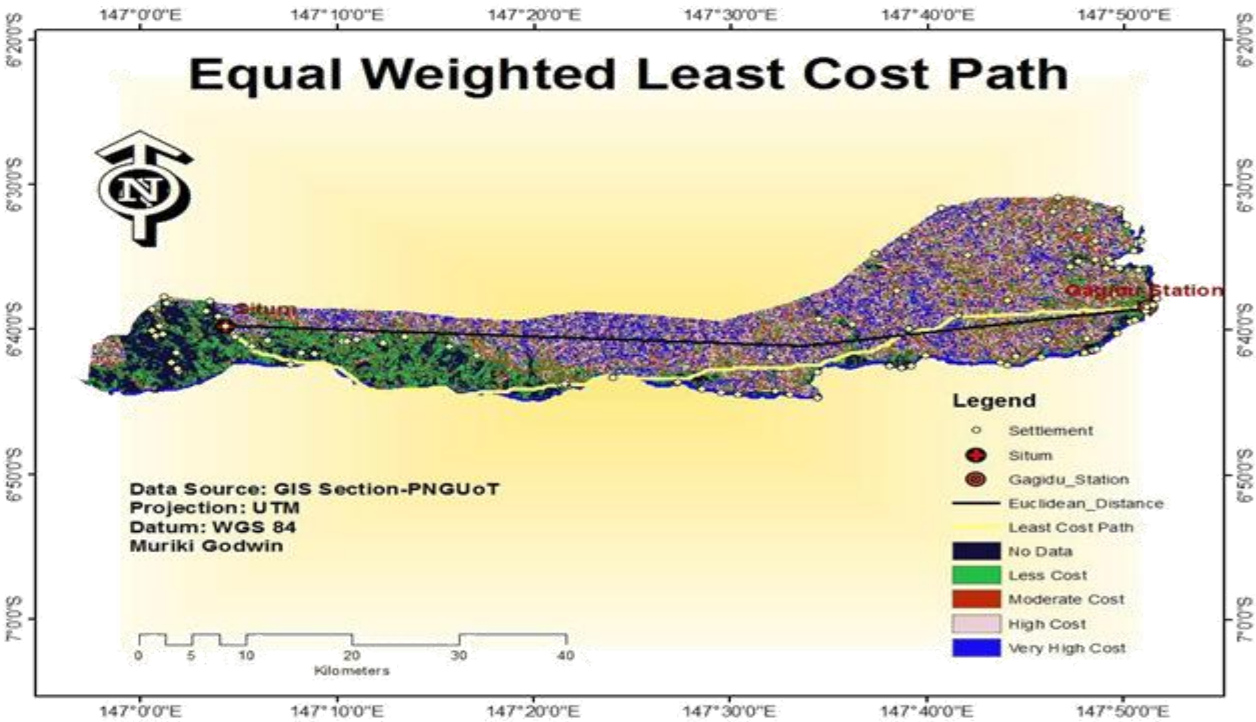

Figure 5**:** Map showing the route alignment based on equal weighted least cost path

The second technique involved assigning different weighting factors to each criterion and verifying how they affected the route. Multiple route alignments were generated from this method.

3.2.1 Land Use Weighted Overlay

Land Use-Land Cover (LULC) shows more details about the study area. Therefore, to minimize unnecessary disruption to the environment the LULC parameter was given a higher weighted value. The allocation of percentages is shown in Figures 6 and 7.

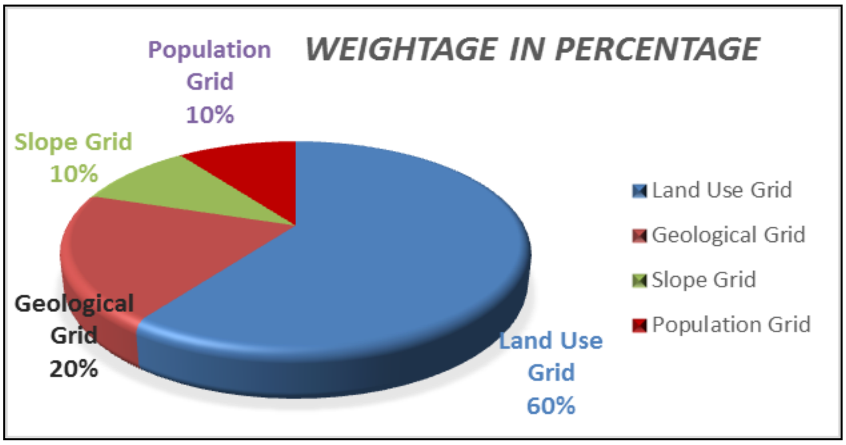

Figure 6: Pie chart showing the Land Use Grid assigned a higher percentage weighting.

