COMPUTER BASED LEAST COST PATHWAY ANALYSIS FOR ROAD ROUTING IN NIGERIA

Emmanuel Umaru Peter[1], Abubakar Akinyele Musa[2], Nanpon Zitta[3]

ABSTRACT

An effective and efficient route selection process is vital in minimising the construction time and cost. Loss of man hours as a result of distance from source to destination, insecurity and damage of perishable goods has necessitated the need for this study. This paper presents the results of a study for the development of least cost pathway (LCP) between two points using different criteria and to compare the existing route path with LCP. Landsat 8 OLI/TIRS image, shuttle radar topography mission (SRTM) digital elevation model (DEM) and soil map were used to meet the criteria. ArcMap 10.1 was used for data analysis. The criteria determined were reclassified to a common scale and weighted using analytical hierarchy process to create the cost surface. The output distance raster and output backlink raster were created. LCP was found to provide much shorter route compared to the existing route In addition, LCP based on the inputted criteria was able to show a considerable level of compliance.

Keywords: least cost pathway; cost surface; cost distance; geographic information system; image classification; cost raster; land use.

1. INTRODUCTION

Least cost path analysis (LCPA) allows designers to determine the most economical way to link the source and destination points within a cost surface which can be calculated by combining multi criteria to account for different problems (environmental impact, economic investment) [1]. LCPA identifies best way from one point to the other on the cost surface raster. To identify the cost of travelling through each of the cells (that gives the cost and determines how expensive the cost of the route is), it is necessary to pass that cell [2]. LCPA is an important step in the process of design and construction and has the potential to create its impact on the construction and environment of the area. It can be defined as the process of determining the cheapest route between two points on a cost surface. LCPA is not limited to roads only and can be applied to linear engineering structures. The use of geographic information system (GIS) and remote sensing in carrying out LCPA is not new and has been widely used in different parts of the world [3-6].

The application of remote sensing and the capability of GIS to manipulate data from specific geographical location make it possible to create a real world view of an area and provide an opportunity to view the effects of future actions. This unique can be used to analyse and combine

[1] PhD student, Surveying and Geoinformatics Department, Modibbo Adama University of Technology Yola, Nigeria, Ph. +234(0)7069241478, Email: emmapeter504@gmail.com.

[2] Lecturer, Surveying and Geoinformatics Department, Modibbo Adama University of Technology Yola, Nigeria, Ph. +234(0)8036127598, Email: drabumusa@yahoo.com.

[3] Lecturer, Surveying and Geoinformatics Department, Federal University of Technology, Minna, Nigeria, Ph. +234(0)7030061896, Email: nanponzitta@yahoo.com.

Manuscript received on 26th July 2016, reviewed and accepted on 30th May 2017 as per publication policies of *NED University Journal of Research*. Pertinent discussion including authors' closure will be published in September 2018 issue of the Journal if the discussion is received by 28th February 2018.

Emmanuel Umaru Peter received his Bachelors from Federal University of Technology, Yola, Nigeria and Masters from MAUTECH, Yola, Nigeria, respectively, in 2008 and 2016. He has remained consultant in various research projects related to GIS/remote sensing applications. His research interests include digital mapping and engineering surveying.

Abubakar Akinyele Musa is a Lecturer in the Department of Surveying and Geoinformatics at MAUTECH, Yola, Nigeria. He received his PhD in remote sensing and GIS applications from Federal University of Technology, Minna, Nigeria in 2004. His research interests include studying and modelling environmental issues, digital mapping, network analysis and geospatial information system.

Nanpon Zitta is a Lecturer of surveying and geoinformatics at Federal University of Technology, Minna, Nigeria where he received his Bachelors in 2008. He is a PhD student at MAUTECH, Yola, Nigeria where he received his Masters. His research interests include in remote sensing/GIS applications, spatial data analysis, digital mapping techniques, and environmental change detection, monitoring, prediction and mapping.

large sets of spatial data into useful information, offering new perspectives and fresh approaches to problem solving [7]. Kang-tsung [8] defined GIS as a computer system for capturing, storing, querying, analysing and displaying geographic data. The conceptual principles of GIS has been presented by Ndukwe [9] as a computerised information system for capturing, storing, integrating, manipulating, analysing, checking and displaying data which are spatially referenced to the earth. It is capable of handling both positional and attributes data.

In order to determine LCP, GIS makes use of analytical hierarchy process (AHP) where weights are given to the various criteria. GIS and Multi-criteria analysis has helped the planners to achieve the desired and accurate results by reducing the complex nature of the planning process and allowing different stakeholders to reach a general conclusion [10]. Transportation and property are important in physical and economic development of towns and cities all over the world. Property and land values tend to increase rapidly in areas with expanding transportation networks as compared to areas without such improvements. A continuous and rapid rise in housing and land prices are expected in cities with transportation improvements, and rapid economic and population growth.

