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Research Article

Spatial analysis of transportation infrastructure distribution in Adamawa State, Nigeria: A location quotient perspective

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Abstract

Transportation constitutes one of the pivotal systems crucial to the advancement of socioeconomic conditions. However, numerous communities, particularly in Nigeria, face a multitude of transportation challenges. The primary objective of this study is to examine the spatial arrangement of transportation facilities in Adamawa State, Nigeria, with the intention of identifying spatial-related challenges confronting the transportation sector and the socioeconomic development of the state. During the period spanning 2018 to 2019, an investigation into the spatial distribution pattern of transport facilities within the state was conducted. To gather data pertaining to the geographical concentration and developmental trajectory of the transportation system in the state, the ArcGIS 10.5 Length Calculation Module, Google Earth Pro, and questionnaire administration were employed. Data were subjected to inferential statistical analysis, results were tabulated, and maps were generated. The findings unveiled three distinct modes of transit, namely road, water, and air, with roads emerging as the most prominent option. Furthermore, the state exhibited a higher prevalence of paved (engineered but untarred) roads compared to tarred roads. Moreover, an analysis of the spatial pattern encompassing the state's population and road network revealed that the length and density of tarred roads were greater in less populated Local Government Areas as opposed to the more populated ones. Ultimately, the road network pattern has yielded negative consequences for the state's development. In light of these findings, the study puts forth recommendations that emphasize the urgent need to tar the numerous paved roads within the state in order to enhance connectivity with markets and other urban-centric facilities.

Key words: Road network, rural roads, socioeconomic development, tarred roads, transport facilities, transportation challenges, transportation system

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1. Introduction

The need for socioeconomic development in any society, state, or nation is dependent on many operational and effective systems. Transportation is one of the systems that are central to socioeconomic development. Transportation systems (especially public) are open to the general public and, sometimes, operate on a set schedule (Public Transportation Systems 2017). The system is encompassing as it comprises road, rail, pipelines, maritime, and air transportation, among others, and involves the use of the likes of buses, trains, trams, ferries, and aeroplanes of various sizes and capacities (Jean-Paul 2017). An effective transportation system has proven valuable to national development in many countries, including India, Japan, Singapore, and America (Smriti 2013; Winston 2013; Okotie 2020). It increases trade, the dynamicity of freight and passengers, industries and markets, economic growth, job opportunities, rural areas' quality of life, and offers tourism and business opportunities to the government (Byju's n.d.). A developed transportation system can have a significant impact on a region's economic prosperity by providing a sufficient supply of commodities, ease of distribution, price stability, and reserves to maintain economic growth (Djajasinga 2021).

However, the transportation system requires the adequate provision of supporting transportation facilities. Law Insider (n.d.) described transportation facilities as all the publicly owned modes and means of moving people and goods, including physical infrastructure, parking lots, highways, roads, bridges, airports, seaports, and railroads, among others. These facilities aid the easy movement of people, goods, and services within and across borders and are beneficial to economic development. Also, transportation facilities are considered essential to economic growth and social development, as they increase the competitiveness of the economy (Djajasinga 2021). Accordingly, Rodrigue (2016) stressed the need to invest in transportation facilities due to their positive effects on social welfare and economic opportunities. Also, Madon (2000) stated that to promote positive change in socioeconomic development, wider connectivity in terms of transportation facilities is not negotiable. High-quality roads help to attain efficient population, industrial, and income distribution, the marketing of farm produce, accessing healthcare, and the provision of education facilities (Enwerem and Ali 2016).

Unfortunately, studies such as Oyesiku and Olaseni (2012), Anjorin (2021), and Ngalle (2021) have shown that one of the main challenges to efficient transportation systems and economic development is the uneven spatial pattern of transport facilities among nations and especially between urban and rural areas. For instance, road distribution is reportedly spatially uneven in China (Hu et al. 2018). According to Zhang et al. (2022), the road networks with high global integration in Dalian City, China, are mainly situated in the central city, the main road to the outer city, and the key transport hubs. Similar to other countries, Nigeria's transportation facilities, which include railways, roads, waterways, pipelines, and airports, among others, are unevenly spatially distributed across the country. For instance, about 200,000 km of roads in Nigeria are reportedly uneven (Ighodaro 2009). While 17% of the roads are for the federal government, states and local governments account for 16% and 67%, respectively (Ighodaro 2009). Also, Bankole (2010) discovered significant disparities in the federal, state, and local government roadways in Ekiti State's three senatorial districts. The North senatorial district has 90 km of federal highways, the Central has 130 km, and the South has 78.5 km; and there are many unpaved earth roads that create transportation difficulties and higher costs in many areas of Ekiti State. Additionally, Usman (2014) reported inadequate rural road facilities in Kwara State, especially in Kaiama Local Government Area (LGA), where rural residents face poor road conditions and expensive transportation problems.

