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Spatial Analysis of Road Pavement Condition and Maintenance Actions using GIS

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Abstract: *A country's transportation system is inextricably linked to its development and economic prosperity. Industrial and socioeconomic development will be aided by well-designed and efficient road transportation infrastructure. Due to the fast building of roadways, road pavement maintenance and management are vital. Computer technology should be utilized to compensate for the shortcomings of the conventional management system in order to maintain a safe and comfortable road surface. The purpose of this study was to show how GIS may be used to collect precise data on road conditions, which can then be utilized to make informed and timely decisions about road pavements, resulting in more efficient roadway management and the prevention of widespread deterioration. Taking this into account, this study used spatial technologies such as Geographic Information Systems (GIS) - ArcView 10.7.1, Google Earth, and maps to aggregate roadway data and improve its usage and display for highway administration and operation. This study's findings show that GIS can be utilized to map road pavement, susceptibility, and assessment. The results produced images and maps showing the geographical analysis and interpretation of terrain and surface features along road sections which aids in the Pavement Maintenance and Management System (PMMS) process. The study further reveals that majority of the roads have failed roads and they possess alligator cracks and potholes at regular intervals. The average Pavement Surface Evaluation and Rating (PASER) is 4.7 indicating that the roads are in a poor state thereby requiring repairs.*

Keywords: *Controller, Differential Drive, Kinematics, Mobile Robots, Modelling*

INTRODUCTION

Highway pavement performance deteriorates steadily with increased highway life and traffic load (Yang *et al.*, 2016) whilst poorly maintained roads increase the number of accidents and the accompanying human and property costs, as well as exacerbate isolation (Oyedepo *et al.*, 2019). The quality of a pavement's performance is determined by understanding of the pavement condition and proffering adequate maintenance actions promptly. Road pavements will erode with time, no matter how properly it is constructed hence the timeliness of repair is critical. If a pavement is allowed to deteriorate to a dangerous state, the subsequent performance could endanger human life and property. Geographic information system (GIS) applications in network-level pavement requirements analysis systems, policy making and prioritization is increasingly getting a lot of interest (Zhang *et al.*, 2012; Fakhri and Dezfoulian, 2017; Ahmad and Firincioglu, 2020).

Decision makers and policy implementers are mandated to provide policies, strategies, and programs for effective road construction and maintenance. Such an undertaking necessitates the development of a well-structured decision support system capable of capturing relevant information about road infrastructure, manipulating it, and presenting the results in a format that will aid road managers in making informed decisions. A decision support system is required to keep roads in good repair on a restricted budget while also maximizing the advantages of a transportation program to its users and integration of GIS in such systems are essential (Coutinho-Rodrigues *et al.*, 2011; Zhou and Wang, 2012; Zagvozda *et al*., 2019; Tariq *et al.*, 2020) but no such studies has been conducted remotely within the study area and context.

Geographic information system facilitates the management, analysis, and graphical representation of all sorts of geospatially referenced data. It enables the user to evaluate, examine, track, and visualize data in ways that reveal trends, patterns, and connections using maps, reports, and charts. In these ways, incorporating GIS into the PMS development and implementation process has proven to be advantageous (Smadi, 2004). For example, GIS has been utilized in pavement management to analyze road conditions, establish maintenance strategies and improvement recommendations to prioritize road projects, and develop preliminary cost estimates (Robert, 2011). Adeleke *et al.* (2015), recommended that road agencies consider using GIS for pavement maintenance management to improve decision-making processes. Based on GIS data with Micro PAVER software, Al-Neami *et al.*, (2018) calculated the pavement condition index (PCI) for a road and revealed a PCI value of 64 indicating a fair pavement condition. Obaidat *et al.*, (2018) used GIS in obtaining query for pavement conditions and traffic levels. Using GIS, Asli *et al.*, (2020) identified four different types of pavement zones comprising of very high, high, medium risk and low risk zones and results showed a good correlation between and GIS data when considering parameters such as number of wheels, temperature and mean profile depth. Beto (2021) using GIS, categorized pavement condition index value for a flexible pavement and used it to prioritize pavement section in relation to the available budget. GIS is a vital technique for pavement maintenance management systems (PMMS) because it can be used to visualize pavement layers and other engineering attributes of a highway, resulting in early identification of pavement deterioration and assisting highway engineers and government entities in their decision-making (Hashim *et al.*, 2021). In their study, Nautiyal and Sharma (2021) discovered that GIS may be used to gather both spatial and non-spatial data, as GIS is a multi-criteria decision-making technique that can be used in pavement repair and maintenance operations.

This study therefore aims to provide a rational approach for prioritizing pavement repair within local road authorities that takes into account the most relevant elements on pavement maintenance prioritization. The project makes use of GIS capabilities, especially as a decision-making tool. In the field of transportation engineering, GIS is becoming increasingly popular. It has certain unique capabilities, such as geographic analysis and visualization that might help improve pavement management. The work adds to the body of knowledge by demonstrating how to use a geographic information system (GIS) as a pavement management tool for collecting, managing, and assessing pavement condition data, which will help with better planning and prioritization of pavement operations. As a result, this research entails employing a Geographic Information System (GIS) to conduct a spatial analysis of road pavement conditions and maintenance actions.