The establishment of the Federal University Kashere (FUK) has placed a once rural community of Kashere in Akko Local Government Area of Gombe State, Nigeria on the global map which allowed creation of linkages with overseas universities including Florida International University, University of Canterbury and Lincoln University [11]. The area is known for agricultural products (especially perishable goods) such as tomatoes, pepper, onions, cattle rearing, etc which need to reach their destinations in time. The village is linked by a network of roads from Alkaleri LGA of Bauchi State and Billiri LGA of Gombe State. The establishment of FU has brought new challenges such as provision of portable drinking water, housing and provision of linear infrastructures (route networks to places of interest such as the Yankari game reserve, Gombe International airport as well as the state capital). The road network to this community from the Gombe International Airport is about 84.67 km (53.6 miles) which is much longer and time consuming as one has to pass through the state capital and other towns before reaching the community. This also increases cost of transportation. This study aimed at combining remote sensing and GIS to determine LCP between the Gombe International Airport and Kashere settlement in Akko LGA.

1.2 Review of Literature

Various studies have been carried out by the researchers to use GIS LCPA selection of route, pipeline, natural gas oil pipelines, irrigation drying channels and railways. Isah [5], Ahmed and Asmael [10], Kaoutar and Lahcen [12] and Yunliang et al. [13] were able to determine suitable site(s) or LCP. Grassi et al. [6] conducted viewshed analysis to their study. Yildrem et al. [4] and Alexander [14] compared LCP with the existing route and provided aspect maps for drainage construction along LCP. This avoided surface run off of water to the road. Flow accumulation was also included by these researchers to show the channels of streams within the study area and to add it with other criteria to generate the cost surface upon which LCP was created. This would enable policy makers to know number of bridges and culverts to be constructed along LCP.

2. STUDY AREA

Gombe and Akko Local Government area is located right within the expanse of the Sahel Savannah region (latitude 11°11’20.44”N to 11°14’37.4”N and longitude 10°16’20.8”E to 10°19’16.00”E). Gombe covers an area of 80 km^2 (31 miles^2) while Akko covers 2840 km^2 (1097 miles^2). Gombe Local Government serves as the State capital which is surrounded by Kwami Local Government Area to the north and Akko Local Government to the south (**Figure 1**). Two distinct climates exist; the dry season (November-March) and the rainy season (April-October) with an average rainfall of 850 mm (33 in.). The topography is defined by the prominent inliers and relatively high igneous body with gentle, steep slope and undulating sedimentary rocks.

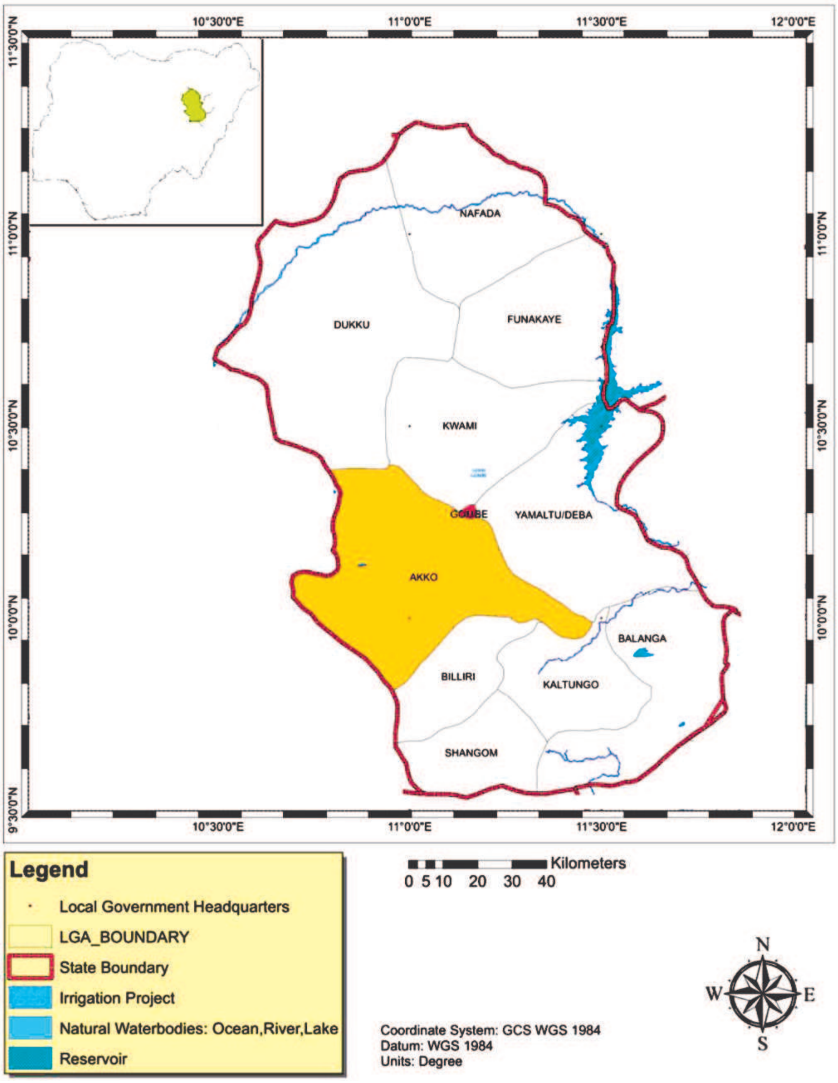

Figure 1. Map of study area (Source: Space Applications Department, Nigeria (NASRDA)).