One glaring implication of the uneven spatial pattern of transportation facilities is that communities with restricted mobility often end up with poor economic development and a poor standard of living (Usman 2014). A lack of accessible transport choices in rural locations is said to be a barrier to social inclusion and accessibility in contemporary society (Berg and Ihlström 2019). Often times, the result of such hindrances to social inclusion in modern society is fewer opportunities for rural residents to engage in typical social interactions and activities. Also, regions and/or communities with limited access to efficient transport facilities will be characterized by inefficient population and industrial development, poor marketing of farm produce, and inaccessible healthcare, security, banking, and education services.

In Adamawa State, there are signs of poor accessibility and obstructions to the flow of people and products. Many of the state's roadways are either in poor condition or are only paved. These paved surfaces are solely constructed without the application of tar. In the wet season, both paved and crumbling roads frequently flood and degrade. Many settlements lack the few kilometers of paved roads that some enjoy; however, some do have them to some extent. In some places, the expense of moving around the state can be staggering. As a result, the state's transit system can be emotionally, psychologically, and financially taxing. Additionally, the state's current transportation facility restricts the capacity of rural residents, particularly when it comes to transferring their farm products to metropolitan markets and seeking out better medical care in hospitals located in urban areas (Onu and Iliyasu 2008; Anjorin 2021). The state government's efforts to improve the socioeconomic growth of the state and the living standards of its citizens are ultimately undermined by these circumstances. On the spatial distribution pattern of these significant socioeconomic facilities in the state, there is sadly a shortage of research literature. As a result of the aforementioned circumstances, this study aimed to investigate the spatial pattern of transportation (road, water, and air) facilities in Adamawa State in order to identify the spatial-related problems that the transportation industry, the state's population, and socioeconomic development are currently facing. Therefore, studying the spatial distribution and concentration pattern of road, water, and air transportation facilities in Adamawa State are the specific objectives of the study.

2. Materials and methods

2.1. Study area

According to Adebayo (2020), the northeastern state of Adamawa in Nigeria is located between latitudes 07°15' and 10°58'N of the Equator and longitudes 11°29' and 13°47'E of the Prime Meridian (Fig. 1). The state is 37,852.33 km^2 in size and borders Borno State to the north, Gombe and Taraba States to the west, and the Cameroon Republic to the east. From north to south, the state is 434.50 km long and 165.58 km long from east to west (Zemba et al. 2020). Adamawa State is home to numerous commercial, social, medical, and educational facilities, as well as extensive networks of interstate and intrastate roads, and transportation and farming are some of the state's well-known trades (Anjorin 2021). There would inevitably be socioeconomic development in the communities, LGAs, and regions of Adamawa State when there was a balanced spatial distribution of these facilities.

