Structural Analysis of Existing Road Transport Networks in Adamawa State, Nigeria

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Abstract

This study examines the structural analysis of regional road transport network with a view to assess the types and the degree of connectivity of road transport network in Adamawa State, Nigeria. Data were obtained mainly from secondary sources particularly the use of Google earth map. Using topological abstractions, a graph theory was adopted to analyze the collected data. This was achieved through devising a connectivity matrix, from which various connectivity indices were used to describe the degree of connectivity of the study area. Findings of the study revealed that, 64% of the total road networks that linked up the study area were owned by the federal government and were classified as trunks A and F roads, which connect majority of the local government headquarters while the remaining 36%, mostly un-surfaced were owned by the state/local government authorities. The findings also revealed that 74% of the road networks are in a deplorable condition. The result also revealed that the overall accessibility in the study area was fairly low. The study, therefore, recommends the need for a synergy between all the tiers of government to quantify the number of existing road transport infrastructures, establish a state government maintenance board which will mainly focus on rehabilitation of any recent damage on paved road before it reach a deplorable stage, provision of more roads through public-private partnership, provision of alternative means of transportation to reduce burden on the existing road transport among other things.

Keywords: Accessibility, Connectivity, Graph Theory, Network Analysis, Road Transport

Introduction

Transportation, a term derived from the Latin word "trans" (meaning across) and "portare" (meaning to carry) is the movement and exchange of people, goods and services as an obligatory feature of modern life (Umoren *et al*, 2009). Transportation has a multi-dimensional functions and importance, keeping relations and making integrations among every aspect of a society ranging from an individual to a nation (Sarkar, 2013). Road Transportation is one of the most important modes of transport because it operates on land and is the most flexible. Road transportation act as key for transportation of people and materials from one place to another have spread like veins and arteries throughout an area, a region or in a country and brought about substantial development (Badigar & Badigar, 2003). A good road network is a critical infrastructure requirement for rapid growth. It provides connectivity to remote areas; provides accessibility to markets, schools, and hospitals; and opens up backward regions to trade and investment. In most Nigerian cities and towns, transport demand for freight and passenger movement is met mainly through road transport. Federal highways in Nigeria have been plagued by a number of problems ranging from faulty designs, inadequate drainage system, uneven distribution by zones and poor maintenance culture, which have significantly reduced the ability of the roads to perform its function (Yakubu, 2016). These problems have made it difficult, expensive and more odious to move products and services from point of production to that of consumption, farm produce from rural to urban centers, which often lead to loss of man-hour and high cost of goods and services. In addition, many studies have been carried out to assess of Road Transport infrastructure in Nigeria using various sources and methods. In contrast, this study assessed the state, condition, types, ownership as well as the degree of connectivity in Adamawa state, Nigeria.

Conceptual Clarification

Basics of Graph Theory

Graph theory is a branch of mathematics concerned with how networks can be encoded and their properties measured. It has been enriched in the last decades by growing influences from studies of social and complex networks. A graph is a symbolic representation of a network and of its connectivity (Rodrigue *et al*, 2013). It implies an abstraction of the reality so it can be simplified as a set of linked nodes. The goal of a graph is representing the structure, not the appearance of a network (Rodrigue *et al*, 2013). The most important rule is that:

- Every terminal and intersection point becomes a node or vertex.
- Each connected node is then linked by a straight segment or edge.

The outcome of this abstraction is the actual structure of the network. A graph (G) is a set of vertices/nodes (v) connected by edges/links (e). Thus G = (v, e).

Roads Classification in Nigeria

The Nigerian road network from the colonial days to the present day has been classified into 4 categories namely trunk A, B, C and F with length in excess of 200,000 km (Federal Ministry of Works, [FMW], 2013).

Trunk A Roads: It forms the skeleton of the national road grid that cut across regional boundaries in the country and even extended to the international borders of neighboring African countries. With total length of about 34,000 km (17.3%), these categories of roads are under federal government ownership. They are designed, constructed, maintained and financed by the federal government through the federal ministry of works. The Federal roads maintenance agency (FERMA) is in charge of carrying out maintenance of this class of roads (FMW, 2013).