3. METHODOLOGY OF WORK

The methodology of work is illustrated in **Figure 2**. The software entitled ESRI's ArcMap 10.1 was employed for the data analysis.

3.1 Criteria for Site Selection

The following predefined criteria were adapted for this research

1. The road should avoid land use of built-up area because road construction through built-up area requires payment of compensation and also cost of demolition [15].
2. The road should follow shallow slope not greater than 20 deg [16].
3. Since soils such as peat or clay are prone to differential settlement and pose a potentially higher construction cost, such areas should be avoided as much as possible. Coarse texture soil (gravel and sand) can be considered suitable [17].

3.2 Creation of Maps

3.2.1 Data preparation

Image clipping was performed on the Landsat 8 OLI/TIRS scene to obtain the actual size of the study area. A principal component analysis was carried out on the six bands to form a single multiband raster to remove data redundancy in satellite images. An SRTM DEM with 30 m (98 ft) resolution was also clipped to conform to the extent of the study area. Since the geological map of the study area provided information on various types of soils, only the soil types was used as one of the input criterion.

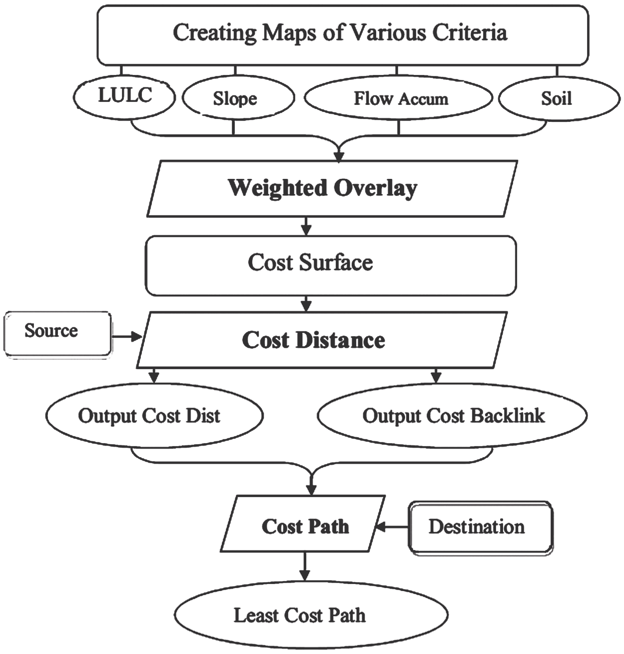

Figure 2. Flow chart of LCPA methodology.

3.2.2 Creation of criteria layers

The supervised image classification was used to classify the PCA image into five classes of land use land cover (LULC), bare surface, vegetation, water body, built up and rocks. The output classified raster was automatically added to ArcMap at the end of the process. An error matrix was generated to assess the accuracy of classification. The slope, aspect maps and flow accumulation maps were generated from the SRTM DEM (30 m (98 ft) resolution) while the soil map was converted from vector to raster form.

3.3 Creation of Least Cost Path

3.3.1 Creating new model

The model found a route by calculating path through the landscape from the source to the destination point taking into consideration the slope of the land, the soil type and land use the path will cross. The model logic can consider multiple criteria simultaneously (land use, slope and soil effect). LULC, slope map, and soil raster layer data were overlaid in ArcMap 10.1 using weight output from AHP to generate cost dataset. In creating the new model, a new tool box entitled LCP was created. LCP tool box was automatically added to the Arc Tool box where the new model was subsequently created. It should be noted that all the tools needed were dragged into the model sequentially as the analysis progressed, as shown in **Figure 3**.