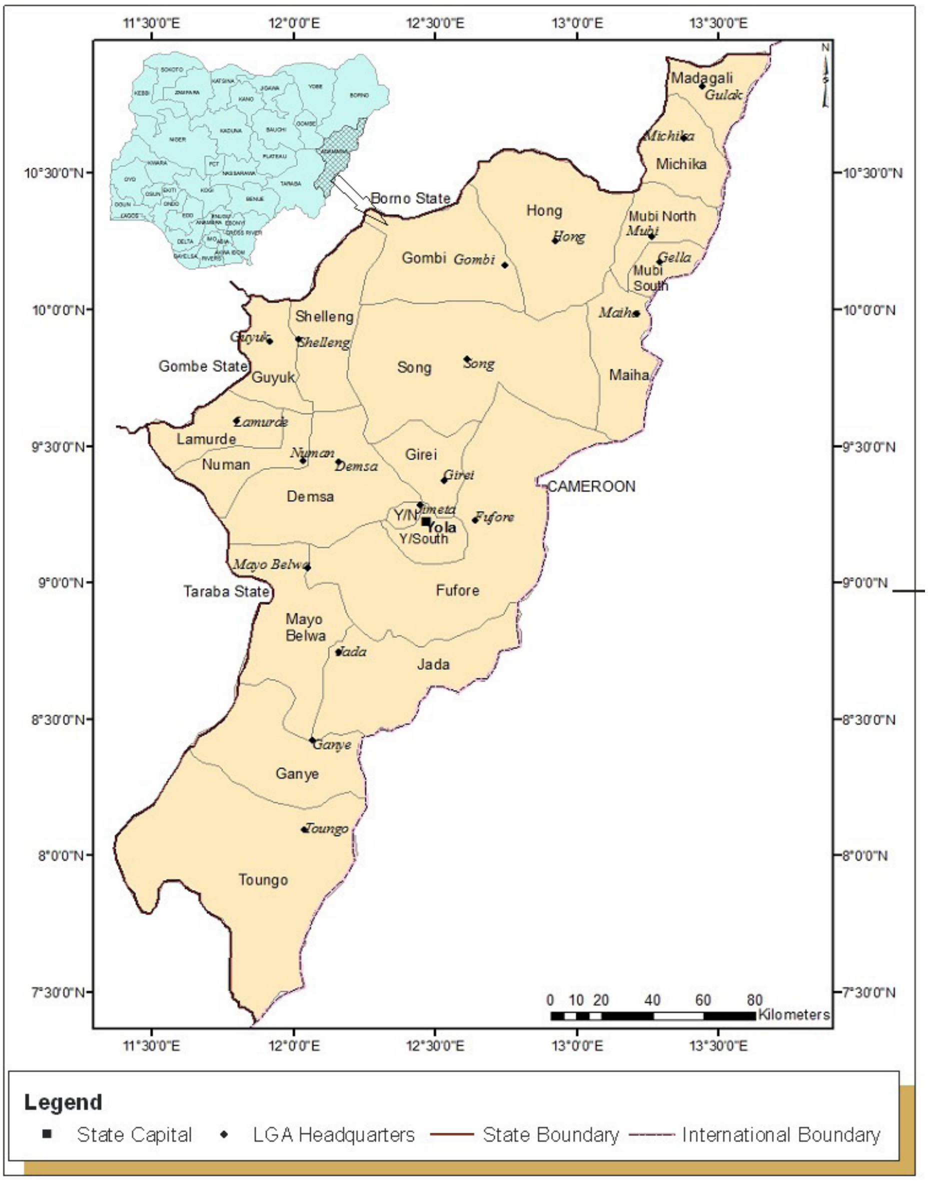

Figure. 1. Adamawa state showing LGAs and their capitals. Source: Anjorin (2021).

2.2. Methods

Table 1 presents the transportation facilities in Adamawa State, from which both primary and secondary data on the spatial distribution, concentration, and spatial development pattern were sourced and analyzed. The scope of the transportation system is extensive, encompassing physical infrastructure such as parking lots, highways, roads, bridges, airports, seaports, and railroads, among others. However, this particular study focused specifically on examining the length of roads (tarred or paved), navigable rivers, and the number of airport. It did not consider the number of buses, trains, ferries, and airplanes that utilize these facilities in the state. The details of the assessed facilities are provided in Table 1.

Table 1. Assessed road, water, and air transportation facilities in Adamawa State.

S/No	Transportation Variables
1	Length of major tarred roads (km)/'000 population/LGA)
2	Length of paved roads (km)/'000 population/LGA)
3	Length of navigable water ways (km)/'000 population/LGA)
4	No. of air port /'000 population

Between 2018 and 2019, research was carried out to analyze the spatial concentration pattern of road networks, navigable rivers, and airports in Adamawa State's LGAs in relation to these facilities. The study excluded the state's transport facilities provided after the data-gathering period. The lengths of road segments (tarred and paved) and navigable rivers in each LGA were measured using the Length Calculation Module of ArcGIS 10.5 and Google Earth Pro. This module was utilized because it allowed the calculation of road lengths and facilities, providing insights into connectivity and accessibility. Thereafter, the calculated length and density were quantified, and their distribution in relation to population density was assessed. Other relevant information, including the number of airports in the state, was sought from official documents of the Nigerian National Bureau of Statistics published in the literature.