Trunk B Roads: They are the second category of roads in Nigeria. They link the major cities within state with the state capitals. These roads are designed, developed, financed and maintained by various state governments through their ministry of works, transport and infrastructure. The primary objectives of Trunk B roads are to enhance the socio-economic development of the various states in the country. It has total length of about 30,000 (15.7%) of the total road network in Nigeria (FMW, 2013).

Trunk C Roads: They are local feeders' roads constructed and maintained by the works department of local government authorities in Nigeria. This class of road are primarily not concrete, asphalted and are affected by seasonal weather changes. The roads link villages and communities in the remote part of each local government region. It is about 136,000km and constitute about 67% of the total road network in Nigeria (FMW, 2013).

Trunk F Roads: They are road that formerly belong to Trunk B and C categories but later taken over by the federal government for direct finance, redesigned, construction and maintenance (FMW, 2013).

Description of the Study Area

Adamawa State is located between latitude 7^0 15'N and 10^0 58'N of the equator and between longitude 11^0 09'E and 13^0 47'E of the Greenwich meridian The study area is bounded geographically by Taraba State in the South and West, Gombe State in its Northwest and Borno State to the North. It also shares an international boundary with the Cameroon Republic along its eastern border (Figure 1). With an area of about 39, 972.3 km^2 square kilometers, the state had a total population of 4,504,337 people (2006 national census projected figure) majority of whom were farmers. This gives the state an average population density of 97.81 per square kilometers. The political and administrative setting of Adamawa state is made-up of 21 Local Government Areas, 37 development areas and 226 electoral wards (Adebayo, *et al*., 2020; Tukur & Barde, 2014).

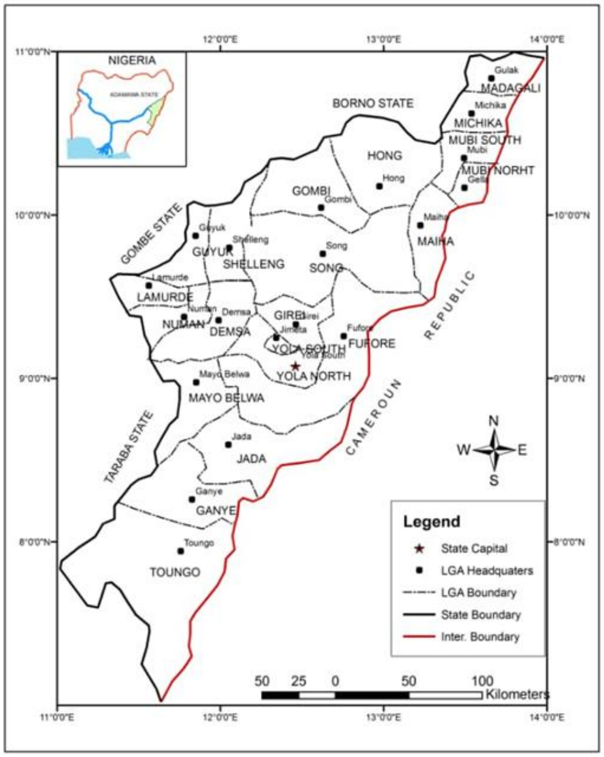

Figure 1: The Study Area

Materials and Methods

The study strictly used secondary data which include road network images that linked up the study area and a topographical map of the study. The road network images were mainly sourced from Google Earth (2010 version) while the topographical map was sourced from Adamawa State Ministry of Land and Survey. Both the satellite imagery of the existing road networks and the topographical map were then geo-rectified in ArcGIS 10.2 in order to update the existing road map upon which a topological map was prepared. All the 21 local government headquarters were purposefully adopted as the study nodes and the road networks as edges. Various connectivity measures were used to determine the network accessibility of the study area using the formulas indicated in Table 2. In addition, Personal observation was also used to specifically examine the state and condition of the road networks. Data collected were then analyzed and presented using simple descriptive statistics such as frequency counts, percentages inform of tables and inform of maps.