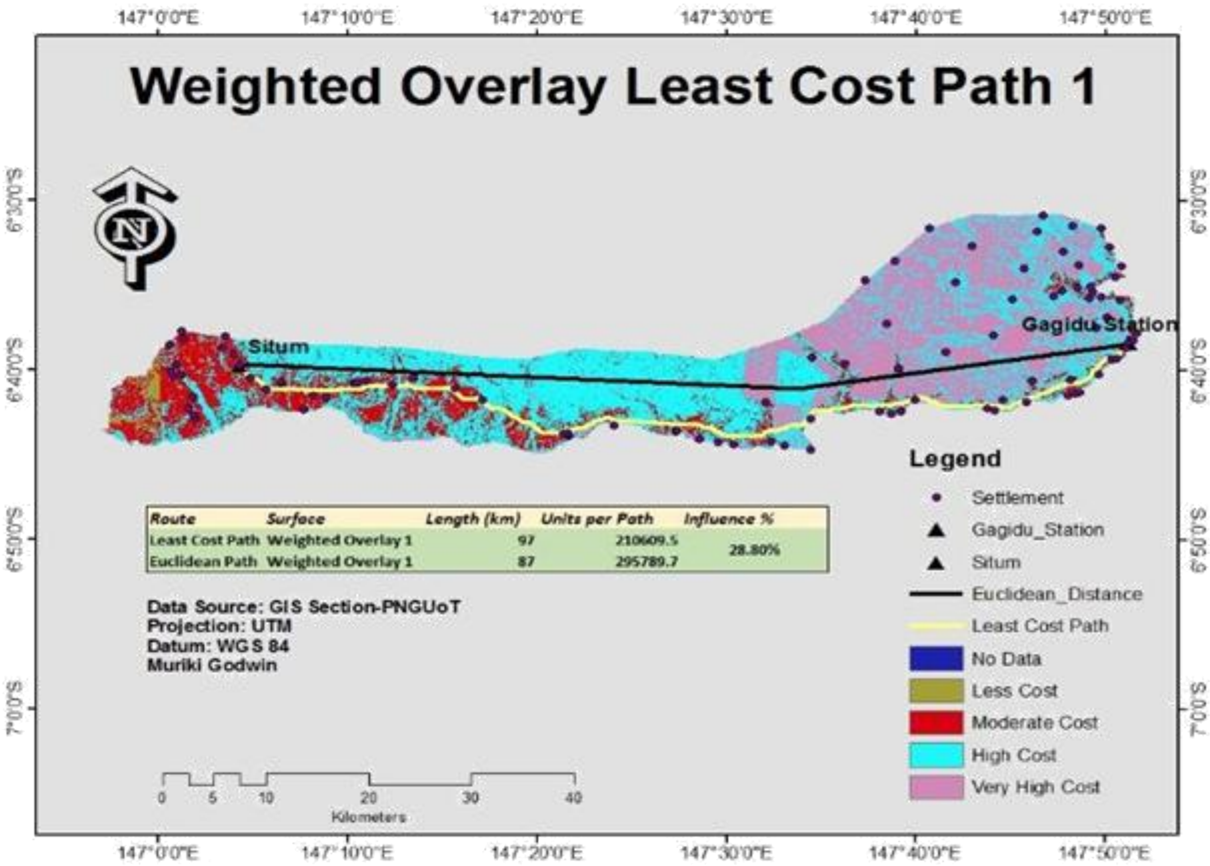

Figure **7:** Map showing route alignment based on Land Use Grid assigned a higher percentage

3.2.2 Population Grid Weighted Overlay

The second weighted overlay route was increasing the percentage of the population grid. The function of the grid was based on the population density of the study area. The study wanted the route to pass through densely populated areas (Figures 8 and 9).