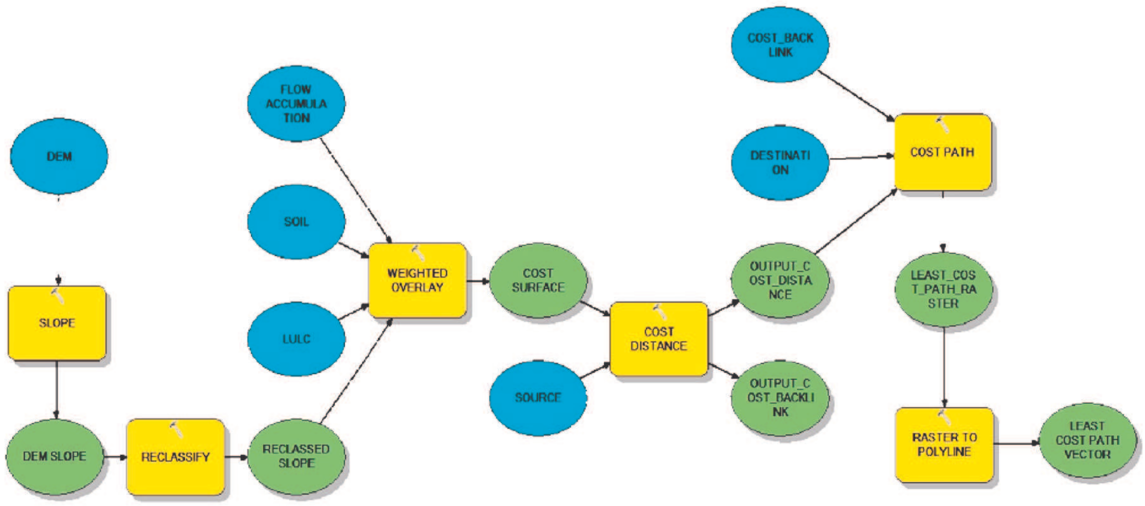

Figure 3. Least cost path model.

3.3.2 Cost raster

A cost raster identifies the cost of travelling through each cell. To create this raster, the cost of constructing a road through each cell was identified. Although the cost raster is a single dataset, it is often used to represent several criteria. It should be noted that land use, soil type and slope influence the construction cost. All these maps need to be reclassify into a common scale in LCP model.

Reclassifying dataset to common scale

The slope map, land use and soil map, and the flow accumulation raster were reclassified to a common scale of 1-10. The attributes of each dataset were examined to determine their contribution to the cost of constructing a road. Since traversing through steep slopes will cost more, steeper slopes were assigned higher cost (that is value 10) during reclassifying the dataset.

In reclassifying the land used, AHP (which involved pair wise comparison to create a ratio matrix) was used. AHP for weighting the land use criteria was assigned various weights from 1–10; land use with least cost carried value of 1 while others follow the range up to 10. The land use was classified into bare surface, vegetation, water body, built up areas and rocks. As a result, bare surface was assigned 1, vegetation was assigned 2, rocks was assigned 8, water body was assigned 10 while built up land was assigned 9. The reclassed land use is given in **Table 1**. Similarly, the soil map was reclassed based on the different types of soil in the study area and was named reclass soil (**Table 1**). Furthermore, the resample slope map was reclassified where areas with gentle slope were assigned less value and vice versa as can be seen in **Table 2**. The flow accumulation was also reclassified; areas where water flows were made to have a higher pixel value than the others (i.e the frictions) as given in **Table 2**.

Based on the above, four maps were generated for the model namely reclass slope, reclass land use, reclass soil and reclass flow accumulation. The maps were combined into cost surface using weighted overlay.

Four maps were generated for the models, namely reclass slope, reclass land use, reclass soil and reclass flow accumulation. The maps were combined into cost surface using weighted overlay. A cost distance surface was also created using the source, destination data sets and cost surface raster as inputs. Since LCP was obtained in raster format, it was converted to polyline for better understanding of results.

Table 1. Reclass land use and soil raster

S. No	Land use type	Pixel value	Soil type	Pixel value
1	Bare surface	1	Sandy clay	7
2	Vegetation	2	Sandy clay loam	6
3	Rock	8	Sandy loam	5
4	Built up	9		
5	Water body	10		

Table 2. Reclass slope and flow accumulation

S. No	Slope	Pixel value	Flow accumulation	Pixel value
1	0° - 3°	1	1	1
2	3° - 6°	2	2	2
3	6° - 9°	3	3	3
4	9° - 12°	4	4	4
5	12° - 15°	5	5	5
6	15° -18°	6	6	6
7	18 - 22°	7	7	7
8	22° - 25°	8	8	8
9	25° - 28°	9	9	9
10	28° - 31°	10	10	10

4. RESULTS OF LCP ANALYSIS

4.1 Land Use Land Cover Map

Figure 4 shows the LULC image which was developed using the maximum likelihood approach. Five classes are displayed in **Figure 4**. It is seen in **Figure 4** that vegetation and bare surface are the dominant land cover classes. Scattered rocks were found all over the study area. Built up area is clustered in the eastern region (Kumo) and north east (Gombe) settlement along the existing road and south of the study area.

In order to determine the accuracy of classification the error matrix is given in **Table 3** such that the referenced data is entered as the columns while the classification generated from the remotely sensed data is represented by the rows. Overall classification accuracy was calculated with the help of Eq. (1)

$$\text{Overall classification accuracy} = \text{sum of correct cells/total cells} \quad (1)$$

Kappa coefficient was calculated with the help of Eq. (2)

$$K = \frac{K = \Sigma_{i=1}^{r}\ x_{ii} - \Sigma_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \Sigma_{i=1}^{r}(x_{i+} \times x_{+i})} \quad (2)$$

where

N is the total number of ground truthing pixels = 250

$\Sigma_{i=1}^{r} x_{ii}$ = sum of correct cells = 210

$\Sigma_{i=1}^{r} (x_{i+} \times x_{+i})$ = sum of all row total × column total = 12500

The overall accuracy and kappa coefficient came out to be 84 percent and 0.8, respectively.