Table 1: Geographical Characteristics of the Study Area

S/N	Local Gov't Areas	LGA Headquarter	Landmass (Km2)	Population (2018)
1	DEMSA	DEMSA	1900.31	252,666
2	FUFURE	FUFURE	5,169.32	296,644
3	GANYE	GANYE	2,011.47	240,686
4	GIREI	GIREI	1,151.64	183,905
5	GOMBI	GOMBI	1,953.56	209,301
6	GUYUK	GUYUK	791.54	249,972
7	HONG	HONG	2,753.20	239,602
8	JADA	JADA	2,926.11	238,557
9	LAMURDE	LAMURDE	1,174.69	157,562
10	MADAGALI	GULAK	976.10	191,393
11	MAIHA	MAIHA	1,385	156,033
12	M/BELWA	M/BELWA	1,702.45	216,405
13	MICHIKA	MICHIKA	1,082.05	219, 853
14	MUBI N.	MUBI	924.32	214,580
15	MUBI S.	GELLA	517.99	184,048
16	NUMAN	NUMAN	940	131,071
17	SHELLENG	SHELLENG	1,572.48	210,296
18	SONG	SONG	4,325	276,432
19	TOUNGO	TOUNGO	5,665.37	73,898
20	YOLA N.	JIMETA	111.85	282,785
21	YOLA S.	YOLA	719	277,861
Total	**21**	**21**	**39, 972.3**	**4,504,337**

Source: Authors, (2021) and Zemba and Tukur (2020)

Table 2: Formula for the Connectivity Indices

S/No	Indicators	Formula	Correlation with Connectivity
1	Shimbel Index/Distance	Σ (edge)	Lower number indicate shortest route possible
2	Associated Number	Σ (edge)	Lower number indicate shortest route possible
3	Network Density	ND = L/S	Higher the density higher the Development
4	Beta Index	$\beta = e/v$	Higher value indicates more connectivity
5	Cyclomatic Index	$\mu = (e-v)+1$	Higher value indicates more connectivity
7	Alpha Index	$\alpha = ((e-v)+1)/(2v-5) \times 100$	Higher value indicates more connectivity

Source: Authors, (2021)

Results of the Findings

Road Classification and Ownership in the Study Area

Vast array of road transport networks has linked up most settlements of the study area with other part of the country and beyond. Table 3 classifies the road transport network ownership in the study area which shows that approximately 1,992 Kilometers of road network connect the study area, out of which 64% are classified as "trunk A and F roads". These federal highways were owned and maintained by the federal arm of government and constituted only 3.28% of the total federal roads in the country. Prominent among which are the trunks A13, A4, A8, A345, F252 and F253. These serial network systems systematically connect all the local government headquarters with the exception of Lamurde and Shelleng LGAs. As cited by Umar and Galtima (2020), these federal highways served as the main linkage of spatial interaction and also the main facilitator of import & export between the study area and other parts of the country including some part of the neighboring Cameroun Republic.

Trunks A4 emanated from Calabar-Makurdi-Taraba via Numan-Guyuk into Borno state via Biu-Damaturu. While trunk A13 emanated from Taraba via Mayobelwa-Ngurore-Jimeta and continued through Gombi, Hong, and Mubi terminating at Madagali into Borno state via Gwoza-Bama. Trunk A 345 emanated from Jos-Bauchi-Gombe via Numan-Demsa and terminating at Ngrurore Junction with Trunk A13. The remaining 36% of the road networks mostly un-surfaced made up the Trunk B and Trunk C mainly classified as the "Minor roads". Most of these minor roads were owned and maintained by the state/local government authorities. These minor roads were solely liable for all the socio-economic interactions between the central areas in the state and their hinterlands. Together these roads are responsible for almost all the rural freight and passenger connections in the state. Most of these roads are not motor-able during rainy season when their surfaces either become water logged or being devastated by gully erosion. This greatly hampered passenger movement and freight supplies, including fertilizers, the most needed farm input during this period in the affected settlements (Umar & Galtima, 2020).