MATERIALS AND METHODS

The study area, Ilara-Mokin in Ondo State, South western Nigeria. The study area is situated within latitudes N07° 21′ 16″ and N07° 22′ 20″ and longitudes E005° 05′58″ and E005° 07′ 12″. The study area is on moderately undulating terrain with elevations ranging from 336 to 350 meters above sea level with a precambrian basement complex beneath it. The study area has two distinct seasons and is located in Nigeria's tropical rainforest, with an average annual rainfall of roughly 1800mm and annual mean temperatures of 24°C to 27°C. Fig. 1 shows the map of the study area.

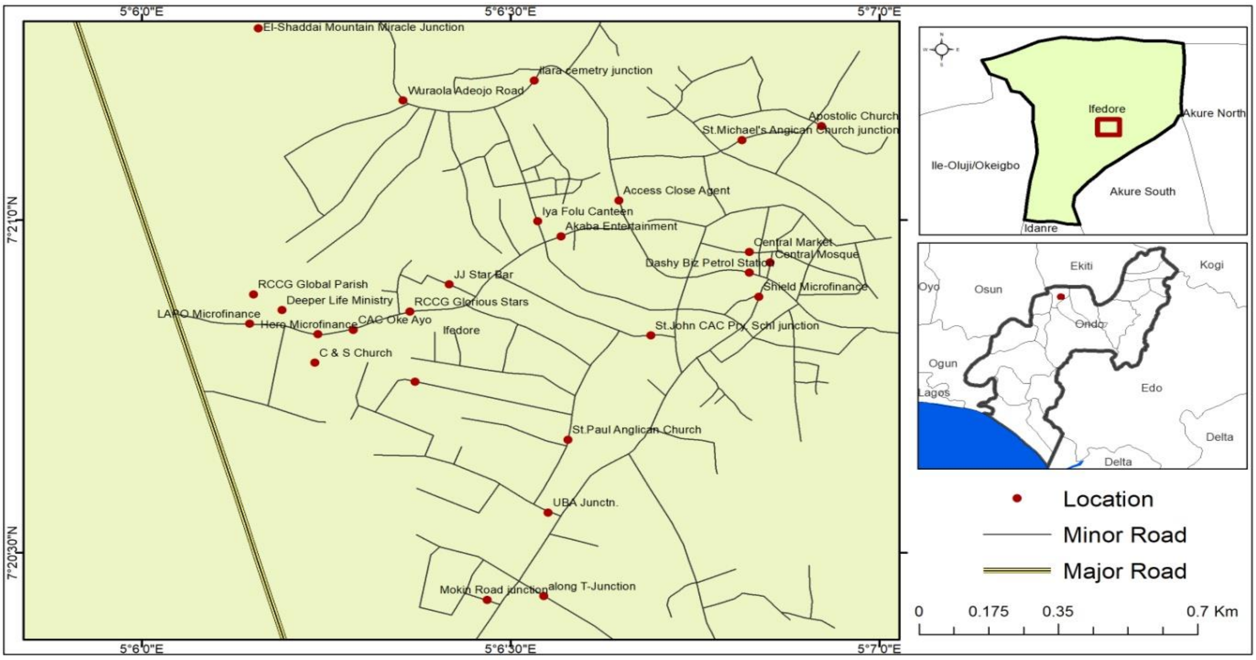

Fig. 1 Map of Ilara-Mokin showing the study location

The methods adopted in this study include data acquisition in maps and charts formats, scanning, geo-referencing, digitization, attribute database creation, spatial database query and analysis and ground trothing.

Two types of data namely primary and secondary were used in this research.

i. Primary Data : obtained from the field (e.g GPS coordinates of the damaged road sections)
ii. Secondary data: obtained from high resolution satellite images, the Topographical map, Digital Elevation Model data obtained from the United States Geological Survey website.
iii. The street map covering Ilara-mokin, which was obtained from CESRA.

Basically, four different types of software were used for this study. These included

a) Erdas Imagine – this was used for image sampling and image corrections of the Ikonos satellite imagery. It was also used to produce accuracy assessment for the analysis.

b) ArcGIS – this was used for displaying and subsequent processing and enhancement of the image. It was also used for the masking of the area of interest, using both the administrative and local government maps.

c) ENVI 5.3 – This was used for performing geometric correction and spatial image enhancement on the Ikonos imagery.