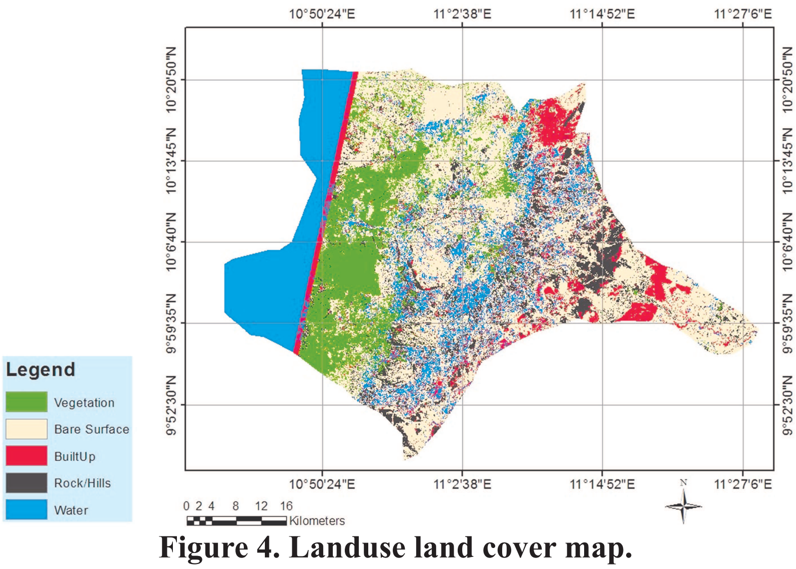

Figure 4. Landuse land cover map.

Table 3. Error matrix for accuracy of classification

LULC	Referenced data					Nc	Pa (%)	Ua (%)
Bare Surface	Bare Surface	Vegetation	Water body	Built-up	Rock			
	40	0	11	0	0	51	80	78
Vegetation	10	**50**	14	0	0	74	100	68
Water body	0	0	**24**	0	0	24	48	100
Built-up	0	0	0	**47**	1	48	94	98
Rock	0	0	1	3	**49**	53	98	92
Total	50	50	50	50	50	**250**	80	78

Note: LULC = land use land cover, NC = number of correct, PA = producers accuracy, UA = users accuracy

4.2 Maps of LCP Analysis

Figure 5 shows the cost surface which serve as a guide in terms of costing. Area with red colour reflects high cost while yellow to green areas indicate low cost. **Figure 6** shows the result as least accumulative cost distance from each cell to the source. From the source (0 cost units), travel cost increases up to the destination over the cost surface.

Figure 7 shows the cost backlink which is more of a direction raster map. It essentially provides a road map that identifies the route to be taken from any cell along LCP back to the nearest source (0 cost units). **Figure 8** shows the map of LCP overlaid on LULC cover map of the study area. **Figure 9** shows overlay of LCP with existing road.

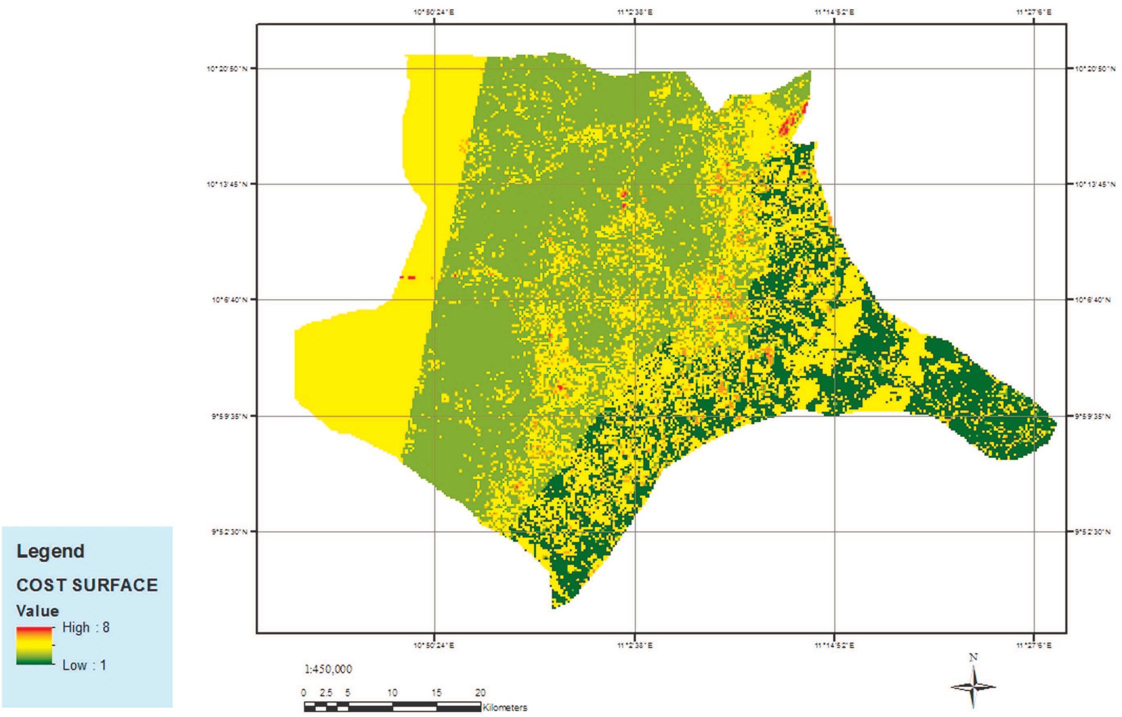

Figure 5. Cost surface map.