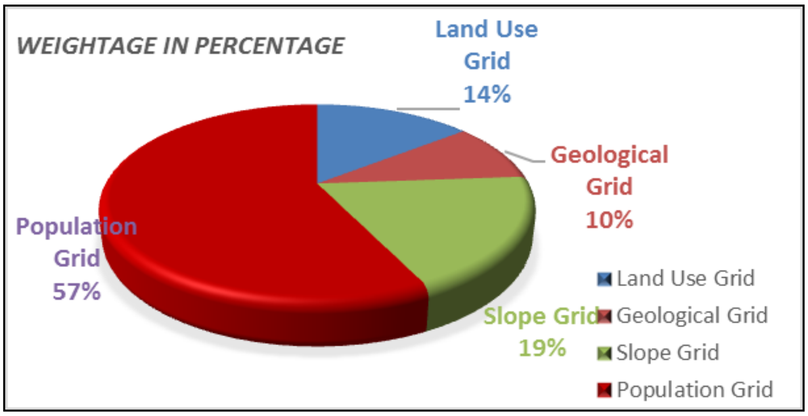

Figure 8: Pie chart showing Population Grid assigned a higher percentage weighting.

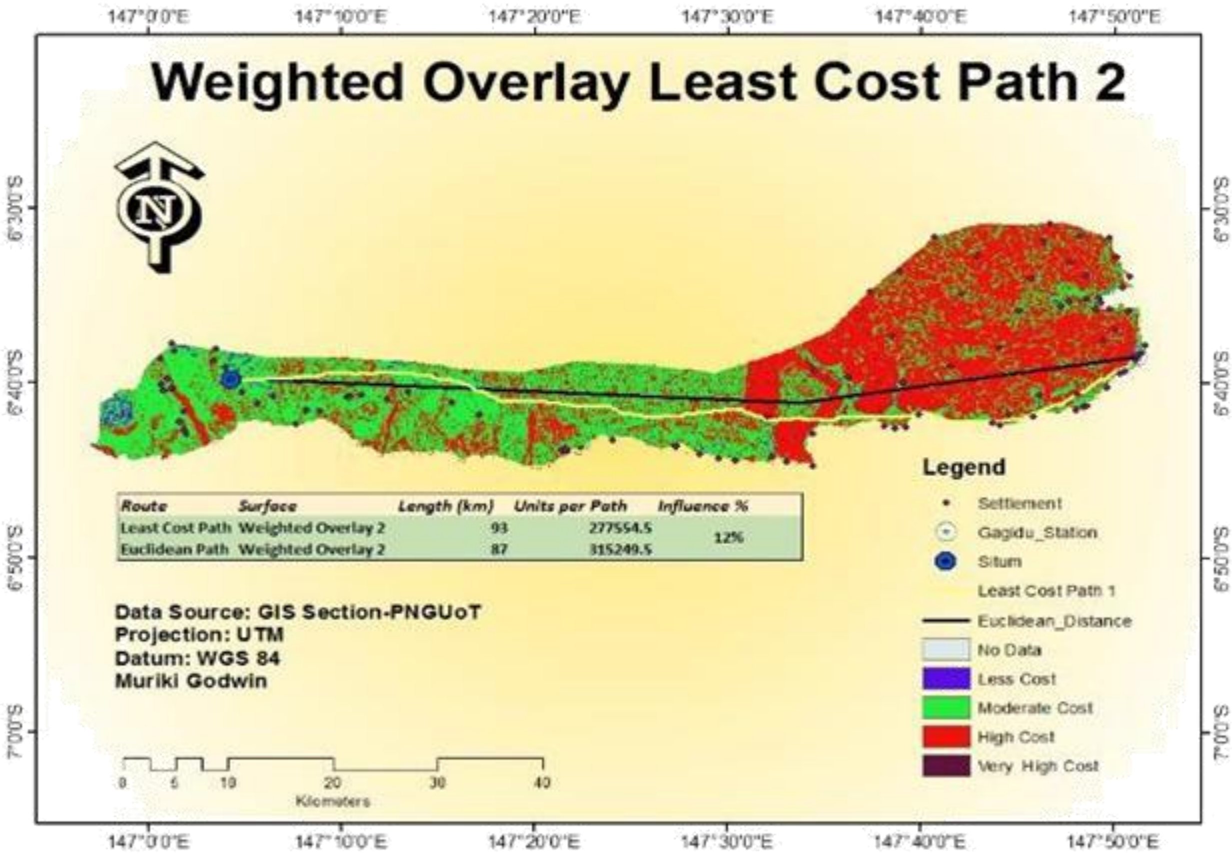

Figure 9**:** Map showing route alignment based on Population Grid assigned a higher percentage.