The underpinning data comes from a field reconnaissance survey to assess the current state of the roads and damaged sections. Supplementary data for this study came from the Ondo state ministry of lands and survey, as well as the Centre for Space Research and Applications (CESRA), which provided high-resolution photographs of the study area. The data was then scanned, georeferenced, and digitalized for the road networks using the on-screen digitizing tools of ArcGIS 10.7 software. The road attributes database was generated using secondary data obtained in a GIS environment. The database table was filled with the attributes of each digitized road section. The extraction of relevant and required information for road maintenance purposes from the roadway database was then performed. The pavement condition was then determined using the heat map created with GIS software.

Road networks assessment and maintenance procedures involved detailed visual assessment using primary and secondary sources. PASER system was used to evaluate the condition of road segments. The PASER system rates each segment on a scale of 1-10 with 1 being the worst condition, and 10 being the best condition (new pavement). The assessment not only involves the condition of the pavement but also involves the safety considerations, volume of traffic, pavement structural design and drainage availability and condition. The ratings directly correspond to the expected remaining service life as well as appropriate maintenance activities.

RESULTS AND DISCUSSION

The result of the analysis produced the visual representations of the contour maps, drainage patterns, topographic maps of the study area showing soil properties, and all these are vital in analyzing the pavement management strategies to be employed in the study area.

The contour map (Fig. 2) displays an output isoline data set showing the varying heights of the study area. The value of each line represents all contiguous locations with the same height, magnitude, or concentration of whatever the values on the input data set represent. The topographic map of the study area of 5m contour interval, the upper parts, showed low land-terrain areas with gentle slope.

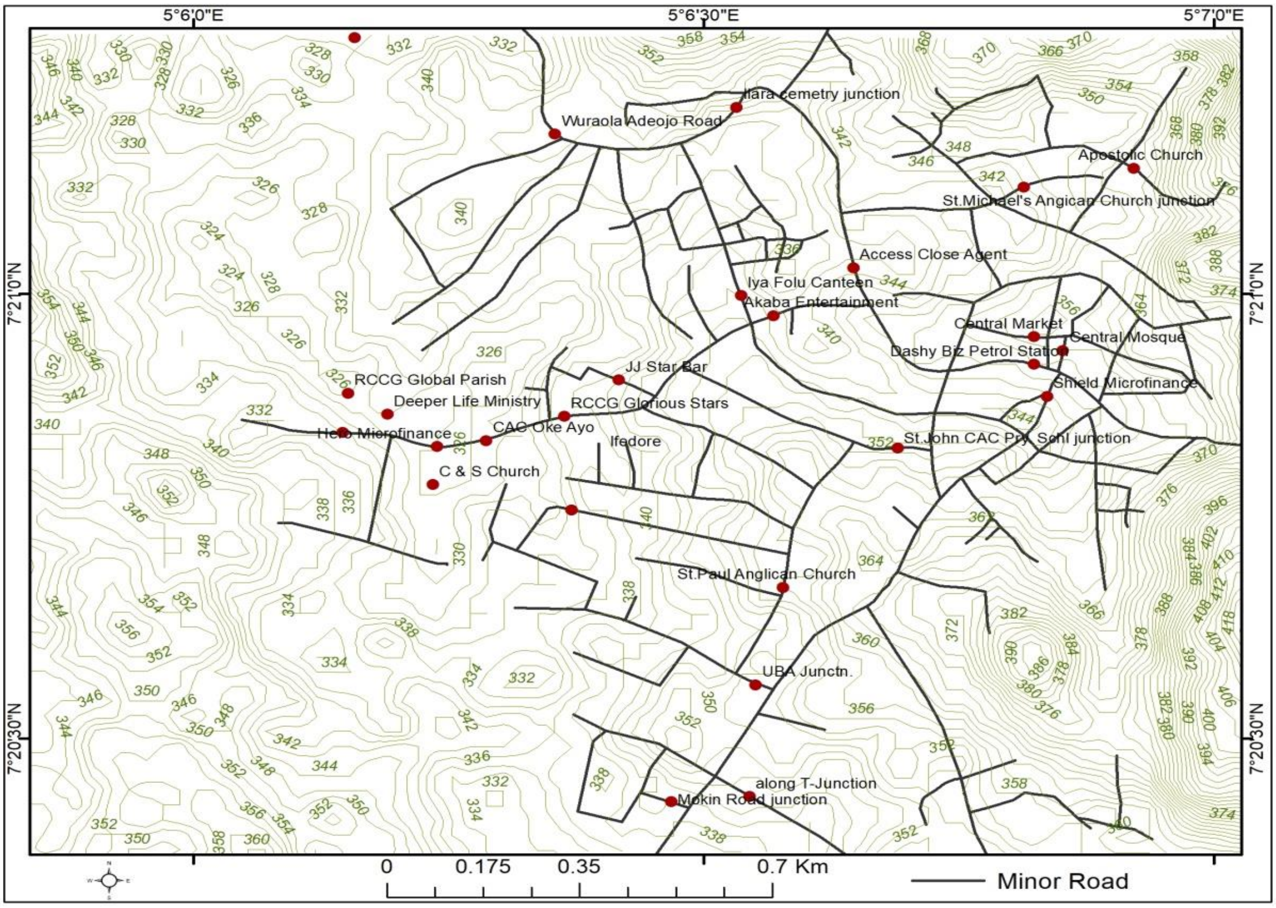

Fig. 2 Contour map of the study area

The study revealed that the study area is characterized with varying degrees of slope ranging from flat to gently sloping to very steep topography. Region around Shield Microfinance, Apostolic Church are with very steep slope. The Eastern parts of the study area are categorized under steep slope and more than 50% of the basin area is flat to gentle sloping.