Table 3: Road Classification and Ownership in the Study Area

S/N	Trunk Name	Ownership	Type	Length (Km)
1	Bauchi-Gombe-Numan-Ngurore Junction	Federal	A345	70
2	Ganye (A8)-Mapeo-Fufore-Yola-Jimeta (A4)	Federal	F252	125
3	Garin Kunini (A4)-Mayobelwa-Jimeta-Gombi-Bama	Federal	A13	350
4	Gombi (A13)-Garkida-Biu-Damaturu	Federal	F253	46
6	Jimeta (Trunk A13)-Yola Rd	Federal	A4-4	15
7	Mararraban Mubi (Trunk A 4)-Mubi Rd	Federal	A4-6	50
8	Mayobelwa Junction (A13)-Toungo-Taraba Border	Federal	A8	187
9	Mubi (A4-6)-Gella-Cameroun Border	Federal	F255	75
10	Mubi (A4-6)-Maiha-Belel-Malabu-Jiberu	Federal	A4-5	76
11	Mubi (A4-6)-Maiha-Belel-Malabu-Jiberu (A13) Rd	Federal	F255-1	27
12	Jalingo-Numan (A345)-Guyuk-Biu-Maiduguri Rd	Federal	A4	105
13	Yola (F252)-Fufore-Ribadu-Gurin	Federal	F252-1	55
	Total			**1,181**
14	Ganye (A8)-Damasi Rd	State/Local	B/C	12
15	Ganye (A8)-Mbulo-Jada (A8) Rd	State/Local	B/C	48
16	Ganye Bypass	State/Local	B/C	3
17	Ganye Bypass-Jada	State/Local	B/C	6
18	Gombi (F253)-Kiri-Ga'anda-Bilel Rd	State/Local	B/C	50
19	Gorobi Road	State/Local	B/C	23
20	Guyuk (A4)-Shelleng Rd	State/Local	B/C	5
21	Gyawana (A345)-Lamurde Rd	State/Local	B/C	15
22	Jada (A8)- Kojoli Rd	State/Local	B/C	34
23	Lafiya (A345)-Lamurde- Karim-Lamido Rd	State/Local	B/C	43
24	Mayo Belwa Bypass Rd	State/Local	B/C	5
25	Mayo Belwa- Numan Rd	State/Local	B/C	37
26	Mayobelwa (A8)-Tola Rd	State/Local	B/C	20
27	Muva (A4-6)-Mayo Bani-Wamdiyo Rd	State/Local	B/C	10
28	Numan (A4)-Shelleng Rd	State/Local	B/C	67
29	Shelleng-Bakta-Dombi-Dungma-Song (A13) Rd	State/Local	B/C	70
30	Shelleng-Numan Rd	State/Local	B/C	42
31	Shelleng-Shani Rd	State/Local	B/C	17
32	Song (A13)-Maiha Rd	State/Local	B/C	84
33	Song Bypass	State/Local	B/C	6
34	Song-Maiha Rd	State/Local	B/C	84
35	Toungo (A8)-Cameroun Border Rd	State/Local	B/C	31
36	Toungo (A8)-Kiri Rd	State/Local	B/C	13
37	Yola (F252)-Fufore-Dasin Rd	State/Local	B/C	16
	Total			**741**
	Grand Total			**1,992**

Source: Authors (2021)

Nature of Road Networks in Adamawa State

The state of road transport networks in the study area shows that the total length of road networks in the state was approximately 1,992 Kilometers (Figure 2 and Table 4). The result shows that 54% of the total road networks were paved while 46% were not paved. Table 4 further reveals the condition of the roads which shows that only 15% out of the total paved roads in the study area were in very good condition while 74% were in very poor condition. This result therefore implies that majority of the road transport networks in the study area that facilitates the movements of both passengers and freights are in a deplorable condition. The implication here is that travel will be restricted, travel time will be long, passengers will encounter physiological stress and in addition, traveling on such roads can cause damage to both vehicle and commodities being transported.

