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An application of Multi-Attribute Utility Theory (MAUT) to the prioritization of rural roads to improve rural accessibility in Nigeria

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ABSTRACT

Good quality rural road infrastructure seems to contribute substantially to improvements in several socio-economic indicators in rural areas: increases accessibility to markets, educational and health facilities, and stimulates economic activities. However, several millions of people in sub-Saharan Africa do not live in proximity to an all-season road. A robust process of prioritizing roads for upgrade is needed to ensure efficient allocation of scarce resources in a manner that will maximize accessibility to key social amenities and economic opportunities. This study uses Multi-Attribute Utility Theory (MAUT) to examine how rural roads in Akwa Ibom State, Nigeria may be prioritized for upgrade to maximize access to key socio-economic facilities. In our analysis, the rural roads to be prioritized are the alternatives while the decision criteria are: social, economic, demographic, financial, and political. The MAUT is preferred to the commonly-used Analytic Hierarchy Process (AHP) because the number of alternatives is large. Geographic information system (GIS) techniques are applied to process some of the data used in the performance matrix of the MAUT. We specify non-linear marginal utility functions for the criteria. Scenario analyses are also carried out to examine the impact of changes in the weights of the criteria on the utility score of each alternative. The study identifies 10 roads that will yield the highest socio-economic benefits and promote rural accessibility. Finally, the study recommends that decision-makers adopt a similar approach in selecting rural roads for upgrade, instead of selecting roads based on political considerations.

1. Background

The quality of rural road infrastructure[1] may enhance or hamper socio-economic development in rural areas. Studies have shown that good quality rural road infrastructure contributed positively to employment and income in rural Indonesia [1]; created several direct and indirect positive impacts on rural communities in the Philippines [2]; improved per capita income and working hours of households in Viet Nam [3]; and contributed substantially to reducing poverty in many developing countries [4–8]. Further, improvement in the quality of rural road infrastructure resulted in improved access to markets and reduced cost of transportation in Ghana [9], Nigeria [10], and Brazil [11].

Rural accessibility has gained prominence in the development sector with the inclusion of the Rural Accessibility Index (RAI) as one of the indicators of Goal 9 of the United Nation's Sustainable Development Goals (i.e. indicator 9.1.1). The RAI measures the proportion of the rural population who live within 2 km of an all-season road [12]. A recent study estimated that over 450 million people in sub-Saharan Africa have limited rural accessibility because they do not live within 2 km of an all-season road [13]. Within a broader context, rural accessibility also includes the number of social amenities that are within a given distance from a paved road. Better rural accessibility is contingent on improvement in the quality of rural road infrastructure as well as the quality of rural transport services [14,15]. The concept of accessibility extends beyond rural areas in developing countries and can also be applied in urban settings or in developed countries to examine the level of ease in

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[1] The quality of rural road infrastructure is used here in a descriptive manner because there is no standard measurement for rural road quality. In this study, we assume that the quality of rural roads ranges from "poor" to "good". A quality of a rural road may be described as "poor" if it is an earth road that becomes sodden and impassable during the rainy season. On the other hand, the quality of road may be described as "good" if it is an asphalt road with pavement condition index (PCI) above 70. Between these extremes, there may be undisturbed earth roads, gravel roads, or asphalt roads with PCI lower than 70.

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which residents can reach certain destinations or access certain facilities [16–19].

In Nigeria, roads are classified as federal, state, or local roads.[2] The federal roads connect two states; the state roads connect two local government areas (LGAs); while the local roads connect two communities/villages. Most of the local and some state roads are regarded as rural roads. The quality of roads in Nigeria is generally poor: 78% of state roads and 87% of local roads are in poor condition [20]. Given that a large percentage of the population of Nigeria resides in rural areas and are agrarian [21,22], the poor quality of rural roads poses a huge barrier to the socio-economic transformation of rural areas, and the upgrade of these roads is crucial to the development of these rural areas.

Rural road infrastructures are considered to be public goods and are provided by governments. In Nigeria, the upgrade of rural roads is usually carried out by the state governments even though local governments also have the mandate to upgrade existing local roads and build new ones. The decision on which road(s) should be upgraded among a set of poor quality roads is usually taken by political actors based on financial, economic, and political considerations. Studies have shown that political considerations play a vital role in the selection of roads for upgrade in developing countries [23–25].

Given the role of good quality rural road infrastructure in stimulating socio-economic development in rural areas, a comprehensive process of prioritizing rural roads for upgrade is needed to ensure efficient allocation of scarce resources in a manner that maximizes accessibility to key social amenities and economic opportunities. Several studies have carried out prioritization of rural roads for upgrade in different countries [26–32]. However, this topic is under-researched in Nigeria and it might not be appropriate to extrapolate findings of road prioritization studies from other countries due to the differences in the socio-economic and socio-political situation across developing countries. Country-specific studies are needed to provide better insights on how prioritization of rural roads may be carried out in a country based on the local socio-economic and political situation. This study intends to fill this knowledge gap: the study examines how rural roads may be prioritized for upgrade in a manner that maximizes access to social and economic facilities in rural areas in Nigeria. We conceptualize our research problem as a multi-criteria decision problem. We use the Multi-Attribute Utility Theory (MAUT) instead of the commonly-used Analytic Hierarchy Process (AHP) because the number of roads to be prioritized (i.e. alternatives) is large.

The remaining part of the study is organized as follows: Section 2 will be a review of literature on prioritization of rural roads; Section 3 will be the Methodology; Section 4 will be the results and discussion; while Section 5 will be the concluding remarks.

2. Review of literature

Several studies have been conducted on the prioritization or ranking of rural roads for upgrade and have applied diverse methodologies such as cost-benefit analysis (CBA) [29]; Integrated Rural Accessibility Planning (IRAP) [33,34]; multi-criteria decision analysis (MCDA) [30,31,35–37]. Other studies have used methods that are descriptive and less formal [26,28,32].