The study as shown in Fig. 3 revealed that majority of the study area is characterized by low topography which is below 323 meters. These results in pavement management challenges as a result of high volume of fill materials in the sections with low topography and cut in the sections with high (421 m) topography. Failure to do this will result in high level of pavement deterioration due to lodgement of water in areas with low topography.

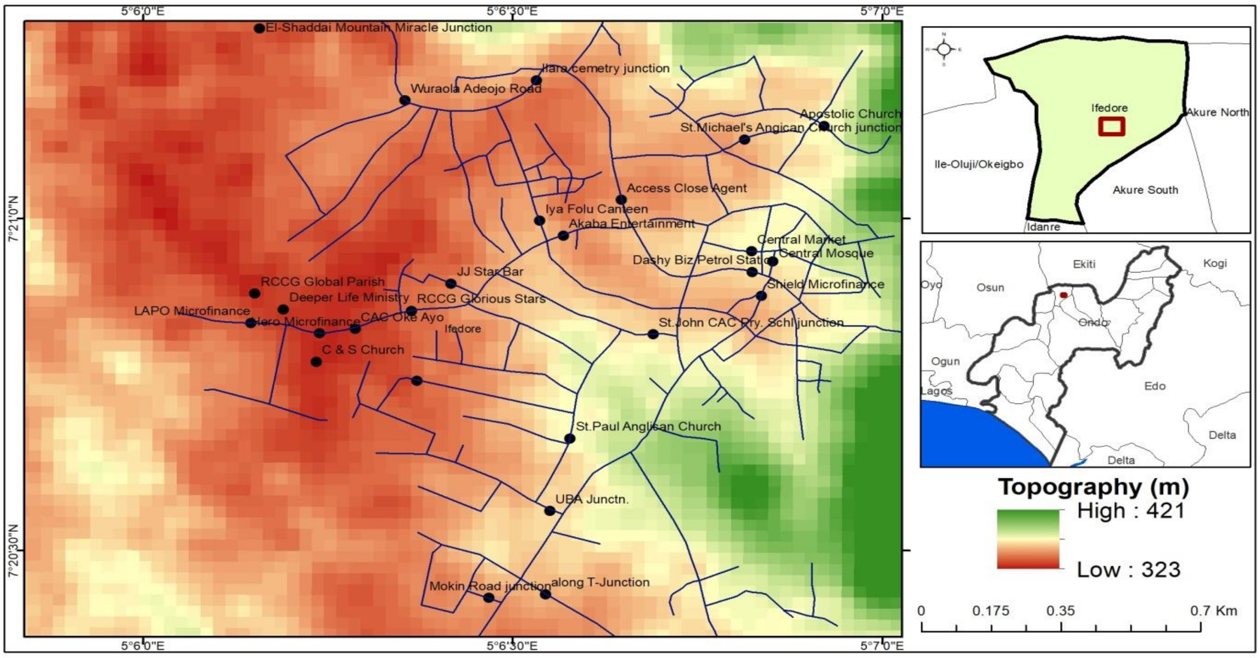

Fig. 3 Topography map of the study area

The slope map of the study area is as shown in Fig. 4. In the case of poor drainage system, the slope drives erosion along the road pavement, gradually causing potholes and cracking on the road segment. The steep land has more potential to water erosion than flat land in the sense, that, erosive forces; scour, detached transport and deposit soil particles in a distance place. Therefore, land cover with slope > 30 are considered to be steep to very steep while 10-30 are sloping to strongly sloping; and less than 10 are flat to gently sloping (FAO, 2006). The results from the slope analysis show that the areas with the gentle slope have the higher probability of the paved road sections. Larger percentage of the road sections have gentle slopes, depicting that almost all the entire study area are susceptible weathering and cracking.