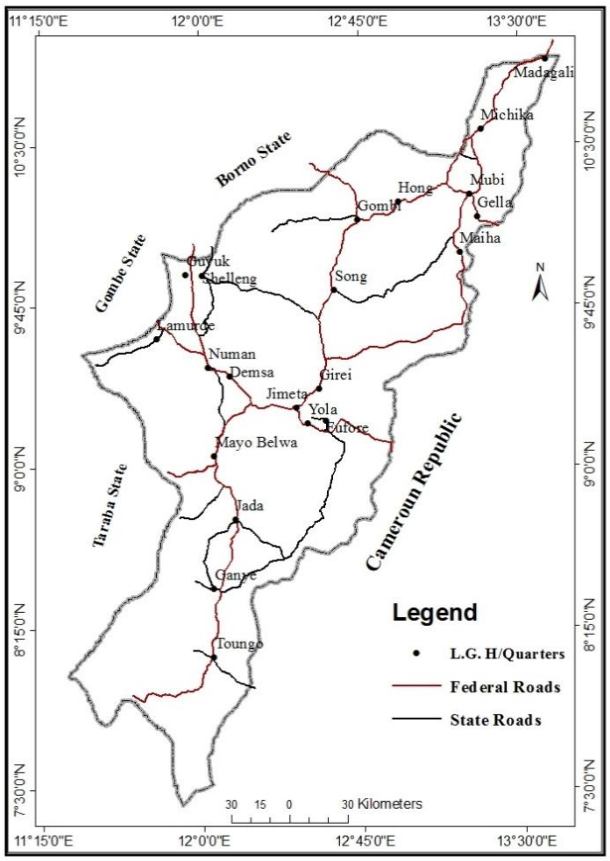

Figure 2: Road Classification
Source: Authors (2021)

Table 4: Nature and Condition of Road Networks in the Study Area

Description of Road Conditions	Nature of Road Networks in Kilometers			
	Paved	**Not paved**	**Total**	**%**
Very Good (Smooth Paved Surface)	301	-	**301**	**15%**
Fairly Good (Road with Numerous Potholes)	214	-	**214**	**11%**
Very Poor (Road's Major Components Eroded off)	558	919	**1,477**	**74%**
Total	**1,073**	**919**	**1,992**	**100%**
Percentage	**54%**	**46%**	**100%**	

Source: Authors (2021)

Analyzing the Existing Road Networks using Connectivity indices

The topological map of the study area (Figure 3) shows that there were 38 networks of roads (edges) that linked up the entire study area. Therefore, a total of 38 sampled edges that linked up a total of 21 vertices (LGAs) were used for the purpose of revealing the connectivity indices for the study area.

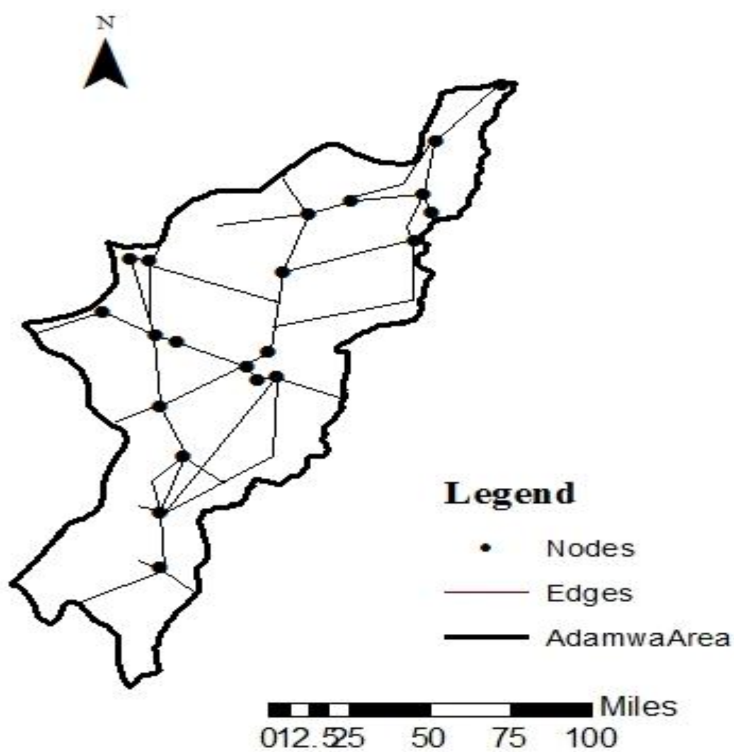

Figure 3: Topological Map
Source: Authors, (2021)

Road network density in the Study Area

Road network density measures the territorial occupation of a transport network in terms of kilometers of links (L) per square kilometers of surface (S) (Waugh, 2014). This was calculated using the total length of the road networks (1,992 km, both paved and un-paved) that occupies a total land area of 39, 972.3 km^2. Table 5 revealed that the average density of the road network system in the study area was very low (50m/km^2), this may serve as a great threat to socio-economic development and there is a greater restriction on mobility with attendant negative effects on the economy and general wellbeing of the people.