The CBA involves estimating the potential economic costs and benefits of a project, or that will accrue to a project by the end of the project's life, by aggregating estimates of monetary values of the expected costs and benefits over a given period. The costs and benefits may include financial, social, and environmental cost/benefit of a project [38]. The primary setback in the use of CBA is the difficulty in estimating the costs and benefits, especially in places where data are scarce [26,27].

The Integrated Rural Accessibility Planning (IRAP) is a multi-sectoral, integrated planning tool developed by the International Labour Organization to support rural access planning (International Labour Organization, 2000). The tool is designed to reflect the travel needs of rural population, the locations of basic social amenities, as well as the transport infrastructure in different sectors. The tool adopts a participatory approach to planning and involves communities in all the stages of the planning process [39]. [40] notes that the main limitation to the IRAP is that it requires strong institutions to implement, especially given the level of community involvement and data requirement. These strong institutions are often lacking in developing countries and there are other challenges in terms of managing community expectations.

The prioritization or ranking of rural roads for upgrade is a decision-making problem that may be analyzed using Multi-Criteria Decision Analysis (MCDA). MCDA incorporates different criteria into the decision-making process through diverse analytical techniques. This results in straightforward and better-considered solutions because it allows for conflicting objectives to be addressed simultaneously [27]. Decision-making problems under MCDA may be classified as "Choice Problems", "Sorting Problems", "Ranking Problems", or "Description Problems" [41]; pp. 3–4; [42]. Our study may be considered a ranking problem. Ranking problems may be analyzed using different MCDA techniques such as Multiple Attribute Utility Theory (MAUT), Analytic Hierarchical Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [41]; p. 4). The AHP seems to be the most popular MCDA technique for solving ranking problems [43]. Notwithstanding its extensive use in this direction, it is difficult to apply AHP when the number of alternative choices available to decision-makers is large because it will be cumbersome to complete the AHP pairwise matrices [44]. The MAUT is preferred to the AHP in such situations [42]. Given a set of decision options to be ranked subject to certain criteria, the MAUT provides a method for ranking these decision options such that the highest-ranked decision option is the one that maximizes a specified utility function. The MAUT has been used extensively in the literature for ranking problems in diverse fields including health [45]; maritime transport [46]; international investment [47]; pavement management [48]; selection of diplomats [49]; evaluation of cooking devices [50]; flood risk prioritization [51].

In terms of geographic spread of studies, most MCDA studies on prioritization or ranking of rural roads are carried out in Asia. Specifically, in India [30,35,52–54]; Nepal [31,36,55]; the Philippines [56]. Studies in sub-Saharan Africa are scarce [37], hence the need for this study.

Due to the advancement in information and communication technologies (ICT) and spatial science, Geographic Information Systems (GIS) is now being used as an improvement to the traditional management information system (MIS) because GIS integrates spatial data into MIS and can be very useful in analyzing data and making inference from spatial data. GIS has been applied extensively in the planning of infrastructure projects in different sectors such as power, telecommunication, rails, and road transport [57]. The contribution of GIS to the planning process is multi-fold as it helps in virtually all phases of planning. In this direction, some studies have integrated GIS into the process of planning and prioritizing of rural roads for upgrade [35,40,52–54,56,58].

It is clear from the foregoing that there are gaps in the literature in terms of the geographic coverage of studies on prioritization of rural roads: studies in sub-Saharan Africa are scarce. Furthermore, the methodologies used, i.e. CBA or AHP, are appropriate when the number of roads to be considered for prioritization is small. These methods may not be appropriate when the geographic coverage of roads to be prioritized is national or sub-national because the number of roads under consideration will be large. Hence, we use MAUT. The process of generating data to develop the performance matrix in MAUT can benefit greatly from GIS. Through GIS, planners may easily visualize the spatial locations of different features that influence the prioritization of rural roads and carry out different spatial analyses to generate useful data.

[2] There are 36 states and a Federal Capital Territory in Nigeria. Each of the 36 states are further divided into local government areas (LGAs) and each of the LGAs are then divided into wards.

3. Materials and methods

3.1. Study location

This study will be conducted in Akwa Ibom State, Nigeria. Akwa Ibom State is one of the 36 states in Nigeria located in the Niger Delta region. It adjoins the Atlantic Ocean and lies between latitudes 4° 32.1′ and 5° 33.1′ North, and longitudes 7° 25.1′ and 8° 25.1' East. The state is selected because it is relatively small in size and has a good mix of urban and rural areas[3] . Administratively, the state is further divided into 31 local government areas (LGAs). The 2015 population of the state was estimated at 5.27 million [59] and the state falls within the tropical rain forest and mangrove swamp agro-ecological zones. The map of the study area is presented in Fig. 1.

3.2. Methodology: Multi-Attribute Utility Theory

Our problem is presented in a hierarchical structure in Fig. 2. Level 1 highlights the main objective. Levels 2 and 3 represent the criteria and sub-criteria respectively, while level 4 is the alternatives.

3.2.1. Performance matrix

3.2.1.1. Alternatives. The rural roads in the study are the alternatives. To identify all candidate roads, we note that the definition of "rural road" varies significantly depending on the country and environment. In this direction, a working definition of "rural road" is necessary to facilitate the development of inclusion/exclusion criteria. The criteria for selecting the rural roads for this study are:

(i) the road is not a federal road (i.e. it may be a state or local government road)
(ii) the road is not an asphalt road; and
(iii) the length of the road is greater than 5000 m;

To obtain the rural roads, we use secondary data of road networks in Nigeria obtained from Open Street Map using an online tool.[5] Using the *Intersection* geo-processing function in QGIS, we extracted the road network in Akwa Ibom from that of Nigeria. This yielded a total of 33,628 entries in its Attribute Table. The frequency distribution of these entries shows that 27,849 are less than 500 m; 3383 are between 500 m and 1000 m; a total of 2113 are between 1000 m and 5000 m; while 283 are above 5000 m. We carried out further assessment of the 283 roads greater than 5000 m and a total of 126 roads met our inclusion criteria.