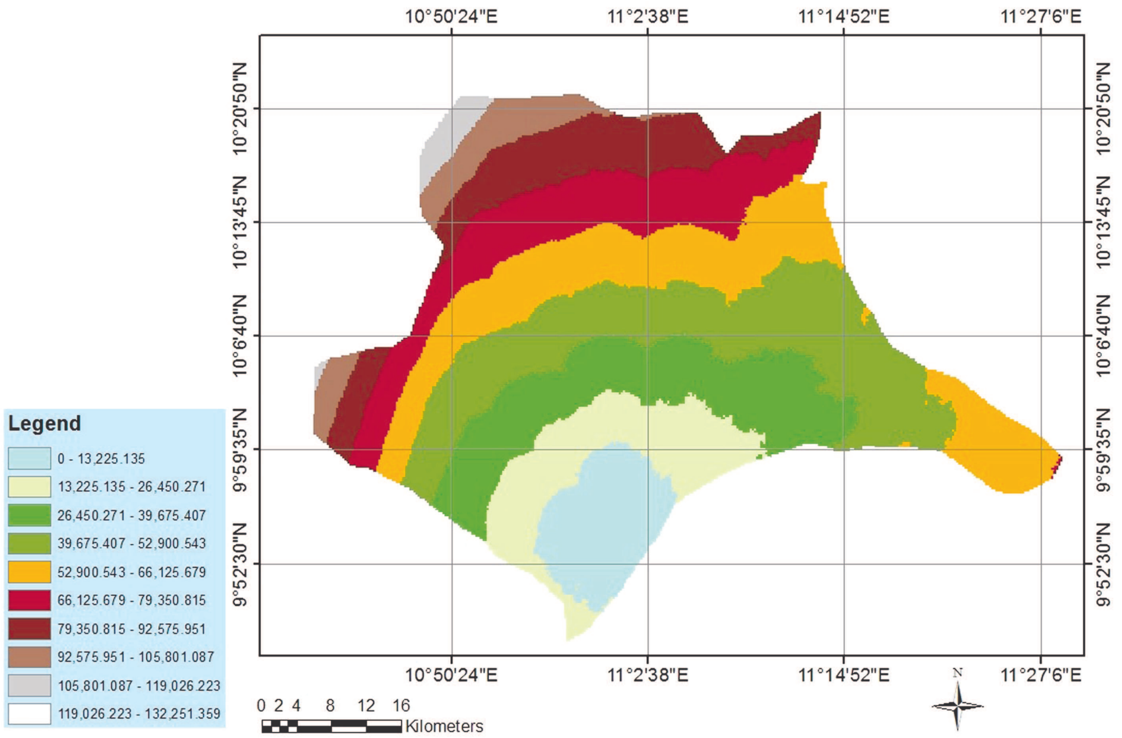

Figure 6. Map of cost distance raster.

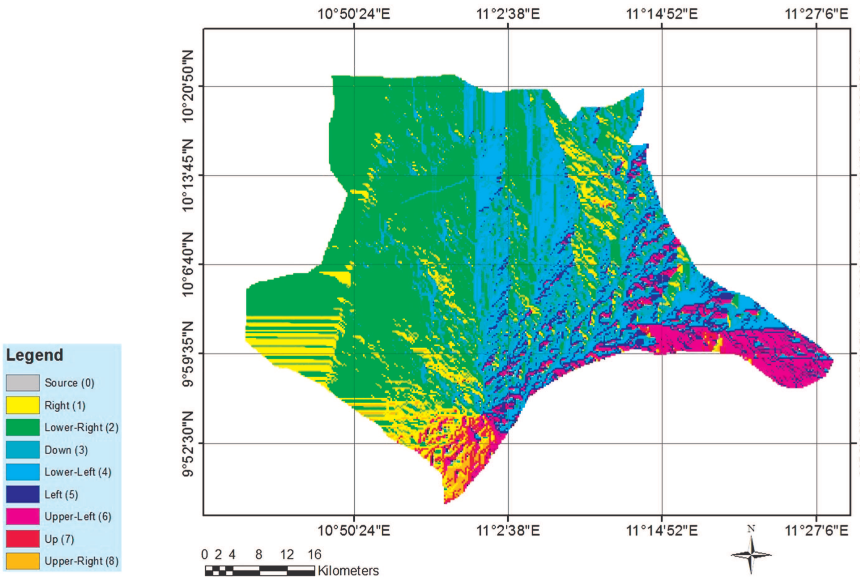

Figure 7. Map of cost backlink.

