ROAD NETWORK EXTRACTION FROM HIGH-RESOLUTION SATELLITE IMAGERY OF WUSE DISTRICT, ABUJA, NIGERIA USING ON SCREEN MANUAL DIGITIZATION

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Abstract

The advent of high resolution satellite imageries has paved way for easy and faster approach in map updating and production. This study was aimed at extracting road network from high resolution Google Earth satellite imagery of Wuse District, Abuja using manual on-screen digitization. Data for the study was acquired from Google earth with the aid of Universal Map Downloader and Global Mapper. ArcGIS 10.8 software was used for further analysis. Twenty (20) ground control points were acquired on the field using a hand-held Global Positioning System (GPS) of notable intersections for accuracy assessment. Root Mean Square Error (RMSE) was used to assess the accuracy of the features extracted from the high resolution satellite image. The results revealed that the major and minor roads have a total length of 58.284km / 152,174km which is 27.69% / 72.31% of the total road network. The result of accuracy assessment revealed 0.507 of RMSE implying high level of accuracy of the work. This study concludes that high resolution satellite imageries can provide an easy and effective means of updating road network map. This study recommends that the Federal and State Ministry of Transportation should explore the availability of high resolution satellite imageries to produce and update road network maps for effective road transport management.

Keywords: Road, Network, Extraction, Satellite, Image

Introduction

Satellite image provides information about earth surface on a large scale within short frame of time. With the emergence of high-resolution satellite images detailed information on road network can be extracted (Fareed, 2014). Thus, the availability of high-resolution satellite images and their potential for use in various applications such as preparing and updating road network maps has become an interesting area in Remote Sensing (RS) (Mokhtarzade, Zoej & Ebadi, 2008).

Road extraction is described as extracting the roads from an image by accessing it through the features of road on the satellite image (Desai & Vala, 2014). Zhijian *et al.* (2014) noted that extracting road information from high-resolution satellite images is complex and hardly achieved by exploiting only one technique. In extracting road features from RS images, there are difficulties embedded which are due to characteristics of road features affected by the sensor type, spectral and spatial resolution, ground characteristic, weather and light variation (Wang *et al.*, 2016). It is easy to recognize and manually extract road from satellite image because road feature in such image appears as linear geometric features with slowly varied gray values.

Road networks are significant infrastructure in any city and the maps showing such network are very important. However, due to the dynamic nature of cities' infrastructure like roads keep on changing, there is need to update the existing road maps if any to reflect the current reality on ground. Up-to-date road maps are of greater importance for many service providers. In cities, road network maps are needed for routing emergency vehicles like fire fighters and ambulances, and also a GPS-based navigation system needs the up-to-date road maps in order to provide the best directions to its users. On the need to update road map, Zitnanska (2020) opined that the precision of each navigation system hugely depends on the accuracy of the data included on maps. The use of updated maps enables people to get to their destination faster and safer, as this will also eventually save money and the environment by reducing the carbon footprint and kilometers driven. This has necessitated this study that is aimed at extracting road network from high resolution satellite image using on screen manual digitization in Wuse district of the Federal Capital Territory (FCT), with a view to enhance road associated service delivery in the FCT.

Statement of the Research Problem

Road network plays a significant role in traffic management, road monitoring, city planning, GPS navigation services (Wang et al., 2016), but it is a dynamic infrastructure that changes frequently as cities and towns develop. A road map which is a map showing road networks in an area, therefore, needs a constant update to reflect the current reality on the ground. Since new roads are constructed frequently keeping road maps up-to-date is an important undertaking. More often road network map is rarely available, especially in developing countries, where people have to depend on an online platform like Google Map and Open Street Map to get such information. In a case where one gets map showing roads, usually a topographical map, the road information on the map is usually outdated compared to current reality.