3.2.3 Slope Grid Overlay

The slope factor does not have much impact as compared with the other three factors with an influence of 9.3 percent (Figure 11).

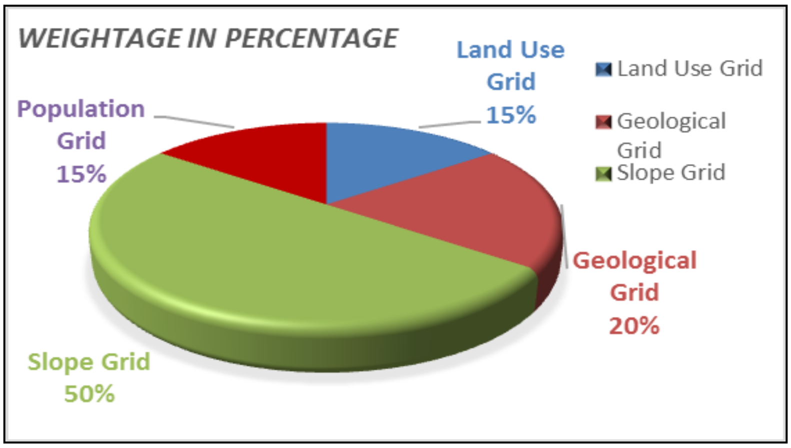

Figure 10: Pie chart showing the Slope Grid assigned a higher percentage weighting