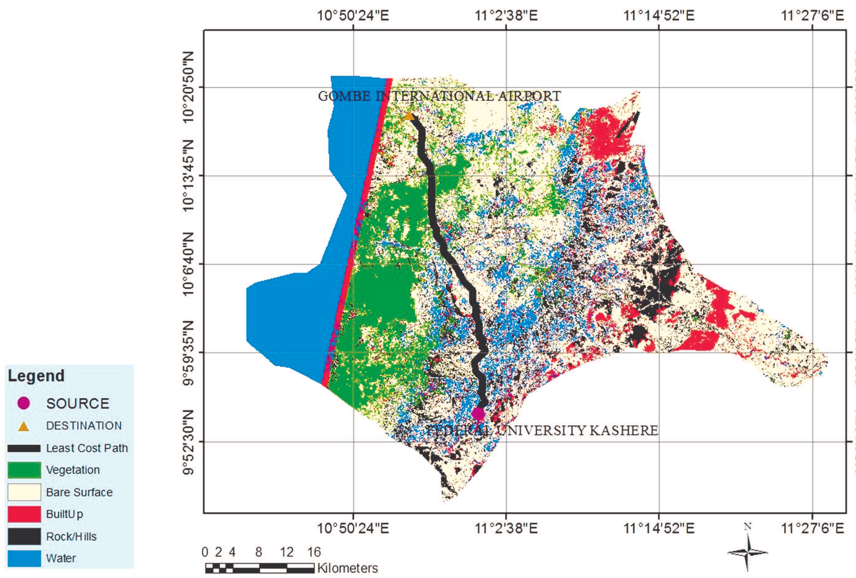

Figure 8. Map of least cost pathway.

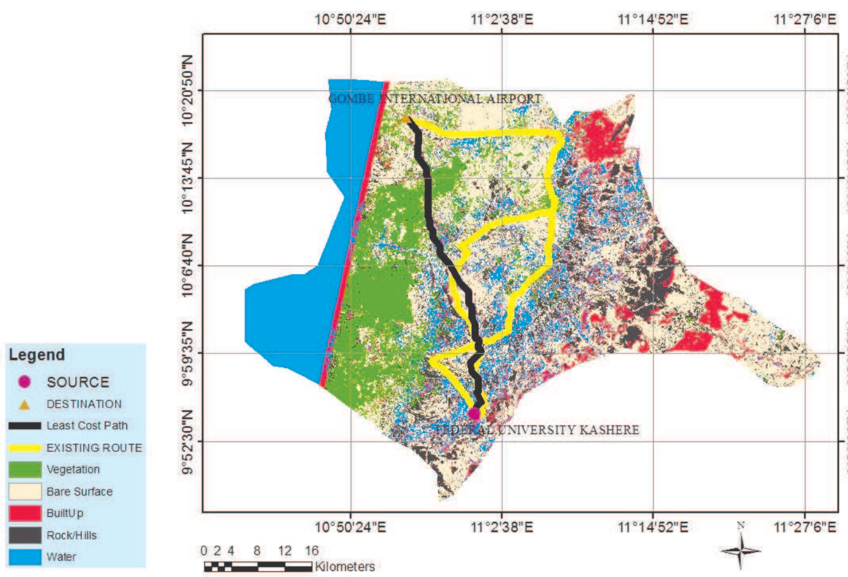

Figure 9. Overlay of least cost path and existing road.

5. DISCUSSION ON RESULTS

LCP was generated based on the predefined criteria mentioned earlier. It tried (as much as possible) avoiding built up, steep slopes, water body, rocky surfaces and flow accumulation. Although LCP should be a straight line road between start (source) and destination point making the cost of construction less, it tend to show some deviation due to the criteria. It was found that LCP generated was shorter than the existing route in the study area. There are two existing routes to the destination point (Federal University Kashere). The first route is 84.62 km (52.6 miles) long while the second route measures 75.77 km (47 miles). LCP was found to be 50.17 km (31.2 miles) which is 34.45 km (21.4 miles) and 25.60 km (16 miles) shorter compared to the first and second existing routes, respectively.

From the start point (FUK), LCP tends to follow the first existing route but subsequently deviated by moving north to join the destination point (Gombe International airport). LCP on a general note move away from the path of the existing road but at some points followed this road for few kilometre from the source point.

The study of the geological map of the area indicated that the area was dominated by the sandy clay soil type (fine textured soil) whose bearing capacity and resistance to wear and tear was poor, with clay having high compressibility when compacted. This soil along LCP is to be replaced with coarse textured soil which consists of gravel and sand. Coarse textured soil has excellent bearing capacity and resistance to wear and tear. Its compressibility when compacted is also negligible. The long term benefits of this work are that it reduces road maintenance cost to the minimum and the durability of the road is increased.