Accurate and up-to-date road network maps are especially important because of proliferation of location-based mobile services and the impending arrival of autonomous vehicles (Bastani et al., 2018). Many researchers have worked on automatic methods of road extraction from satellite image (Yadav *et al.*, 2020; Xin *et al.*, 2019 and Bastani *et al.*, 2018). Automatic road extraction from satellite image has received attention lately however, roads are always concealed incompletely or completely by trees, high buildings or large vehicles. As a result of this, the automatic method of road extraction is still inherent with inaccuracy which has not been solved with a reasonable degree of success (Zhijian *et al.,* 2014). This has made the methodology adopted in this study timely and relevant. This study is aimed at filling the existing gap in the literature by extracting the road networks from high-resolution satellite image of Wuse Area of FCT, Abuja using onscreen manual digitization technique. This is with a view to providing an accurate and up-to-date road network map of the study area to resource users for a well-informed decision-making process.

Aim and Objectives

The aim of this study is to extract road network information from high-resolution satellite image of Wuse District, Abuja using manual on-screen digitization with the following specific objectives, to:

1. extract road networks from high-resolution satellite imageries;
2. calculate the length of roads in the area;
3. Carry out accuracy assessment of the extracted roads.

Study Area

Wuse District is one of the wards in Abuja Municipal Area Council (AMAC). Wuse District is located within Latitudes 09^{o} 30' 0" and 09^{o} 6' 30" North of the Equator and Longitudes 07^{o} 27' 0" and 07^{o} 30' 30" East of the Greenwich Meridian occupying a land mass of 23.89km^{2} (Figure 1). Wuse has a population of 54,963 (National Population commission [NPC], 2006). Wuse is divided into two neighborhoods namely: Wuse 1 and 2, and the neighborhoods are then further divided into zones ranging from 1 to7. The area has vibrant economic activities. Notable government offices in Wuse District are: National Population Commission, NAFDAC, Federal Road Safety Commission, Central Market, Nigeria Custom Service and many notable private organizations. Just like other part of Abuja, the climate of Wuse is tropical, it falls under Köppen's climate classification scheme as a tropical wet and dry climate (Köppen: Aw). The rainy season starts from March on the southern boundary of the Territory and around April in the northern limits (climate-data.org, 2020)

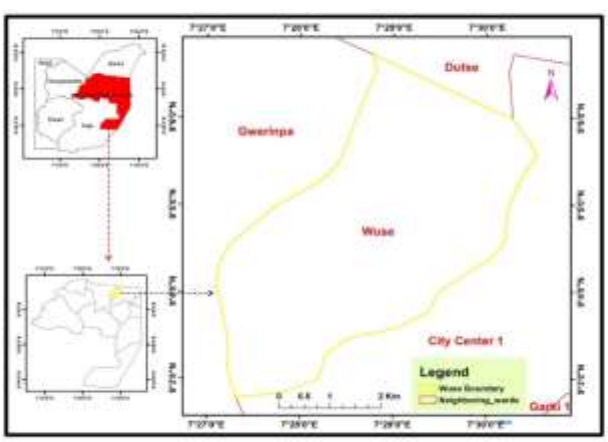

Figure 1: Wuse District
Source: Author's Analysis

Material and Methods

A high-resolution rectified satellite image of the study area was acquired from Google Earth with the aid of Universal Map Downloader and Global Mapper. The study area was searched on Google Earth, zoomed to the desired resolution, the placemarks were placed at the upper left and bottom left of the desired area extent. The coordinates of the study area were copied into Universal Map Downloader to download the desired image with high resolution. The downloaded high-resolution image was imported into Global Mapper and rectified to Geographic Coordinate System (WGS 84). The rectified image was exported within Global Mapper into Geotif format as the final image used in ArcGIS 10.8 for On-screen manual road extraction.

Digitization is a process of converting the raster feature to vector by tracing the feature using the raster feature as background. In the study, the On-screen manual digitization method was used to execute this process. To ensure accuracy in digitization, the raster background image was zoom in as possible to make sure that the road feature was traced appropriately.