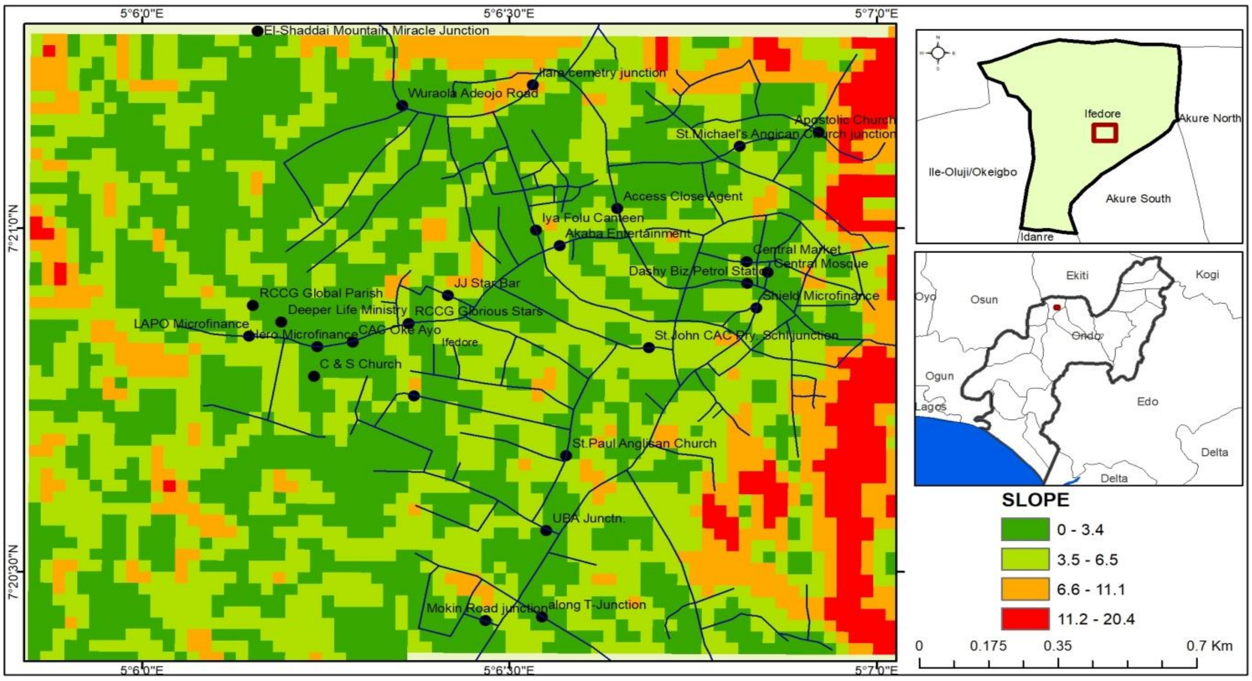

Fig. 4 Slope map of the study area

The viewshed map depicts the geographical data of the study area that may be seen from a specific point. It includes all nearby locations in line-of-sight with that location, excluding points beyond the horizon or those obscured by terrain or other factors (e.g. buildings, trees). The study revealed that the area of Ifedore is viewable from multiple observer places, as illustrated in Fig. 5.