The overlay of LCP on the aspect map (**Figure 7**) was able to show the flow direction of water due to surface run off during the rainy season. Although the flow accumulation was used to generate the cost surface, LCP follow the most cost efficient location. As a result, only one bridge or culvert is needed along LCP. Nevertheless, a good drainage system of about 5 km (3.1 miles) is needed along LCP from the source point.

6. CONCLUSIONS AND RECOMMENDATIONS

It is pertinent to note that computer based approach (GIS and remote sensing) to LCPA is cost effective, simple and specific compared to the conventional method of linear engineering structures site selection procedures used by policy and decision makers. Remote sensing data and LCP modelling in GIS enable determination of LCP using AHP. LCP created in the presented study was found to be 34.45 km (21.4 miles) and 25.60 km (16 miles) shorter than the two existing routes. As a result, an alternative route to the airport is 40.7 percent and 33.8 percent shorter that the two existing routes. Similar studies can also be carried out for other linear construction projects such as railway lines, pipeline routing, power transmission lines, etc. More work, however, can be carried out to add other criteria by involving various stake holders in the construction sector to construct more environmental friendly routes.

REFERENCES

[1] Effat HA, Hassan OA. Designing and Evaluation of Three Alternatives Highway Routes Using Analytical Hierarchy Process and Least-cost Path Analysis, Application in Sinai Peninsula, Egypt. Egypt J Remote Sens Space Sci 2013;16:141-151.

[2] Chandio IA, Matori ANB, Yusof KBW, Talpur MAH, Khahro SH, Mokhtar MRM. Computer Application in Routing of Road using Least-Cost Path Analysis in Hillside Development. Res J Environ Earth Sci 2012;4(10):907-911.

[3] Yusof KW, Baban S. Least-cost Pipelines Path to the Langkawi Island, Malaysia using a Geographical Information System (GIS), 2004 (accessed on 18 October 2015). Available from http://www.geospatialworld.net/Paper/Application/ArticleView.aspx?aid=1506#sthsh.LhbDwARV.dpuf.

[4] Yildirim V, Nisanci R, Reis S. A GIS Based Route Determination in Linear Engineering Structures Information Management (LESIM). In: Proceedings of XXIII FIG Congress-Shaping the Change. Munich, Germany: 2006.

[5] Isah AIO. Introducing GIS and Multi-criteria analysis in Road Path Planning Process in Nigeria: A Case Study of Lokoja, Kogi State. Master thesis. University of Gavle, Sweden, 2008.

[6] Grassi S, Friedli R, Grangier M, Raubal M. A GIS-Based Process for Calculating Visibility Impact from Buildings during Transmission Line Routing: In: Huerta J, Schade S, Granell C, Editors. Connecting a Digital Europe through Location and Place: Lecture Notes in Geoinformation and Cartography. Springer International Publishing, Switzerland, 2014. p. 383-402.

[7] Peter EU. Suitability Analyses for Locating Solid Waste Disposal Site(s) Using Geographic Information System (GIS) in Jimeta Metropolis, Adamawa State. BTech Dissertation, Federal University of Technology, Yola, Nigeria, 2008.
[8] Kang-tsung C. Introduction to geographic information system. Tata McGraw Publishing Company Limited, India, 2008.
[9] Ndukwe KN. Digital technology in surveying and mapping; principles, application and legislatives issues. Rhyce Kerex Publishers, Enugu, Nigeria, 2001. p. 1-23.
[10] Ahmed ND, Asmael NM. A GIS-Assisted Optimal Urban Route Selection Based On Multi Criteria Approach. Iraq J Mechan Mat Eng-Special Issue (D) 2011.
[11] Federal University of Technology Kashere. A Publication of the Office of Vice Chancellor. News Bulletin 2013;1(1):1-6.
[12] Kaoutar B, Lahcen B. A Decision Support Approach for Optimized Siting of Municipal Solid Waste Landfill, A Case Study Tangier Morocco. Int J Eng Res Appl 2012;2(6):1676-1684.
[13] Yunliang M, Malczewski J, Soheil B. A GIS-Based Multicriteria Decision Analysis Approach for Mapping Accessibility Patterns of Housing Development Sites: A Case Study in Canmore, Alberta. J Geograp Inf Sys 2011;3:50-61.
[14] Alexander ER. Traversing the Terrain: A Least-cost Analysis on Intersite Causeways in the Maya Region. MA thesis University of Central Florida, Orlando, Florida, USA, 2014.
[15] Federal Government of Nigeria. Land Use Act. Laws of the Federation, Federal Republic of Nigeria, 1990. 13-14.
[16] City of Nanaimo. Steep Slope Development Permit Area Guideline, 2002 (accessed on 10 August 2015). Available from www.planning.utah.gov/criticallands/critical%20OPDFs/steepslopes.pdf.
[17] Contractor's Handbook. Labour base road works. Ministry of Works and Supply, Road Department. Nigeria, 2004. p. B1-B6.