For the accuracy assessment, seed points (ground control points) were acquired on the field using a hand-held Global Positioning System (GPS) of notable intersections in the study area. These points were entered into a Microsoft Excel sheet and saved in Comma Separated Value (CSV) format. It was imported into the ArcMap, converted to a point shape file, and overlaid on the digitized road to assess the accuracy level of roads extracted. Moreover, the coordinates of these points were extracted and used as data for accuracy assessment as presented in Table 1. Root Mean Square Error (RMSE) as suggested by ESRI (2008) was used to assess the accuracy of the features extracted from the high-resolution satellite image. The digitized roads were also overlaid on Google earth image to see level of conformity to reality.

Result and Discussion

Road Network in the Wuse District

The road network in the study area is classified into Major and Minor roads for the purpose of this study. Major roads are commonly used and go through the main part of a city or town. They are also called primary or arterial roads that carry long distances through traffic to specific areas in urban areas. As shown in Figure 2, there is a high level of the inter-connectivity of major roads in the study area, accounting for 27.69% of the total road network in the study area. The majority of this class of roads are located in the central part of the Wuse District. This high percentage of major roads in the area depicts a high level of connectivity when compared to the result of similar work done by Abdullahi and Rabiu (2014) in Gombe Metropolis where major roads account for 11.5%.

The minor roads in this study refer to the routes that pass-through traffic between specific or local areas and major roads. These are routes that give access and connect local areas or specific land use to major urban areas. Minor roads are numerous and well-spread in all parts of Wuse District, accounting for 72.31% of the total network in the study area (Figure 2).

Figure 2: Road Network in Wuse District
Source: Author's Analysis, 2021

The high level of road network in Wuse may be attributed to the fact that Wuse is among the busiest places in Abuja. It is one of the most renowned districts in the Federal Capital Territory for recreational activities. Many of the city's biggest market, private businesses, best restaurants and nightclubs are located in the district. According to Villaafrika (2021), Wuse District can be accurately described as Abuja's most fun and popular district.

Length of Roads in Wuse District

The length of roads in the study area was calculated within the ArcMap environment using the "Calculate Geometry" function in the attribute table of the road layer created through digitization. The result revealed that the major roads have a total length of 58.284km which is 27.69% of the total road network in the study area and minor roads have a total length of 152.174km (72.31% of the total network). The total length of the road network in Wuse District is 210.458km. This huge total length of road network in Wuse District which is just 23.89km^2 in land mass is evidence that the study area has a good and numerous road networks.

Road extraction accuracy assessment

Accuracy assessment is an important aspect of any spatial database project. It is the measure of "correctness" or accuracy that expresses the degree to which the map agrees with the reference observations (Congalton, 2001). According Congalton (2001), the following are a number of reasons why accuracy assessment is important:
(1) The need to know how well you are doing and to learn from your mistakes;
(2) The ability to quantitatively compare methods; and
(3) The ability to use the information resulting from your spatial data analysis in some decision-making process.
For this study, 20 Ground Control Points (GCPs) were used to assess the correctness of the work (Appendix 2), and Root Mean Square Error (RMSE) according to ESRI (2008) was used to assess the accuracy of the features extracted from the high-resolution satellite image.