3.2.1.2. Data on criteria

3.2.1.2.1. Social: health and education. The social variables to be used in the study are informed by those used in previous studies [35,54, 56]. These criteria are also relevant to the study area. For our study, we use the numbers of educational and health facilities within 1000 m buffer area of each rural road respectively. The data on the spatial locations of educational and health facilities (point vectors) are obtained from the Geo-Referenced Infrastructure and Demographic Data for Development (GRID3) programme in Nigeria[6]

3.2.1.2.2. Economic. About 80% of the population in the study area is rural [60]. As with other parts of Nigeria, agriculture is the primary driver of economic activities in the rural areas. Based on this, the economic criterion focuses on agro-based activities as follows:

(a) Number of markets within 1000 m buffer area of each rural road. Data on spatial locations of markets (point vectors) are obtained from GRID3.
(b) Number of agro-processing facilities with 1000 m of each rural road. Spatial locations of agro-processing facilities within the study area are obtained from the Rural Access and Agricultural Marketing Project (RAAMP).

3.2.1.2.3. Demographic. The demographic criterion refers to the population within 1000 m radius of each selected road. To obtain the population, we used the raster data of population distribution for Nigeria from World Pop.[7] We downloaded the data for Nigeria and used the "intersection" function on QGIS to clip the data for the study area. We re-projected the road shapefiles to an appropriate coordinate referencing system (CRS) for Nigeria that also allows for buffering operation in meters (i.e. EPSG32632 – Minna 32 N), buffered the shapefile at 1000 m, then used the "Zonal Statistics" processing tool in QGIS to extract the population within the buffered area for each rural road.

3.2.1.2.4. Political. It will be unrealistic to expect that decision-makers who are mostly politicians will exclude political considerations from the decision-making process. However, unlike social, economic, or demographic criteria, the variables that may be used for political criterion are difficult to quantify objectively. We use the number of polling units within 1000 m buffer area of each rural road as a proxy. Data on the spatial locations of polling units are obtained from the Independent National Electoral Commission (INEC).

3.2.1.2.5. Financial. We use the cost per km of upgrading a road from an "undisturbed earth road" to a "single carriage asphalt road with side drains and no median". Obtaining the actual cost of upgrading roads would have required (i) physical assessment of each road to understand the terrain; (ii) development of an engineering design for each road; and (iii) development of bill of engineering measurement and evaluation (BEME) for each road. This would have been costly and time-consuming. Instead, we obtained the cost per km of an actual rural road awarded for construction in the study area in 2020 from the Ministry of Works and added a "penalty factor" as follows:

$$Cost_j = A\left(1 + p_j\right) * Roadlength_j$$

Where $Cost_j$ is the cost of upgrading road *j*; *A* is the actual cost per kilometer of upgrading a rural road in the study area in the year 2020 (NGN225.5 million[8]/km); $Roadlength_j$ is the length of road *j*; and p_j is a positive adjustment factor that is used to adjust *A* for the different roads to reflect other factors that influence the cost of rural road improvement (e.g. soil type, elevation).

p_j s are estimated using the digital elevation map of the study area and they range from 0.0 to 0.5. $p_j = 0.5$, if the average elevation of the road is between 0 and 15 m; $p_j = 0.3$, if the average elevation of the road is above 40 m; and $p_j = 0$, if the average elevation is between 15 m and 40 m. A higher value is assigned to p_j for elevations between 0 and 15 m because it suggests that such roads are in a marshy environment which will require additional construction materials or will likely require a bridge.

Further, we carried out a pairwise comparison of the scores of the alternatives across all criteria in the Performance Matrix to eliminate

[3] The smallest state in Nigeria i.e. Lagos is completely urban.

[4] It is important to note that the shapefile used to generate the map of the study area is slightly different from the publicly available shapefiles for the second administrative level (i.e. states) in Nigeria.

[5] https://www.geofabrik.de/data/(accessed on February 22, 2020).

[6] https://grid3.gov.ng/(accessed on April 19, 2021).

[7] Unconstrained individual country data for Nigeria for 2020 (100 m resolution). WorldPop (www.worldpop.org - School of Geography and Environmental Science, University of Southampton; Department of Geography and Geosciences, University of Louisville; Department de Geographie, Universite de Namur) and Center for International Earth Science Information Network (CIESIN), Columbia University (2018). Global High Resolution Population Denominators Project - Funded by The Bill and Melinda Gates Foundation (OPP1134076). https://dx.doi.org/10.5258/SOTON/WP00645.

[8] Monetary figures are presented in Nigerian Naira (NGN). For international readers, the average exchange rate at the time of this study (i.e. January–June 2021) is US$1 = NGN409.