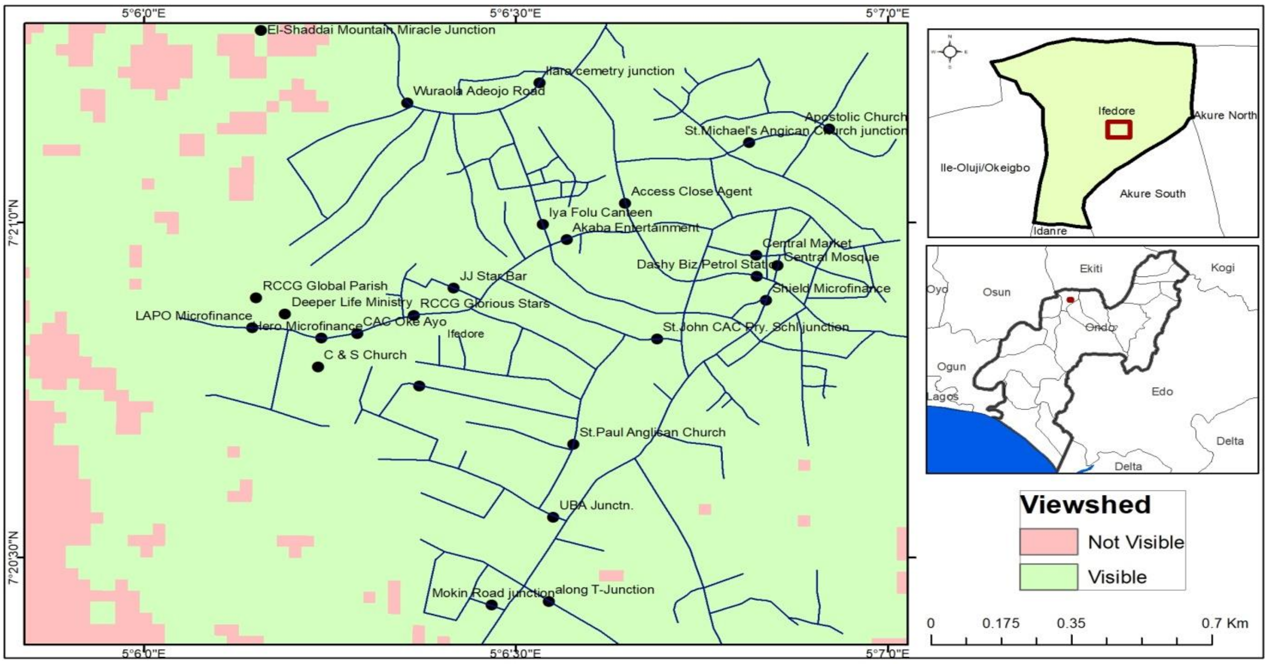

Fig. 5 Viewshed Map of the Study Area

The geologic map in Fig. 6 depicts the structure and composition of geologic materials at the study area's surface. The soil surface of Ifedore town is heavily constituted of undifferentiated basement complexes with pebble beds, as shown on the map. Geologic mapping is a highly interpretive, scientific method for creating a variety of map products for a number of purposes, including assessing ground-water quality and contamination risks, predicting earthquake, volcano, and landslide hazards, land management and land-use planning, and general education.

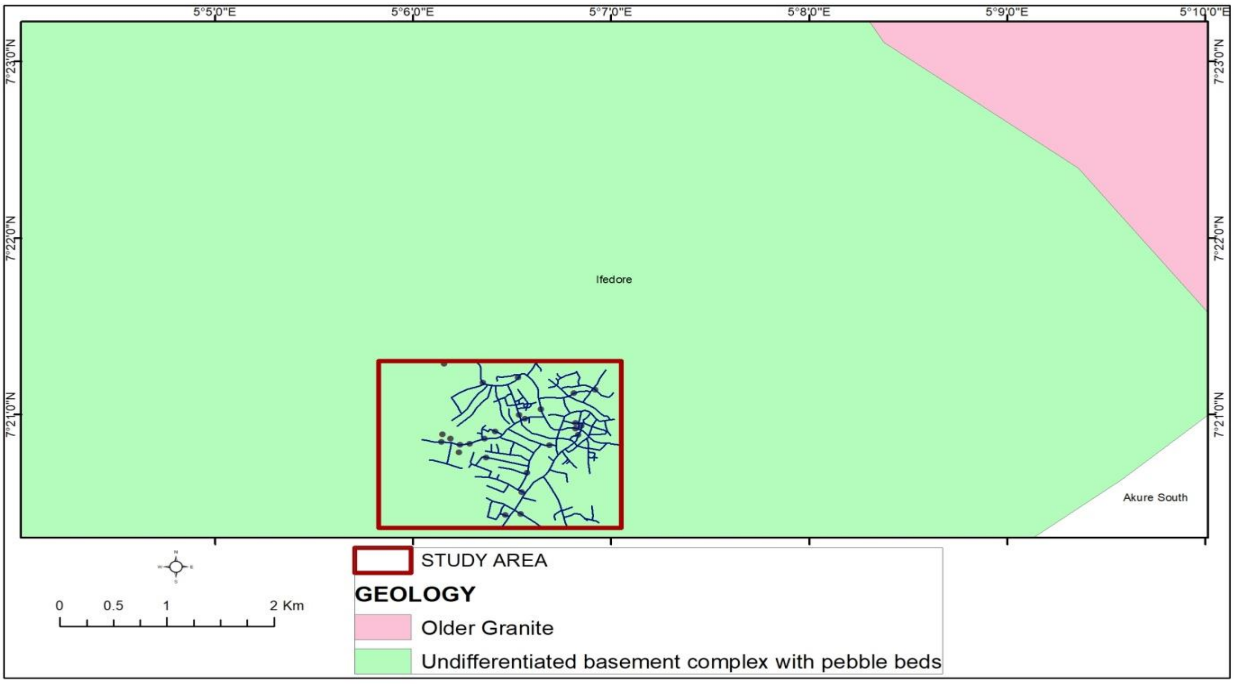

Fig. 6 Geology Map of the Study Area

The digital soil map as shown in Fig. 7 depicts the study area's spatial distribution of soil classifications and properties. This aided in the development of geographically referenced soil databases and their location. The earth surface at the study area is mostly made up of a combination of two types of soil: (1) deep well-drained and shallow well-drained soils; sandy loam surfaces over stony sandy clay subsoils or bedrock, and (2) very deep and deep well drained soils; loam, sandy loam surfaces over gravelly clay loam subsoils.

Fig. 7 Soil Map of the Study Area

Pavement Surface Evaluation and Rating (PASER)
This study revealed that most of the roads in the study area are in Good or Fair condition. The study also revealed portions of the pavements that can be classified as the failed as reflected by presence of alligator cracks and potholes at intervals. Some segments of the road pavement was in an extremely bad condition with visible slippage, cracks and potholes. The PASER rating is as shown in Table 1.