Table 1: Accuracy Assessment

Points	X_{true}	X_{data}	X_{true}- X_{data}	$(X_{true}- X_{data})^2$	Y_{true}	Y_{data}	Y_{true}- Y_{data}	$(Y_{true}- Y_{data})^2$	$a=(X_{true}- X_{data})^2+ (Y_{true}- Y_{data})^2$	e=sqrt(a)	e^2
1	331861.5	331861.4	0.10	0.01	1003908	1003908	0.10	0.01	0.02	0.141421	0.02
2	331268.3	331268.2	0.10	0.01	1003063	1003063	0.01	1E-04	0.0101	0.100499	0.0101
3	330395	330395.2	-0.20	0.04	1002550	1002550	0.10	0.01	0.05	0.223607	0.05
4	332796.9	332796.7	0.20	0.04	1002997	1002997	-0.10	0.01	0.05	0.223607	0.05
5	334218.6	334218.5	0.10	0.01	1004516	1004516	-0.10	0.01	0.02	0.141421	0.02
6	333647.3	333647.3	0.03	0.0009	1003940	1003939	0.70	0.49	0.4909	0.700643	0.4909
7	332423.7	332423.9	-0.20	0.04	1004421	1004421	0.10	0.01	0.05	0.223607	0.05
8	331781.6	331781.5	0.10	0.01	1002374	1002375	-0.80	0.64	0.65	0.806226	0.65
9	330697.1	330697.1	0.01	0.0001	1001283	1001283	-0.10	0.01	0.0101	0.100499	0.0101
10	331310.2	331310.1	0.10	0.01	1001247	1001246	0.20	0.04	0.05	0.223607	0.05
11	335593.2	335593.3	-0.10	0.01	1005415	1005415	0.01	0.0001	0.0101	0.100499	0.0101
12	334350.2	334350.3	-0.10	0.01	1006279	1006278	0.80	0.64	0.65	0.806226	0.65
13	332942.9	332942.9	0.02	0.0004	1005887	1005887	-0.20	0.04	0.0404	0.200998	0.0404
14	333251.4	333251.5	-0.10	0.01	1005595	1005595	-0.80	0.64	0.65	0.806226	0.65
15	333900.9	333900.8	0.10	0.01	1003118	1003118	0.40	0.16	0.17	0.412311	0.17
16	333200.1	333200.1	0.02	0.000289	1003323	1003323	-0.10	0.01	0.010289	0.101435	0.010289
17	335173.9	335173.8	0.09	0.0081	1004256	1004256	-0.20	0.04	0.0481	0.219317	0.0481
18	334484.9	334485.1	-0.20	0.04	1005781	1005782	-0.70	0.49	0.53	0.728011	0.53
19	332506.2	332506.2	0.00	0	1002771	1002771	-0.90	0.81	0.81	0.9	0.81
20	331067.8	331067.7	0.10	0.01	1002255	1002256	-0.90	0.81	0.82	0.905539	0.82
											5.139988999

Source: Author's Analysis

Hint to the table 1:
$X_{true:}$ True value of X-coordinates as measured on the field
$X_{data:}$ The value of X-coordinates extracted from the map digitized
$Y_{true:}$ True value of Y-coordinates as measured on the field
$Y_{data:}$ The value of Y-coordinates extracted from the map digitized
e = Error distance
The calculation was done as thus,

Error distance (**e**) $=\sqrt{(X_t - X_d)^2 + (Y_t - Y_d)^2}$

RMSE = $\sqrt{(e_1^2 + e_2^2 + \dots \dots + e_n^2)/n}$

RMSE = $\sqrt{5.139988999/20}$

RMSE =0.507

According to ESRI (2008), when the general formula is derived and applied to the control points, which signifies a measure of the error; the residual error is returned. This error is the difference between where the point ended up as opposed to the actual location that was specified. The total error inherent in the process is computed by taking the root mean square (RMS) sum of all the residuals to compute the Root Mean Square Error (RMSE). This value describes how consistent the transformation is between the different control points (links). It is recommended that when the error is particularly large, more control points could be added to remove or adjust the error.

From the result of this study, the RMSE was found to be 0.507 implying a high level of accuracy of the feature extracted from the satellite image. Since the errors are squared before they are averaged, the RMSE gives a relatively high weight to large errors. This implies that the RMSE is most useful when large errors are particularly unwanted.

Conclusion

This study employed manual on-screen digitization for the extraction of road networks from high-resolution satellite images with a high level of accuracy achieved. The result of this study revealed that the major and minor roads have a length of 58.284km (27.69%) and 152.174km (72.31%) of the total road network in the study area. The study concludes that on-screen manual digitization still remains an accurate method of updating urban and rural road networks for sustainable development and use of resources and can be applied for the update of road network maps in the Federal capital Territory.

Recommendation

Based on the findings of this study, the following are therefore recommended:

1. Town Planners and Municipal Managers are encouraged to take advantage of open source high resolution satellite imageries to update road network maps in their domain. This can be achieved via the use of on-screen manual digitization.