Beta Index (β)

Beta index (β) is the simplest measure of connectivity where the total number of edges (e) of a network is been divided by the total number of the vertices (v). Beta index ranges from less than one, in simple networks to a beta index of greater than one in a complete network (Waugh, 2014). The result revealed an overall index of 1.67, a value greater than one, indicating a high degree of connectivity. However, lack of well-surfaced road network in the region has made accessibility more inefficient (Table 5).

Cyclomatic Number (μ)

Cyclomatic number (μ) refers to the number of circuit in a given network. The more edges there are in a network, the greater the number of circuits is likely to be (Waugh, 2014). Result from Table 5 shows a high value Cyclomatic number of 18. This indicates that there are 18 numbers of complete networks, denoting higher connectivity in the study area.

Alpha Index (α)

The alpha index is obtained by expressing the number of the actual circuits in a given network (the Cyclomatic number) as percentage of the maximum possible number of circuit in that network (Waugh, 2014). This can range from a value of zero for a minimally connected network to a value of 100% for a maximally connected network. Table 5 therefore reveals in percentage an alpha index of 48.64% indicating a fair connectivity for the study area.

Table 5: Structural Analysis of Existing Road Networks in the Study Area

S/N	Indicators	Formula	Index Score	Correlation with Connectivity
1	Network Density	ND = L/S	50m/km^2	Lower density indicates less connectivity
2	Beta Index	$\beta = e/v$	1.81	Higher value indicates more connectivity
3	Cyclomatic Number	$\mu = (e-v)+1$	18	Higher value indicates more connectivity
4	Alpha Index	$\alpha = ((e-v)+1)/(2v-5) \times 100$	48.64%	Higher value indicates more connectivity

Source: Authors, (2021)

Geographic Accessibility

Geographic accessibility considers that the accessibility of a location is the summation of all distances between other locations divided by the number of locations divided by the number of locations. The lower its value, the more a location is accessible (Rodrigue *et al* (2013). This can be done by generating a distance grid for each place and then summing all the grids to form the total summation of distances grid. The cell having the lowest value is thus the most accessible place (Rodrigue et al (2013). Table 6 shows the shortest distance matrix in kilometers between 21 nodes. The result revealed that Jimeta which strategically is the state capital and located at the center was the most accessible. This was then followed by Girei, Demsa, and Yola. While

Madagali, Toungo, Michika and Maiha having higher value were the least accessible, this is because they are located farther away from the center.

Table 6: Shortest Distance Matrix in Kilometers

Vertices	Vertices Represented by Numbers																					Σd	Σd/n
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21		
DEM	**0**	90	140	66	163	62	190	98	53	314	233	59	271	235	252	17	76	111	174	53	62	2719	129
FUR	90	**0**	170	58	155	143	181	128	134	305	225	89	262	227	241	98	156	100	205	38	29	3034	144
GNY	140	170	**0**	161	258	178	284	43	170	408	328	82	365	330	342	134	192	206	42	140	151	4124	196
GIR	66	58	161	**0**	98	121	126	118	113	248	205	80	205	170	184	75	133	45	196	21	30	2453	117
GOM	163	155	258	98	**0**	224	28	215	224	151	71	177	109	73	86	186	231	52	293	118	127	3039	145
GUY	62	143	178	121	224	**0**	252	243	84	366	286	98	323	288	302	46	67	166	213	106	115	3683	175
HNG	190	181	284	126	28	252	**0**	243	234	124	81	203	81	46	60	198	258	80	319	144	154	3286	156
JAD	98	128	43	118	215	243	243	**0**	130	365	285	39	322	287	301	92	149	164	85	105	116	3528	168
LMR	53	134	170	113	224	84	234	130	**0**	358	277	89	315	280	315	38	105	158	204	97	106	3484	166
MDG	314	305	408	248	151	366	124	365	358	**0**	141	328	55	108	122	322	252	203	443	268	277	5158	246
MAH	233	225	328	205	108	286	81	285	277	141	**0**	247	100	35	49	279	346	160	363	188	197	4133	197
MBW	59	89	82	80	177	98	203	39	89	327	247	**0**	284	250	264	53	111	125	117	70	62	2826	135
MCK	271	262	365	205	109	323	81	322	315	55	100	284	**0**	65	79	279	376	190	400	255	234	4570	218
MUB	235	227	330	170	73	288	46	287	280	108	35	250	65	**0**	14	244	311	125	365	190	199	3842	183
GEL	249	241	342	184	86	302	60	301	315	122	49	264	79	14	**0**	258	325	139	379	202	212	4123	196
NUM	17	98	134	75	186	46	198	92	38	322	279	53	279	244	258	**0**	60	129	169	61	71	2809	134
SHE	76	156	192	133	231	67	258	149	105	252	346	111	376	311	325	60	**0**	175	234	120	129	3806	181
SNG	111	100	206	45	57	166	80	164	158	203	160	125	190	125	139	129	175	**0**	248	71	82	2734	130
TNG	174	205	42	196	293	213	319	85	204	443	363	117	400	365	379	169	234	248	**0**	183	177	4809	229
JIM	53	38	140	21	118	106	144	105	97	268	188	70	225	190	202	61	120	71	183	**0**	11	2411	115
YOL	62	29	151	30	127	115	154	116	106	277	197	62	234	199	212	71	129	82	192	192	**0**	2737	130
Σd	2719	3034	4124	2453	3039	3683	3286	3528	3484	5158	4133	2826	4570	3842	4123	2809	3806	2734	4809	**2411**	2737		
Σd/n	129	144	196	117	145	175	156	168	166	246	197	135	218	183	196	134	181	130	229	**115**	130		