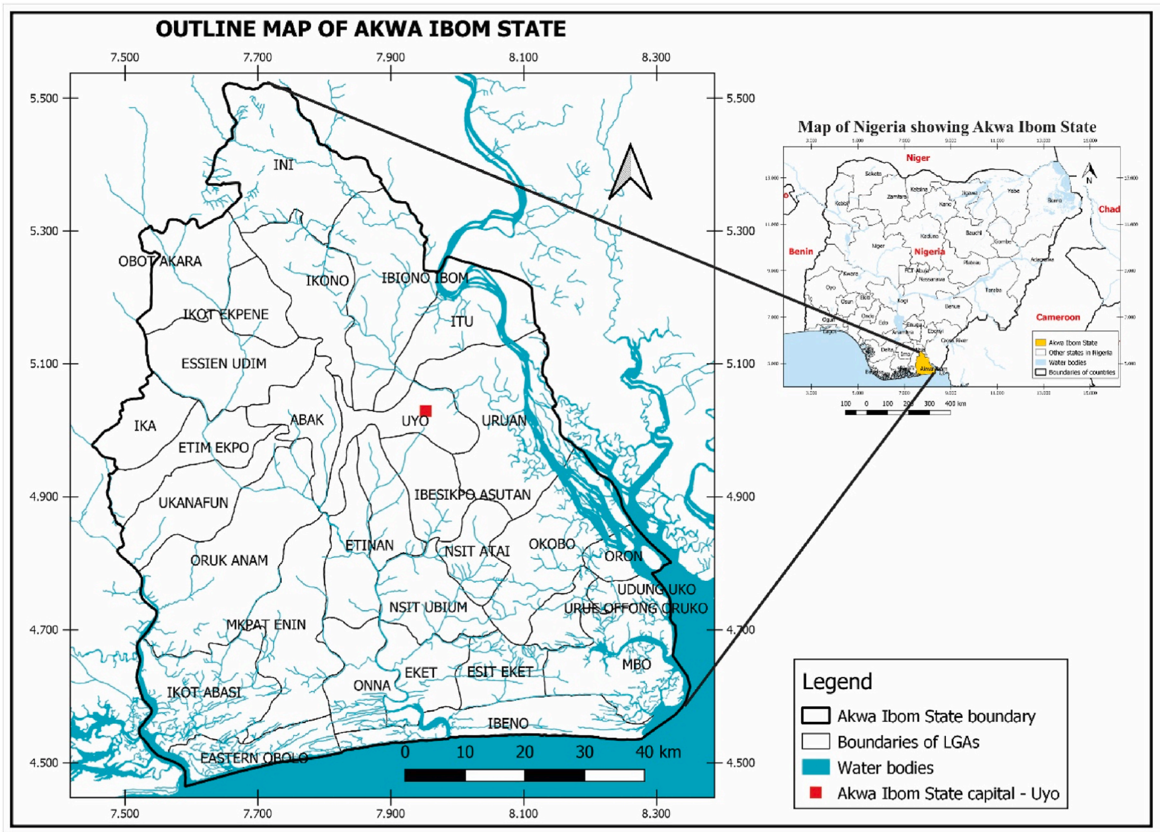

Fig. 1. Map of akwa ibom State.[4]
Source: Authors.

dominated alternatives. This reduced the number of alternatives from 126 to 59. The summary of the data in the performance matrix is presented in Table 1 While the map showing the selected roads is presented in Fig. 3.

3.2.2. Normalization of performance matrix

The entries in the Performance Matrix are usually normalized to values between 0 and 1. This is done to ensure comparability across the criteria since the criteria may have different units of measurement. For criteria where higher values are desirable, the normalization will make the highest value to be 1 and the lowest value to be 0. In contrast, for criteria where lower values are desirable (e.g. cost), the normalization will make the lowest value to be 1 and the highest value to be zero. The normalization method is presented below:

For criteria that need to be maximized (i.e. higher marginal utility scores are desirable)

$$g_{ij} = \frac{c_j(a_i) - Min_j[c_j(a_i)]}{Max_j[c_j(a_i)] - Min_j[c_j(a_i)]} \quad (1)$$

Criteria that need to be minimized (i.e. lower marginal utility scores are desirable)

$$g_{ij} = \frac{Max_j[c_j(a_i)] - c_j(a_i)}{Max_j[c_j(a_i)] - Min_j[c_j(a_i)]} \quad (2)$$

Where a_i is the alternative i; c_j is the criteria j; g_{ij} is the normalized score for of a_i in c_j and $0 \leq g_{ij} \leq 1$; $c_j(a_i)$ performance score of a_i in c_j; $Max_j[c_j(a_i)]$ and $Min_j[c_j(a_i)]$ represents the maximum and minimum elements in the column vectors c_j s respectively.

3.2.3. Marginal utility functions of the criteria

We need to specify the marginal utility function for each criterion. We present the shapes of common marginal utility functions in Fig. 4. We note that the g_{ij}'s obtained from equations (1) and (2) are linear with respect to each criterion. We use these g_{ij}'s to obtain the marginal utility functions as specified in Table 2.

3.3. Weights and scenario building

The weights for the criteria in MAUT have been a contentious issue for researchers because the method for determining the weights is often subjective [61]. The subjective weighting methods include simple multi-attribute rating technique (SMART), pairwise comparison, AHP [42]. We adopt the AHP model and prepared an AHP questionnaire which included a pairwise matrix with a 9-point scale. Prior to completing the pairwise matrix, respondents were asked to rank the criteria from 7-most important to 1- least important. This ranking was to guide the respondent in completing the questionnaire to minimize the risk of having inconsistencies in the AHP analyses. The respondents were selected purposively and included: (i) senior/management staff of the Ministry of Works in the study area, (ii) staff of donor-funded projects focusing on road infrastructure development, and (iii) development experts in the academia. A total of 12 persons completed the questionnaire. The analyses and checks for consistencies were done individually and the weights for all respondents were consistent. We computed the final weights using the arithmetic mean of the individual weights.

It is important to also examine how the changes in the weights will affect the utility scores of the alternatives. We did this by creating realistic scenarios by altering the initial weights used in the base case scenario. The scenarios are as follows:

(i) The main criterion for decision making is financial, i.e. the cost of upgrading the rural roads.
(ii) Social criterion has the highest weight.