To calculate the location quotient (LQ), data was compiled and coded into Microsoft Excel, and statistical tests were run. The LQ statistic compares the spatial distribution of a phenomenon in a subset of data to the entire data in an area, revealing regional traits and specialization, and Microsoft Excel was employed for the purposes of data organization, automation, visualization, and ensuring data security, among numerous other rationales. The study utilized the location quotient formula, as suggested by Balogun (2018), to identify spatial patterns of socioeconomic facilities in each local government area. The LQ result is regarded as either less than 1 (< 1) (deficiency), larger than 1 (> 1) (excess), or equal to 1 (optimum) (Tali et al. 2017). The total LQ values measured at LGA levels were classified using states' LQ average scores, forming the basis for classifying LGAs into low, moderate, and high concentrations. The location quotient formula is:

$$LQ_i = \frac{e_i/e}{E_i/E} \quad \text{(Balogun 2018)}$$

Where, LQ_i = Location quotient for facilities for the Local Government/State.
e_i = The total number of facilities in the Local Government i;
e = Total number of facilities in the State;
E_i = Population of the Local Government i;
E = Total population of the State.

The Mehta (2004) population projection method was employed in this study to forecast the population of Adamawa state, which was determined to be 4,470,434, for the purpose of computing the LQ and examining the spatial concentration pattern of individuals and transportation facilities. The ArcGIS 10.5 categorization module was used to calculate road density, a metric that quantifies the length of roads in relation to the area they occupy. This metric provides valuable insights into the concentration of the road network within the study area. It is determined by dividing the total length of roads by the area. In order to evaluate its significance, the obtained road density was compared to the density benchmarks established by Obafemi et al. (2011). These benchmarks categorize high density as exceeding 120 km^2, medium density as 30 km^2, and low density as less than 30 km^2. Using geospatial tools and LQ data, the study developed spatial concentration map (fig. 4) for the assessed transport facilities in the state.

3. Results

3.1. Distribution of road, water, and air transportation facilities by LGAs

The spatial distribution pattern of road and water transport facilities in the 21 LGAs of Adamawa State was assessed and evaluated. The evaluated spatial data include the number, distance (in kilometers), and density of these facilities, and the result is presented in Table 2.

Table 2. Data on the assessed road, water, and air transportation facilities. Sources: *Zemba et al. (2020); **Calculated based on *; ***Anjorin (2021).

LGA	* Total land area (km^2)	** Roads network				** Navigable water network	
		Tarred (km)	Density (km/km^2)	Paved (km)	Density (km/km^2)	Navigable rivers (km)	Density (km/km^2)
Demsa	1,822.75	57.05	0.03	137.76	0.08	42.19	0.02
Fufore	4,954.17	54.35	0.01	394.49	0.08	32.24	0.01
Ganye	1,885.81	28.99	0.02	101.37	0.05	-	-
Girei	1,097.27	38.17	0.03	24.37	0.02	34.27	0.03
Gombi	1,842.00	58.96	0.03	90.47	0.05	-	-
Guyuk	756.56	49.95	0.07	32.52	0.04	25.47	0.03
Hong	2,613.12	93.29	0.04	56.12	0.02	-	-
Jada	2,787.37	84.29	0.03	196.45	0.07	-	-
Lamurde	1,170.41	31.95	0.03	57.12	0.05	29.09	0.02
Madagali	815.04	38.74	0.05	18.39	0.02	-	-
Maiha	1,266.01	24.89	0.02	142.1	0.11	-	-
Mayo-Belwa	1,766.46	20.95	0.01	83.6	0.05	-	-
Michika	960.9	46.49	0.05	65.27	0.07	-	-
Mubi-North	897.04	47.29	0.05	23.54	0.03	-	-
Mubi-South	411.55	20.91	0.05	38.52	0.09	-	-
Numan	904.84	28.84	0.03	69.34	0.08	44.86	0.05
Shelleng	1,357.02	27.86	0.02	106.75	0.08	25.47	0.02
Song	4,240.37	58.5	0.01	201.52	0.05	-	-
Toungo	5,475.48	73.78	0.01	127.39	0.02	-	-
Yola-North	112.43	48.06	0.43	7.37	0.07	5.86	0.05
Yola-South	715.73	72.08	0.10	29.61	0.04	14.41	0.02
State Total	37,852.33	1005.39	1.12	2004.07	1.17	-	0.24

Table 2 shows Adamawa State has a land area of 37,852.33 km^2, with three largest LGAs (Toungo, Fufore, and Song) each covering over 4,000 km^2. Eight smaller LGAs have smaller land areas of less than 1,000 km^2. The state has a total road density of 2.29 km/km^2, with 1.12 km/km^2 of tarred roads and 1.17 km/km^2 of paved roads. Yola North LGA has a highest kilometer of tar roads, while Maiha LGA has nearly equivalent paved roads. All LGAs have good road connections to the state capital, but only half have access to navigable rivers. The road and the navigable rivers in Adamawa State are shown in Fig. 2.