Table-1 Database of Roadway Condition Assessment

Pavement	Location	WIDTH	PASER	CONDITION
1	UBA Junctn.	7.4	4	Poor
2	St. Paul Anglican Church	9.0	7	Good
3	LAPO Microfinance	9.0	6	Fairly Good
4	Deeper Life Ministry	7.4	4	Poor
5	CAC Oke Ayo	9.0	6	Fairly Good
6	Hero Microfinance	7.4	6	Fairly Good
7	JJ Star Bar	7.4	4	Poor
8	RCCG Glorious Stars	7.4	6	Fairly Good
9	Akaba Entertainment	7.4	5	Fair
10	Iya Folu Canteen	7.4	5	Fair
11	Access Close Agent	7.4	4	Poor
12	Shield Microfinance	9.0	3	Poor
13	C & S Church	7.4	5	Fair
14	RCCG Global Parish	9.0	6	Fairly Good
15	Apostolic Church	9.0	4	Poor
16	Dashy Biz Petrol Station	7.4	4	Poor
17	Central Mosque	9.0	2	Extremely Bad
18	Central Market	9.0	5	Fair
Average			4.7	Fair

Fig. 8 show the road condition of different road spans in the study area. The road conditions are classified into 1. Good (No Alligator, No potholes) 2. Failed (Alligator cracks, potholes), and 3. Extremely Bad (Slippage, cracks, potholes). According to the Fig. 8, there are more failed roads in the study area than Good and extremely bad roads, with Failed roads possessing alligator cracks and potholes at regular intervals.

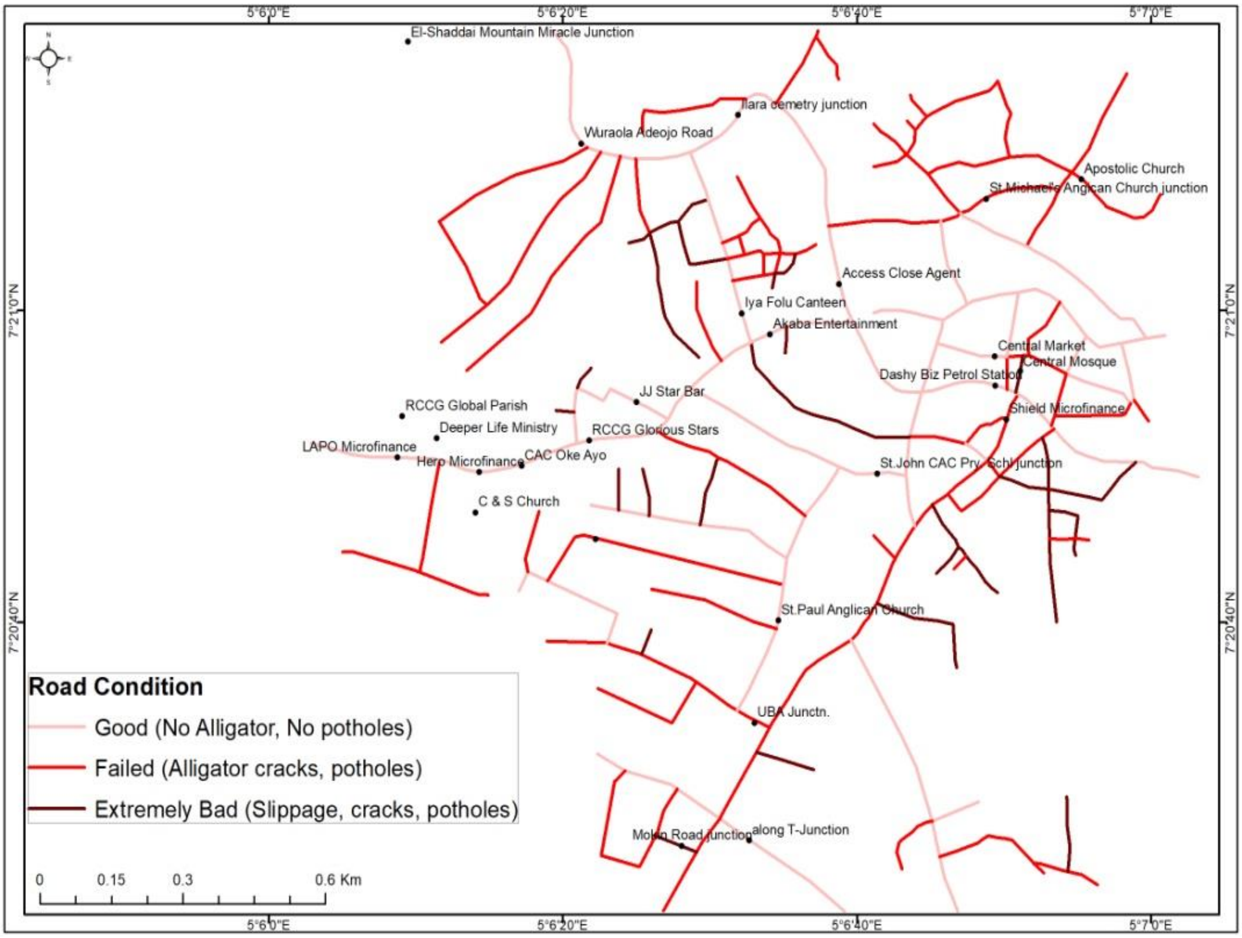

Fig. 8 Map showing road condition of the study area

Fig. 9 describe the road maintenance actions needed for the different roads in the study area. For Good roads, no action in needed. For Failed roads, major repairs need to be carried out at the points of deformation while for Extremely Bad roads; there is need for total resurfacing of the road pavement. Most of the minor roads in the study are in the failed category and thus need major repairs at the points of deformation.