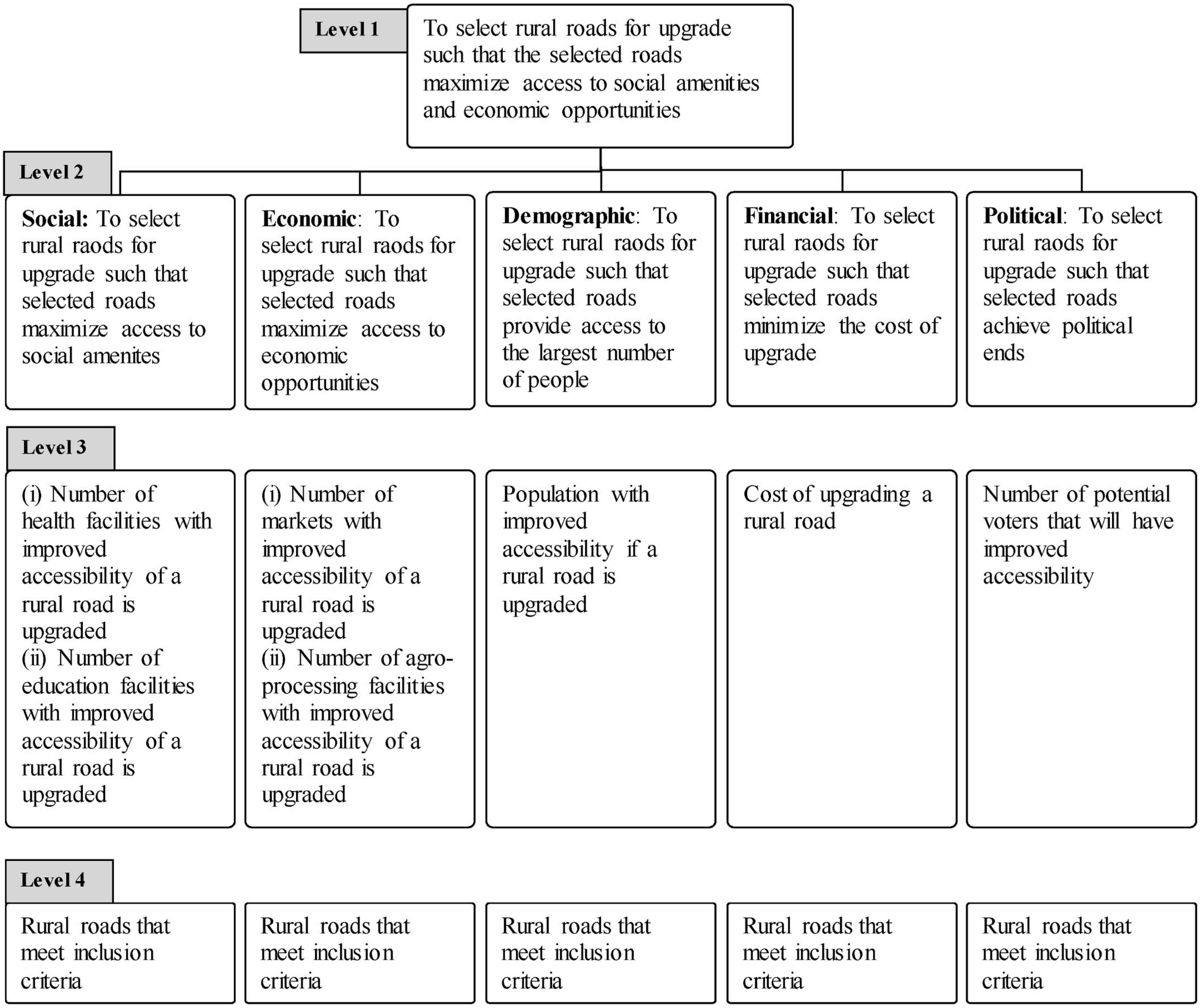

Fig. 2. Hierarchy of decisions to be made.

Table 1
The summary of the data used.

	Financial	Economic- 1	Economic 2	Social 1	Social 2A	Social 2B	Demographic	Political
	Cost of upgrade (NGN million)	No. of Agro-processing facilities	No. of Markets	No. of Health facilities	No. of primary schools	No. of Secondary schools	No. of persons within 100 m × 100 m area	No. of polling units
Min	1144.73	0	0	0	1	0	3085	3
Max	6069.80	17	16	7	16	12	47,899	27
25th percentile	1321.99	0	3	1	4	1.5	12,637	8
50th percentile	1482.22	1	4	2	6	2	18,665	12
75th percentile	2278.03	2	6	3	8	4	22,911	15
Mean	1837.13	1.76	4.64	2.29	6.42	2.69	19194.14	12.27
St. Dev.	825.50	3.02	3.07	1.34	3.32	2.15	9442.85	5.67

(iii) Economic criterion has the highest weight
(iv) Demographic criterion has the highest weight
(v) Political criterion has the highest weight
(vi) The weights are shared equally amongst the criteria.

The summary of the weights for the different scenarios is presented in Table 3.