Source: Authors, (2021)

Estimating the Percentage of Road Network Connectivity (% C) of the Study Area

In order to estimate the actual possible (maximum) links needed to complete percentage connectivity in the study area, we employed the techniques of Percentage Connectivity (% Connectivity) with the formula:

$$\% \text{ Connectivity } (\% \text{ C}) = \frac{\text{A}}{\text{P}} \text{ X } \frac{100}{1} = \frac{\text{Actual (Existing) links}}{\text{Possible (Maximum) links}} \text{ X } \frac{100}{1}$$

Where: P = n (n-1)/2;

n = number of nodes

Using the topological map (Figure 3), we can determine the level of road network connectivity in the study area as thus:

Number of nodes (n) = 21

Number of existing links = 38

Possible links (P) = 21(21-1)/2, = 210

Therefore, % Connectivity = $\frac{\text{A}}{\text{P}} \text{ X } \frac{100}{1} = \frac{38}{210} \text{ X } \frac{100}{1}$ = 18.10%

The above result showed that the percentage connectivity of the study area was only 18.10%, this implies that there is a deficit in the road network links that connect the study area.

Conclusion

The study has examined the structural analysis of regional road transport network with a view to assess the state, types and the degree of connectivity of road transport network in Adamawa state, Nigeria. The study findings have revealed that 64% of the roads were owned and maintained by the federal government and were classified as “trunk A and F roads” which constituted only 3.28% of the total federal roads in the country. These serial network systems systematically connect all the local government headquarters with the exception of Lamurde and Shelleng LGAs. The remaining 36%, classified as Trunk B and C were managed by both state and local authorities. They are mostly un-paved roads and were responsible for almost all the rural freight and passenger interactions. Most of these roads are also un-motorable during rainy season. Majority of the road networks in study area were in deplorable conditions and the overall accessibility was fairly low which pose a threat to all form of movement.

Recommendations

Based on the result of the findings, the study recommends the following:

i. The need for a synergy on all the tiers of governments to quantify and as well upgrade the road transport infrastructures for efficient socio-economic development of the area;
ii. There is need to establish a state government maintenance agency which will mainly focus on rehabilitation of any recent damage on paved road within the state before it reaches a deplorable stage;
iii. There is need for policy enactment on the provision of road transport infrastructures through the public-private partnership to rehabilitate the existing and construct new road transport infrastructures;
iv. There is also need for government to also intensify all the necessary actions for the future provision of alternative means of transportation to reduce burden on the existing road transport infrastructures, this could be through adoption and upgrading abandon unpaved

roads, introduction of rail system in the area etc. and in addition, there is need to re-introduce tolling systems on strategic road transport infrastructures so as to raise additional funds for road maintenance and construction.

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