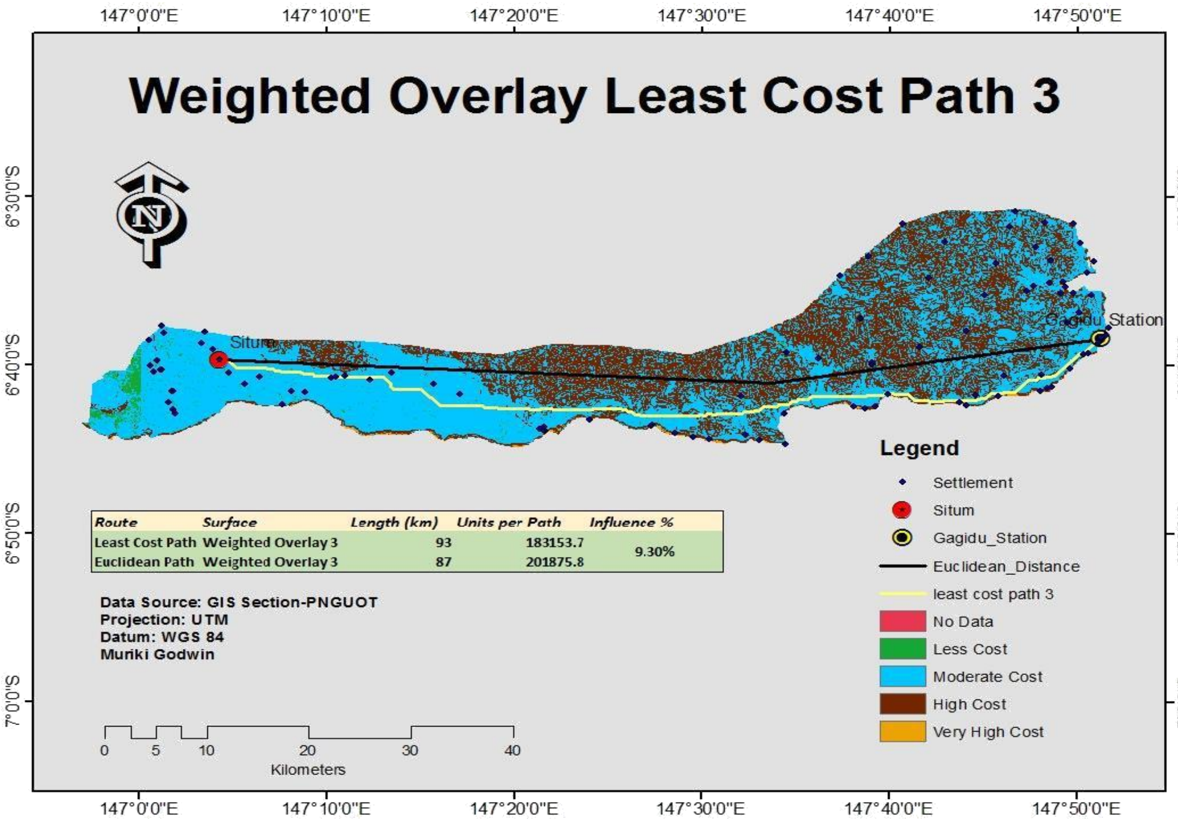

Figure 11: Map showing route alignment based on Slope Grid assigned a higher percentage

__3.2.4 Research Question 3:__ Do thematic maps of environmental features, such as geological structures, land use-land cover (LULC), digital elevation model, river networks, slopes and topography have any influence on identification of the Least Cost Path?

The fourth weighted overlay examined geological stability and the geology of the area. It was used to predict areas that may be susceptible to natural hazards. The geological overlay was based on the composition and age of the geological structure determined by USGS (Figures 12 and 13).

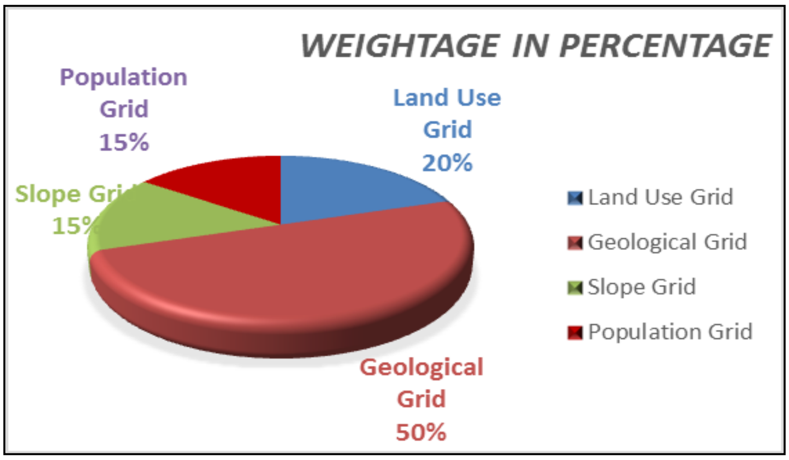

Figure 12**:** Pie chart showing the Geological Grid assigned a higher percentage weighting