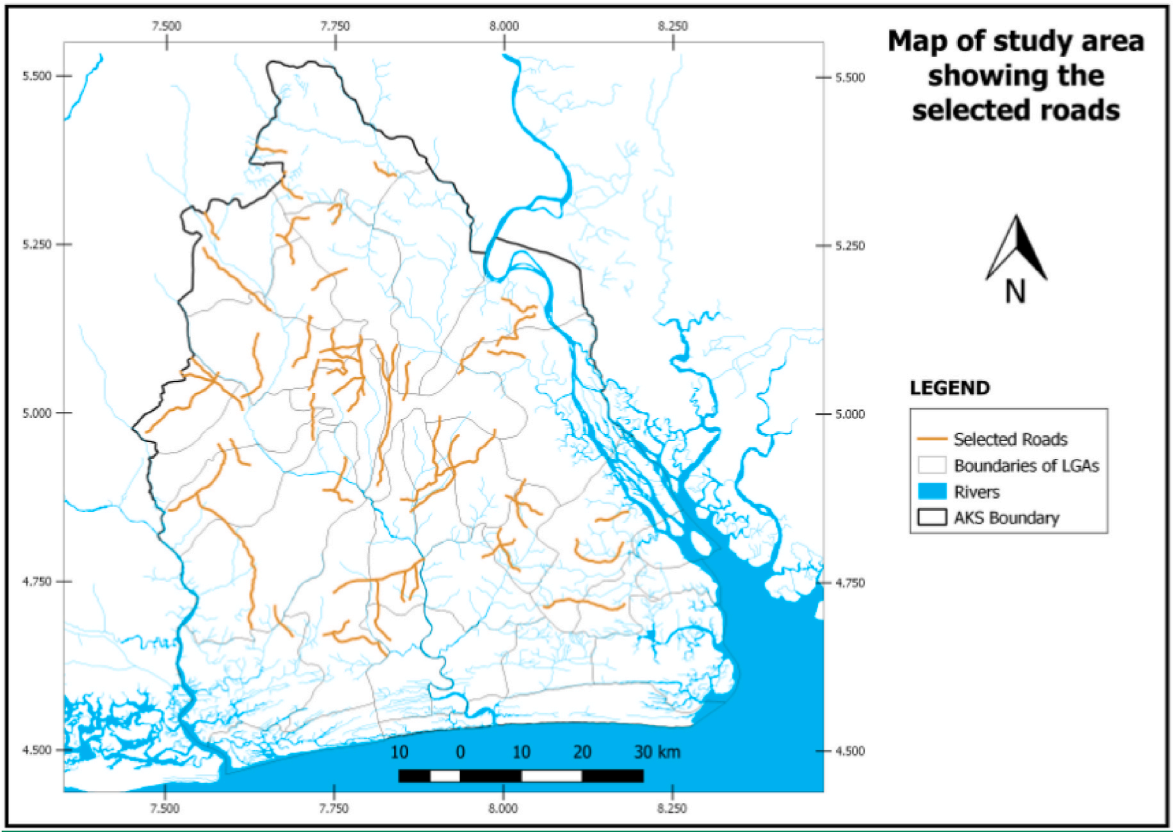

Fig. 3. Map showing the selected roads.

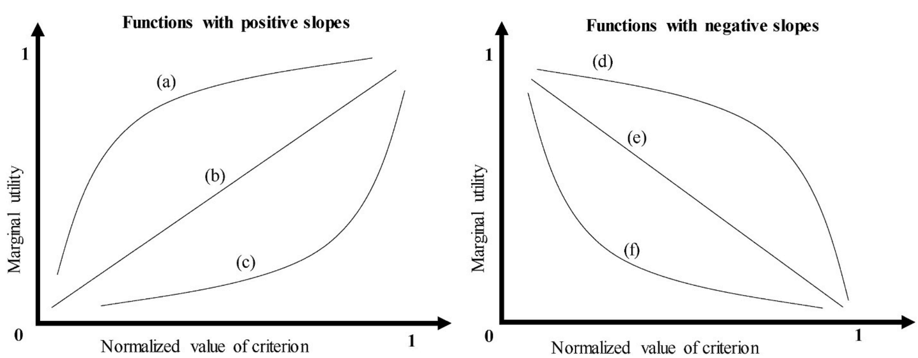

Fig. 4. Diagrammatic representation of positive and negative linear and non-linear functions considered. (a) As the normalized value of criterion increases, marginal utility increases but at a reduced rate (b) As the normalized value of criterion increases, marginal utility increases at constant rate (c) As the normalized value of criterion increases, marginal utility increases but at an incremental rate (d) As the normalized value of criterion increases, marginal utility decreases but at an incremental rate (e) As the normalized value of criterion increases, marginal utility decreases at a constant rate (f) As the normalized value of criterion increases, marginal utility decreases but at a reduced rate.

3.4. Global utility function

To obtain the utility score of each alternative, we aggregated the marginal utility scores of the alternatives across the different criteria. We adopted the additive model which is the most commonly used approach [41]; p. 82 [62]; p. 106) as opposed to the multiplicative or multi-linear model as follows:

$$\forall\, a_i \in A: \; U(a_i) = \sum_{j=1}^{n} W_j U_{ij} \tag{7}$$

Where $0 \leq U(a_i) \leq 1$; W_j is the weight for criteria j; U_{ij} is the marginal utility score obtained from the normalize value of the entry for alternative i and criteria j in the performance matrix – computed using the specification of the marginal utility functions in equations (3) – (6). The analyses were done using MS Excel and the results were appended to the Esri Shapefile of the selected roads using QGIS.

4. Results

The result of the base-case scenario is presented in Fig. 5. The top-ranked road has the following within its 1000 m buffer radius: 2 agro-processing facilities, 16 markets, 4 health facilities, 15 primary schools, 4 secondary schools, and 17 polling units. The population within 1000 m buffer radius of this road is 41,866 and the cost of upgrading this road is estimated at NGN3,557.4million (US$8.7 million). In contrast, the road that ranked last has the following: zero agro-processing facility, one market, zero health facility, two primary schools, zero secondary school, and three polling units. The estimated cost of upgrading this road is NGN1,145 million (US$2.8 million) and the population within 1000 m buffer area of this road is 5017. The roads within these extremes perform better on some criteria on worse on others. The fact that upgrading the road with the highest utility score will have an impact on different economic and social variables also re-iterates the role of improving rural road infrastructure in achieving

Table 2
Marginal utility functions of the different criteria.

Criteria	Marginal utility function (MUF)	Specification
Social-health	The MUF has a positive slope as shown in curve "a" in Fig. 4. The assumption is that the marginal benefits of accessibility to health facilities due to an upgrade of rural roads is positive, but the marginal utility will reduce as the number of such health facilities increases.	$U_{ij} = \frac{100^1 - 100^{1-g_{ij}}}{100^1 - 100^0} \ldots (3)$ $= \frac{100 - 100^{1-g_{ij}}}{99} \ldots (4)$
Social-education	Similar to above	Same as eqn (4)
Economic (markets)	Similar to above	Same as eqn (4)
Economic (agro-processing facilities)	Similar to above	Same as eqn (4)
Demographic	The MUF has a positive slope as show in curve "c" in Fig. 4. As the normalized value of criterion increases, marginal utility increases but at an incremental rate. This is based on the assumption that roads in places with a higher population will have more marginal utility than those in places with a lower population.	$U_{ij} = \frac{100^{g_{ij}} - 100^0}{100^1 - 100^0} \ldots (5)$ $U_{ij} = \frac{100^{g_{ij}} - 1}{99} \ldots (6)$
Financial	Negative function with decreasing marginal utility. This is because as the length of roads increase, the unit cost per km tend to decrease.	Same as eqn (4). The normalization carried out using eqn (2) has already made the highest value to be zero and the lowest to be one. Therefore, we retain this transformation. Otherwise, the appropriate transformation would have been: $U_{ij} = \frac{100^1 - 100^{g_{ij}}}{100^1 - 100^0} = \frac{100 - 100^{g_{ij}}}{99}$
Political	We assume that this criterion will have a function with a positive slope with increasing marginal utility. This is because political actors are more likely to nominate roads in areas with higher population because this will contribute substantially to their popularity	Same as eqn (6)

the Sustainable Development Goals (SDGs).