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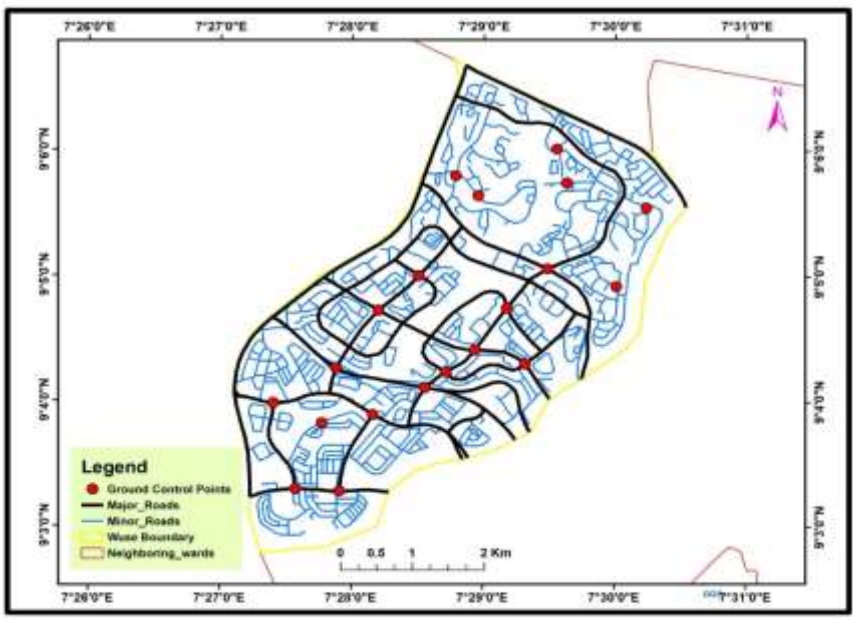
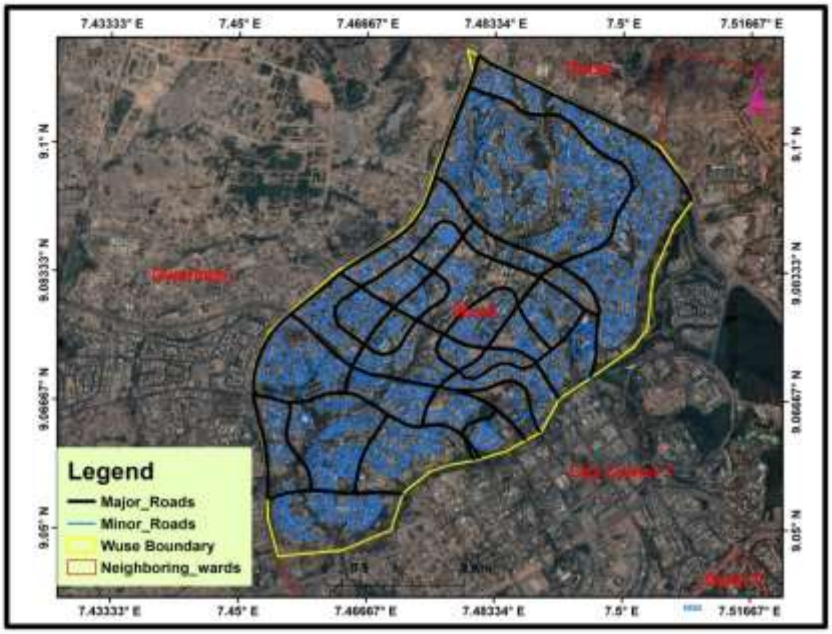
APPENDIX

Appendix 1: Ground Control Points Overlay on Road Network Extracted



Appendix 2: Road Network Extracted Overlay on High Resolution Satellite Image


7.43333° E
7.45° E
7.46667° E
7.48334° E
7.5° E
7.51667° E
9.1° N
9.08333° N
9.06667° N
9.05° N
Legend
Major_Roads
Minor_Roads
Wuse Boundary
Neighboring_wards