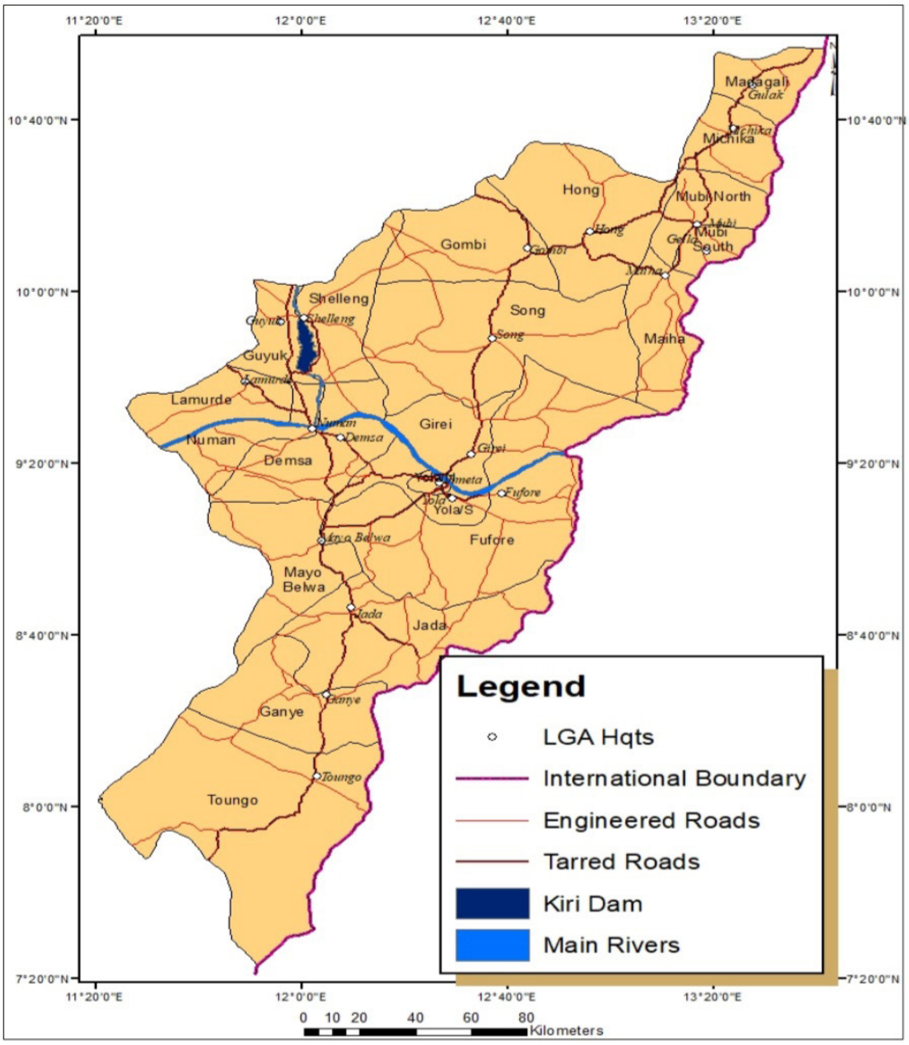

Figure 2. Distribution pattern of road and the navigable rivers in Adamawa state. Source: Anjorin (2021).

3.2. The spatial concentration of road, water, and air transportation facilities by LGAs in Adamawa state

The outcome of the location quotient (LQ) analysis used to assess the spatial pattern of road, water, and air transportation facilities' concentration in Adamawa State is shown in Table 3.

Table 3. LQ analysis of concentration pattern of transport facilities in Adamawa state. Source: Anjorin (2021).