4.1. Scenarios

We summarize the performance of the top-ranked road in the different scenarios in Table 4. We observe that the road that ranked top in the different criteria differ significantly, with the exception of the "financial" and "equal weights" criteria where the same road had the highest rank. Furthermore, except for the "demographic" criteria where the top-ranked road does not have any agro-processing facility, there are social and economic facilities in every other criterion.

We compute the average of the utility scores of the selected roads in all criteria (with the exception of the base-case scenario). The rationale for doing this is to identify roads that will yield balanced accessibility, irrespective of the scenario. We present the map showing the top-ten roads that should be prioritized based on the average of the utility scores across the different scenarios in Fig. 6.

Beyond ranking of the roads, our model also provides answers to other related questions. For example, given a budget of NGN20billion (US$48.9 million), which road should be upgraded to maximize access to health facilities? From the result of the social scenario, 6 roads with a cumulative length of 13.8 km can be upgraded at a total cost of NGN18.7 billion US$45.72 million. These six roads have within their 1000 m buffer area the following: 24 agro-processing facilities, 59 markets, 25 health facilities, 72 primary schools, 30 secondary schools, 113 polling units, and a population of about 290,000. Our model may also be used to estimate the cost of ensuring that all health facilities or educational facilities in the study area are within 1000 m buffer area of an asphalt road.

Our methodology focuses on selecting roads that maximize the potential economic benefits and promote accessibility. However, one aspect of development is the prevalence of poverty. Several studies have noted that there is a high correlation between physical isolation and incidence of poverty [63–65]. In other words, locations that are physically isolated tend to have higher incidences of poverty. In this direction, it seems that our model will be unable to address the problems of poverty vis-à-vis physical isolation. This means that a road that leads to a poor or isolated community may not be selected for construction because it will not have a high global utility score. It also implies that communities living in isolated areas may find it difficult to escape the poverty trap as investment decisions will seldom be in their favor. Nonetheless, the MAUT may also be used to address concerns of poverty and isolation of the objective of a study is framed to address that.

Furthermore, from a political-economy perspective, investment projects have to be distributed fairly across the different parts of the state. Our method may identify rural roads for upgrade in a certain part of the study area which may lead to feelings of marginalization in other parts. One way of avoiding this problem is to sub-divide the study area into other smaller geographic units such as senatorial districts, federal constituencies, or local government areas before implementing the MAUT.

Table 3
Summary of weights used in the different scenarios.

Criteria	Scenarios						
	Base-case	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Financial	0.0781	0.4	0.1	0.1	0.1	0.1	0.14286
Demographic	0.1632	0.1	0.1	0.1	0.4	0.1	0.14286
Social-health	0.1821	0.1	0.25	0.1	0.1	0.1	0.14286
Social-education	0.1942	0.1	0.25	0.1	0.1	0.1	0.14286
Economic	0.1599	0.1	0.1	0.25	0.1	0.1	0.14286
Economic_2	0.1163	0.1	0.1	0.25	0.1	0.1	0.14286
Political	0.1062	0.1	0.1	0.1	0.1	0.4	0.14286
Total	**1**	**1**	**1**	**1**	**1**		**1**

N/B for the "Social-education" criteria, our data covers primary and secondary schools. Consequently, we breakdown the weight assigned to the criteria to cover primary and secondary schools as follows: primary school (30%), secondary school (70%).

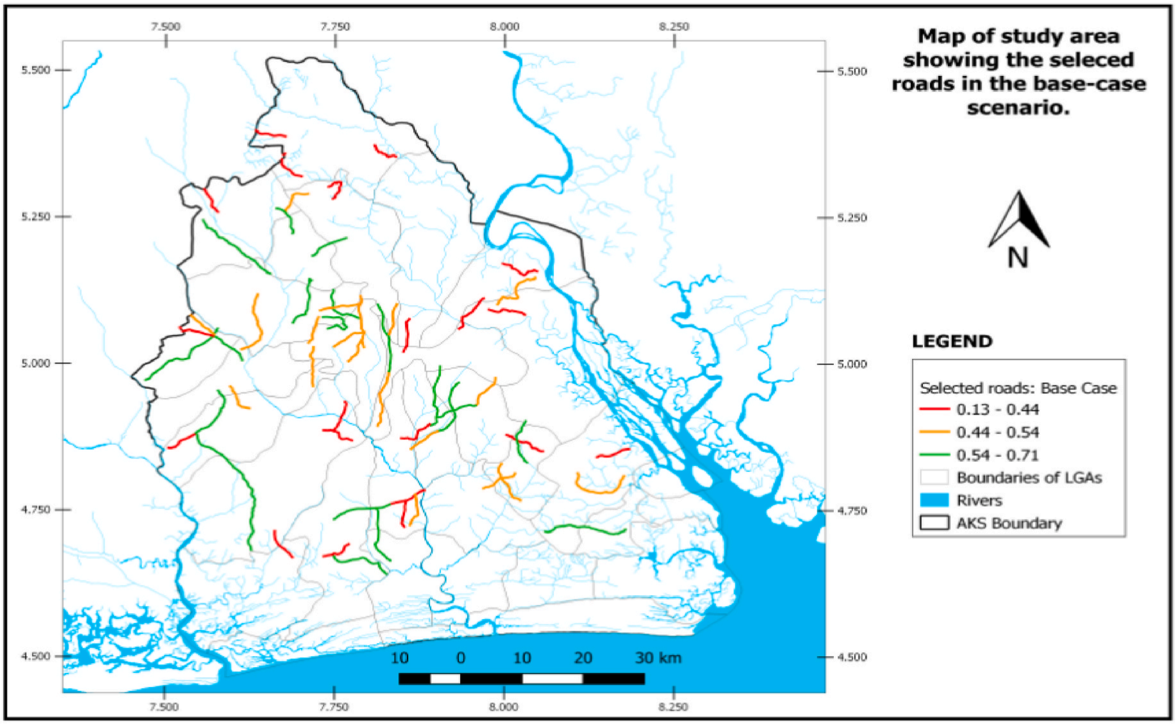

Fig. 5. Map showing roads that should be prioritized based on assumptions in the base-case scenario.