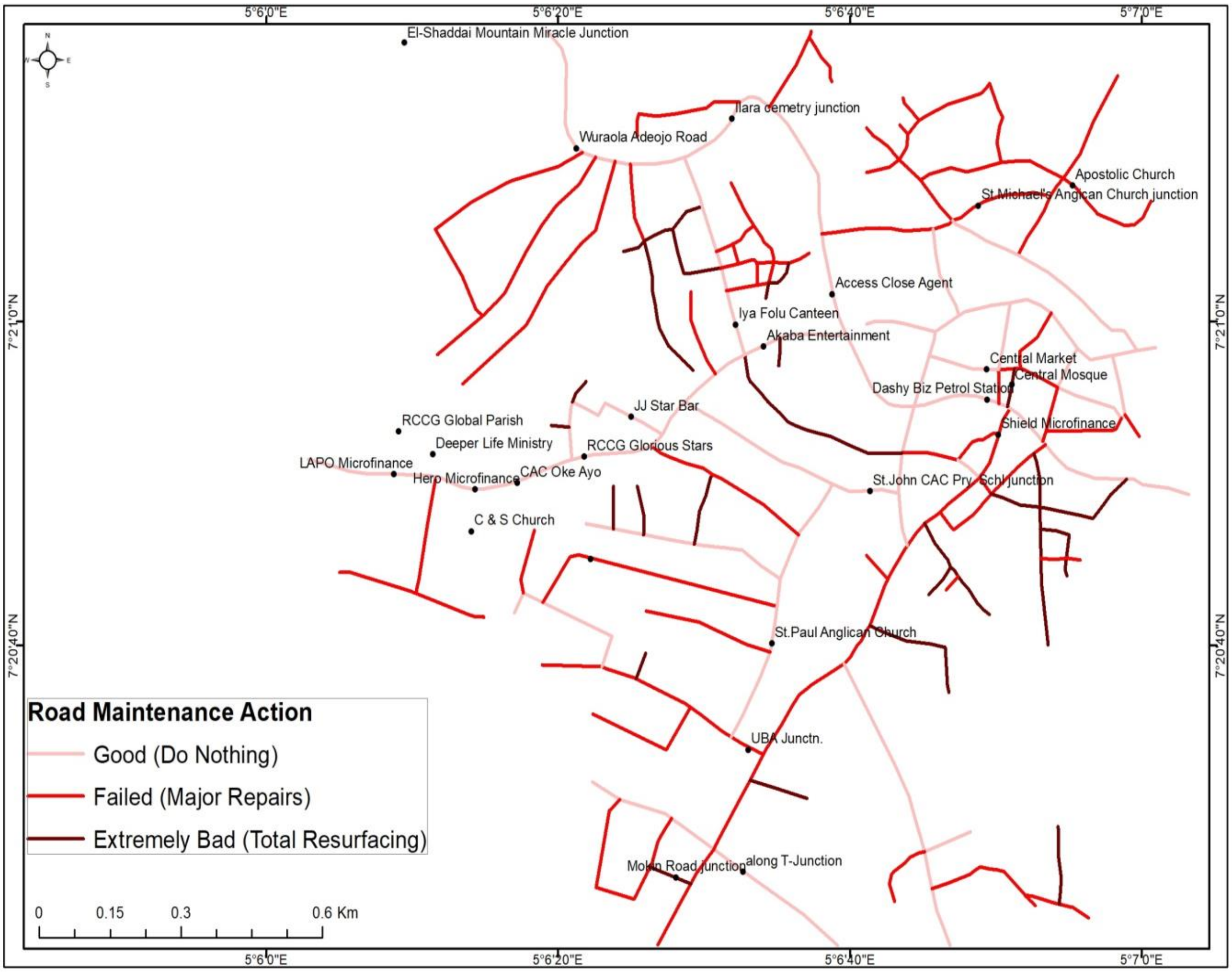

Fig. 9 Map showing Road maintenance action needed in study area

CONCLUSION

The use of GIS in spatial analysis of pavement conditions was described in this research. Following the process of obtaining data and integrating it with the base-map in the Arcmap work area, maps showing the exact positions of the distresses in the site were successfully produced. The maps will help to enhance and optimize the road maintenance management process, from data collection to prioritization and budgeting of road repairs. In a nutshell, GIS is a system that can be employed by highway and transportation engineers to easily keep track of, record, analyze, and solve pavement management (PM) problems. The GIS-PM systems serve as a sophisticated system with spatial capabilities that resembles the geographical nature of assets such as pavement networks, utility network and road furniture.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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