LGA	Tarred roads	Paved roads	Navigable water ways	Airport	Total	Rank	Class
Yola-North	16.09	1.24	7.77	0.00	25.10	1st	High
Yola-South	3.79	0.78	3.00	16.28	23.85	2nd	
Numan	1.20	1.45	7.39	0.00	10.04	3rd	
Guyuk	2.49	0.81	5.02	0.00	8.32	4th	
Girei	1.31	0.42	4.66	0.00	6.39	5th	Moderate
Demsa	1.18	1.43	3.45	0.00	6.06	6th	
Lamurde	1.03	0.92	3.71	0.00	5.66	7th	
Shelleng	0.77	1.49	2.80	0.00	5.06	8th	
Mubi-South	1.91	1.77	0.00	0.00	3.68	9th	
Michika	1.82	1.28	0.00	0.00	3.10	10th	Low
Fufore	0.41	1.50	0.97	0.00	2.88	11th	
Maiha	0.74	2.12	0.00	0.00	2.86	12th	
Mubi-North	1.98	0.50	0.00	0.00	2.48	13th	
Jada	1.14	1.33	0.00	0.00	2.47	14th	
Madagali	1.79	0.43	0.00	0.00	2.22	15th	
Gombi	1.21	0.93	0.00	0.00	2.14	16th	
Hong	1.34	0.41	0.00	0.00	1.75	17th	
Ganye	0.58	1.02	0.00	0.00	1.60	18th	
Song	0.52	0.90	0.00	0.00	1.42	19th	
Mayo-Belwa	0.45	0.89	0.00	0.00	1.34	20th	
Toungo	0.51	0.44	0.00	0.00	0.95	21st	
State Average	1.00	1.00	1.00	1.00	4.00		

Table 3 displays the spatial concentration pattern of transportation facilities in Adamawa State. The state is divided into three zones of concentration: high, moderate, and low concentration zones. In the high zone, there are four LGAs, while the moderate and low zones have five and eleven LGAs, respectively. Accordingly, tarred roads are more concentrated in Yola North and distantly followed by Yola South, and Guyuk LGAs with an LQ values of 16, 3.79 and 2.49, respectively. There are also multiple other LGAs in the state with a lower concentration of tarred roads. Examples of such LGAs include Mayo-Belwa (0.45), Toungo (0.51), and Song (0.52), among others. Fig. 3A, B and Fig. 4 illustrate the transportation on River Benue and the concentration map of the state's transport facilities, respectively.

Figure 3. Transportation on river Benue in Jimeta, Yola North LGA, Adamawa state, Nigeria. **A.** Fishing on river Benue; **B.** Canoes at harbor on river Benue. Source: Anjorin (2021).