Table 4
Summary of performance of the road that had the heist rank in the different scenarios.

	Cost of upgrade (NGN, million)	Agro-processing facilities (number)	Markets (number)	Health facilities (number)	Schools-Primary (number)	Schools -Secondary (number)	Population (number)	Polling units (number)
Base-case	3557.38	2	16	4	15	4	41,866	17
Political	2515.11	1	7	2	7	1	25,939	27
Social	3557.38	2	16	4	15	4	41,866	17
Demographic	6069.8	0	8	5	14	5	47,899	23
Economic	2555.81	17	7	3	9	4	30,249	15
Financial	2305.97	1	14	3	7	2	37,225	26
Equal weights	2305.97	1	14	3	7	2	37,225	26

5. Concluding remarks

Political considerations play a huge role in the selection of rural roads for upgrade in Nigeria. This study presents a simple template that can be used to integrate socio-economic considerations in rural road transport planning such that roads selected for upgrade will unlock the socio-economic potentials of rural areas, promote rural accessibility, while also considering some political goals. We demonstrate how this may be done using one of the states in Nigeria. Particularly, we use GIS in conjunction with Multi-Attribute Utility Theory. Out of the 59 rural roads in the study area that met our inclusion criteria, we have identified 10 roads that should be prioritized. These identified roads have the highest average utility scores across the different scenarios which imply that they will have the highest net socio-economic benefit if upgraded. It is important that decision-makers may adopt a similar approach in selecting rural roads for upgrading.

We consider our methodology to be practical and realistic, especially in developing countries where data on several socio-economic variables that influence rural development are scarce. The GIS is used to overcome some of the constraints of data availability. Notable improvements which may be made to the model include the incorporation of data on road quality as well as data on the number of persons using the education and health facilities. These data could not be obtained for all the education and health facilities in the study area so we had to drop the criteria. Nonetheless, the criteria used are sufficient to provide useful results. The marginal utility functions applied are user-specified. This implies that a different set of specifications for the marginal utility functions may alter the results. This approach may be replicated in other climes if the relevant data are available and with understanding of the local situation which may influence the specification of the marginal utility functions. The approach may further be developed into a decision-support tool for rural road improvement in other states in Nigeria and other developing countries.

Ethics and consent

This data collected in this study were collected with the support of a number of subjects who accepted to complete our questionnaire after agreeing to the Informed Consent statement included at the top of the questionnaire.

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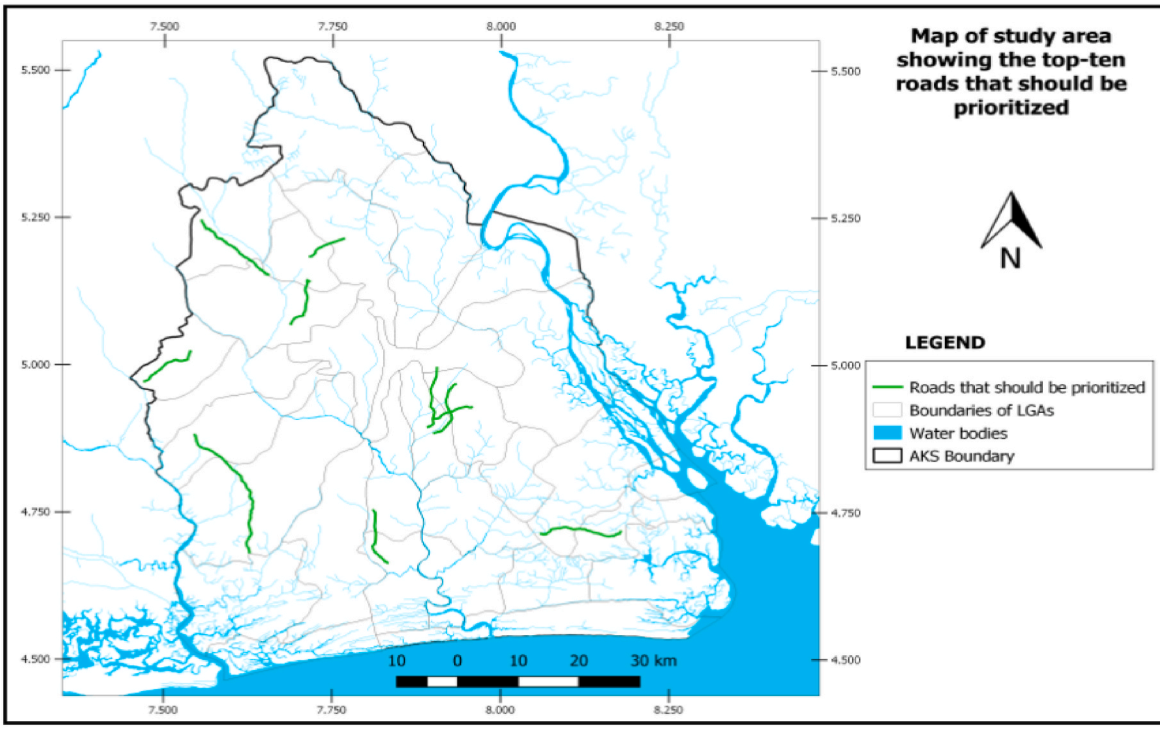

Fig. 6. Map of the study area showing top ten roads that should be prioritized based on the average utility scores across all criteria.

CRediT authorship contribution statement

Uduak Akpan: Conceptualization, Methodology, Investigation, Validation, Formal analysis, Writing – original draft, preparation. **Risako Morimoto:** Writing – review & editing.

Declaration of competing interest

The authors have no competing interests to declare.

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