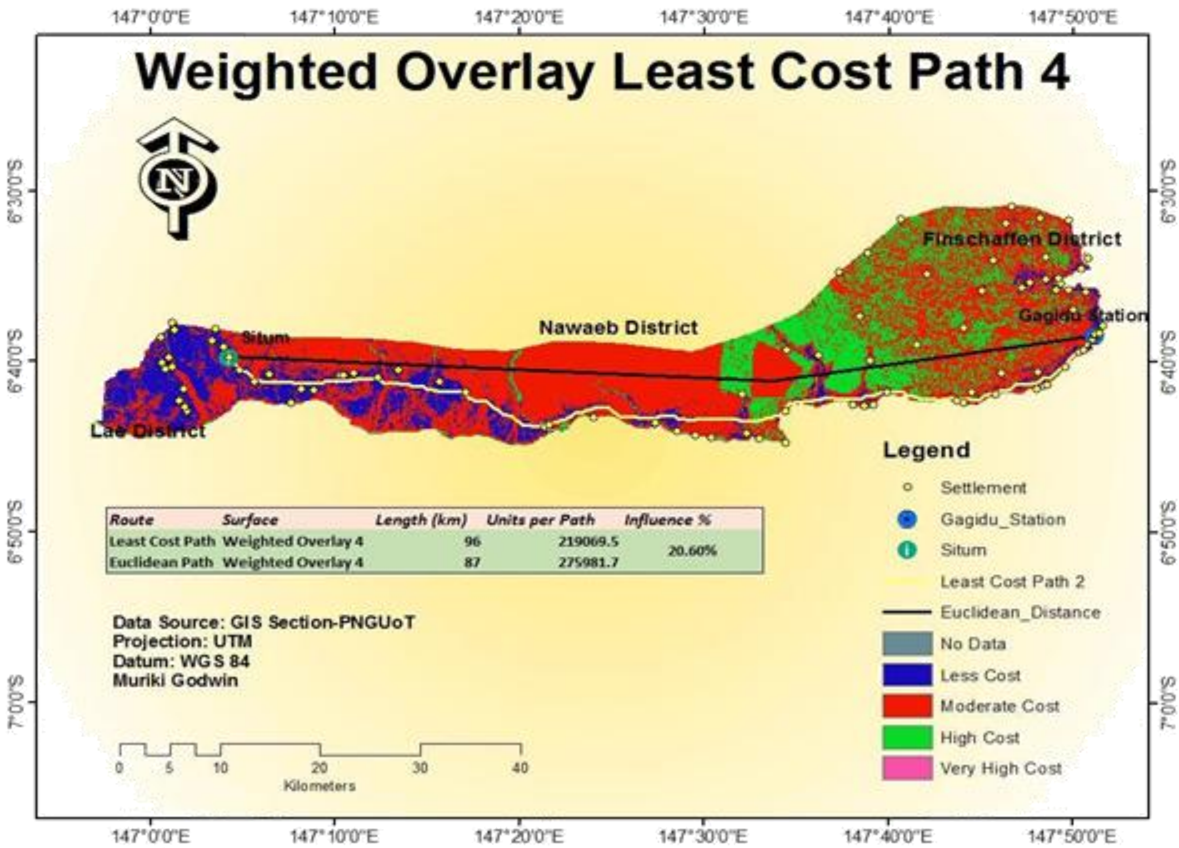

Figure 13**:** Map showing route alignment based on Geological Grid assigned a higher percentage

4. Conclusion and Recommendations

A total of five potential (5) route alignments were generated from the Least Cost Path Analysis (LCPA) method. The first method used the Euclidean Distance method where all parameters (Slope, LULC, Population and Geology) were given equal weights (Figures 4 and 5). The length of the route was 87 km from Situm to Gagidu Station. However, the route covered pixels of high cost, rendering that route alignment not feasible for actual road construction. The second method used the same four parameters interchanging their weightings to determine a feasible route alignment for the two locations. By interchanging the weightings of the four parameters, that is, increasing the weighting factor of each parameter respectively, the study was able to determine which parameter had the highest influence. The parameter LULC gave the highest influence of 28.80% with a total accumulative distance of 97 km (Figures 6 and 7); this was deemed by the study as the most feasible for road construction, pending actual ground truthing. Other parameters; Population has 12 % influence (Figure 8 and 9), Slope has 9.3% influence (Figures 10 and 11) and Geological Grid has 20.6% influence (Figures 12 and 13).

The Least Cost Path Analysis (LCPA) method was implemented from the starting point to the destination by incorporating the four criteria. Based on the results obtained, we can conclude that LCPA is a cost-effective and environment-friendly GIS-based application. Employing LCPA can be helpful to engineers, urban and regional planners and the government in terms of linear infrastructure development, whether it be for roads, sewage lines or even power pole placements. LCPA has the ability to reduce the overall cost and minimize the negative impact on the environment and its surroundings.

Finally, several recommendations can be made. First, when undertaking environmental and economic planning involving linear features, Least Cost Path Analysis should be seriously considered. However, before carrying out such projects, the following recommendations should be thoughtfully considered for adoption:

(i) Policy makers and project officers must have a thorough understanding of the actual cost of proposed projects in terms of their monetary values;

(ii) Project designers must use very accurate datasets as parameters or criteria;

(iii) Project designers and developers must generate a 3D model of the project area and the surrounding corridors; and

(iv) Project analysts must perform an analysis of the Least Cost Route by incorporating Euclidean Distance

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