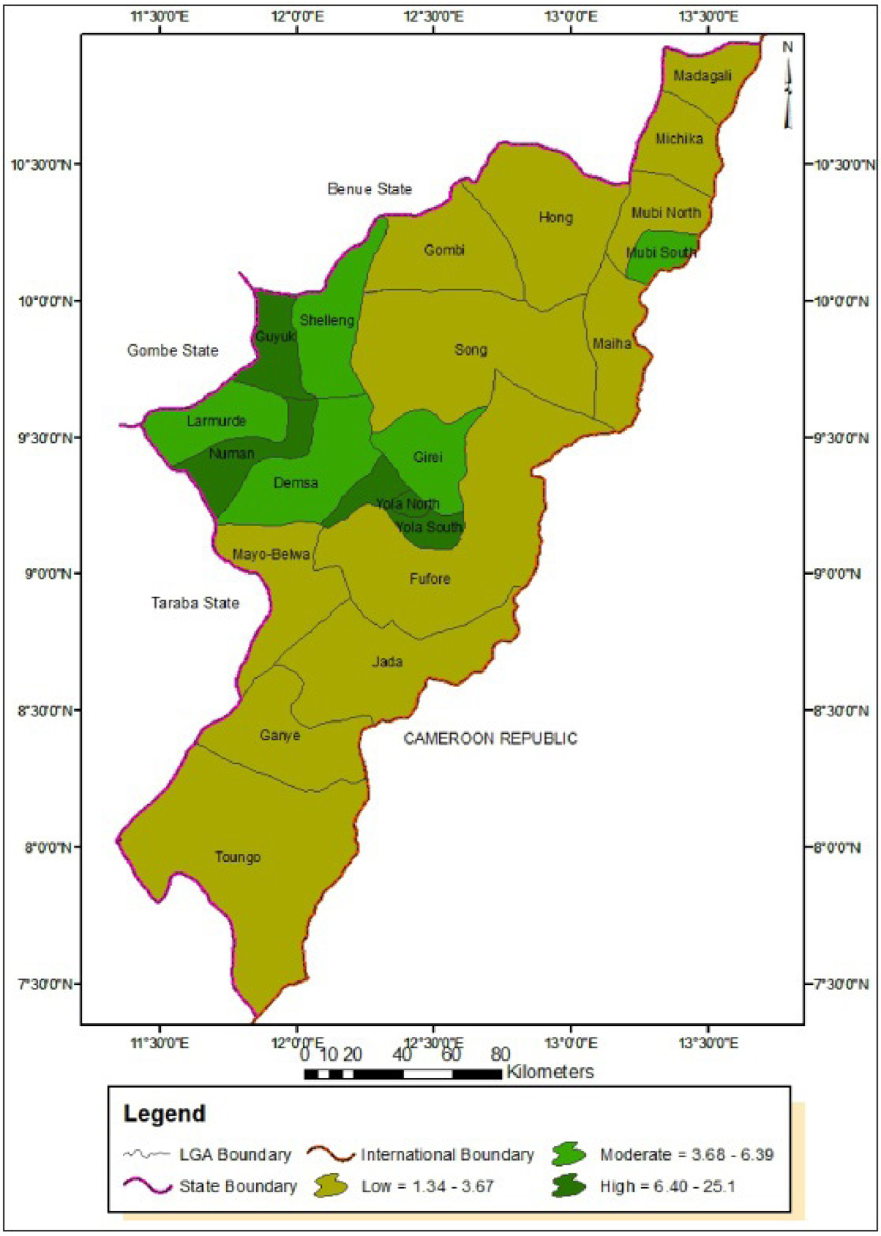

Figure 4. Spatial concentration pattern of road, water, and air transportation facilities in Adamawa state. Source: Anjorin (2021).

3.3. Relating the distribution pattern of the state's population and transport facilities

Table 4 presents data on the distribution patterns of the state's population and transport facilities.

The spatial pattern of Adamawa State transport facilities (including roads, airways, and navigable rivers) and the population can be observed in Table 4. Within Adamawa State, the LGAs with the highest population are Fufore, Yola North, Yola South, Song, and Demsa. Among these LGAs, Fufore, which has the largest population, also has the most extensive network of paved roads, measuring 394.49 km, in contrast to the length of tarred roads, which is 54.35 km. Furthermore, Song and Demsa display a greater proportion of paved roads compared to tarred roads.

Table 4. The nexus between the spatial pattern of the states' population and transport facilities. *Anjorin (2021).

LGAs	*Projected population	Tarred (km)	Paved (km)	Navigable rivers (km)	Airport
Demsa	254,348	57.05	137.76	42.19	0
Fufore	292,497	54.35	394.49	32.24	0
Ganye	231,539	28.99	101.37	-	0
Girei	183,432	38.17	24.37	34.27	0
Gombi	206,622	58.96	90.47	-	0
Guyuk	250,869	49.95	32.52	25.47	0
Hong	238,649	93.29	56.12	-	0
Jada	237,728	84.29	196.45	-	0
Lamurde	159,173	31.95	57.12	29.09	0
Madagali	190,251	38.74	18.39	-	0
Maiha	156,932	24.89	142.1	-	0
Mayo-Belwa	216,076	20.95	83.6	-	0
Michika	219,143	46.49	65.27	-	0
Mubi-North	213,174	47.29	23.54	-	0
Mubi-South	181,940	20.91	38.52	-	0
Numan	128,017	28.84	69.34	44.86	0
Shelleng	210,347	27.86	106.75	25.47	0
Song	271,910	58.5	201.52	-	0
Toungo	73,432	73.78	127.39	-	0
Yola-North	279,741	48.06	7.37	5.86	1
Yola-South	274,605	72.08	29.61	14.41	0
State Total	4,470,434	1005.39	2004.07	-	1

4. Discussion

According to Table 2, there are public transit options for land, water, and air, with roads being the most prominent in Adamawa State. The state, encompassing an area of 37,852.33 km^2, exhibits a road density of 2,290 km. Remarkably, Yola North stands out as an LGA with a substantial distribution of tar roads, whereas Maiha presents a comparable density of paved roads. Notably, the aforementioned paved roads display denser distributions, particularly within 17 LGAs. This implies a pressing necessity to enhance the quality of road surfaces through tar application. These roads are divided into two categories, both of which have a total length of more than three thousand kilometres. The paved roads, which are only engineered but not tarred, are more than two thousand kilometres (2004.07 km) long and have a density of 1.17 km/km^2. The tarred roads are a little over one hundred thousand kilometres (1005.39 km). However, some LGAs in the state are given prominence over others due to the physical layout of these roadways. Despite not being among the LGAs with huge land areas, Hong and Jada have the state's longest tarred roads (93.29 km and 84.29 km, respectively). This is distantly followed by Toungo and Yola-South LGAs with 73.78 km and 72.08 km, respectively. The state's two LGAs with the fewest kilometers of tarred roads are Mayo-Belwa and Mubi South. A similar unequal distribution of paved roads can be seen in the state. Fufore, Jada, and Maiha LGAs have the longest paved roads in the state, at 394.49 km, 196.45 km, and 142.1 km, respectively. Except for Yola-North and Yola-South LGAs, the majority of LGAs with access to navigable rivers seem to own a fairly equal proportion of their length. The spatial patterns clearly show that some communities and LGAs rely solely on man-made transportation facilities, while others have both highways and navigable rivers. This is evident in LGAs like Numan, Lamurde, and Girei, which are located along waterways in the state, as shown in Fig. 2.

The finding of uneven spatial distribution pattern of transportation facilities in Adamawa State agrees with Ighodaro (2009) and Usman (2014), who reported an uneven spatial distribution pattern of road facilities in different states of Nigeria. Also, Onu and Iliyasu (2008), Belel et al. (2018), and Dia et al. (2018) collectively contend that there is an insufficiency of well-constructed roads in various regions of Adamawa State. In addition, uneven distribution pattern of transportation facilities reportedly causes restricted access to transportation facilities, especially in rural communities, leads to poor economic development, social inclusion, accessibility, and living standards (Usman 2014; Berg and Ihlström 2019). According to Enwerem and Ali (2016), communities and LGAs that have more developed roads derive many advantages, including easy access to education, financial and medical services, an efficient population, and industrial development.

Furthermore, Table 3 demonstrates the concentration pattern of transportation facilities, revealing the uneven concentration of transport facilities within the state. Facilities with an equitable spatial concentration pattern would exhibit a location quotient (LQ) of one. Facilities with an LQ value below one indicate a low level of concentration, whereas values above one indicate an excessive level of concentration. As a result, the spatial concentration of transport facilities in Adamawa State is split into three categories: low, moderate, and high. Twelve LGAs in the state make up the majority of the low-concentration zone. While Michika, Fufore, Maiha, and Mubi-North are a few of the LGAs in the low concentration zone, five LGAs—Mubi-South, Shelleng, Lamurde, Demsa, and Girei—are in the moderate zone. Four LGAs, Yola-North, Yola-South, Numan, and Guyuk LGAs, make up the high concentration zone. However, the concentration of each accessed transit facility differs from one LGA to the next. The LQ results in Table 3 show that Yola North, Yola South, Numan, Guyuk, Girei, Demsa, Lamurde, and Shelleng LGAs have an excessive concentration of most of the transport facilities. Only Yola North and Yola South LGAs have a high concentration of tarred roads; the other 12 LGAs, including Numan, Mubi North, Demsa, Girei, Gombi, Guyuk, Hong, Jada, Lamurde, Mubi South, Madagali, and Michika LGAs, have a moderate concentration. Low percentages of tarred roads are found in the remaining seven LGAs, including Fufore, Ganye, Maiha, Mayo-Belwa, Shelleng, Song, and Toungo LGAs. Additionally, 10 out of the state's 21 LGAs have a moderate concentration of paved roads.

Additionally, air travel, and navigable rivers are additional modes of transportation in Adamawa State. According to the National Bureau of Statistics ([NBS] 2018), during the year 2018, a combined total of 75,735 individuals and 638 aircraft embarked on journeys through the Yola airport throughout the initial half of the year. In the year 2021, the overall count of passengers crossing the Yola airport reached a total of 175,699 individuals (NBS 2022). Also, the rivers Gongola and Benue are just a couple of the navigable waterways in Adamawa State. However, only nine LGAs in the state—Demsa, Fufore, Girei, Guyuk, Lamurde, Numan, Shelleng, Yola North, and Yola South LGAs—have access to navigable rivers, even though Yola Airport is accessible by roadways from all LGAs in the state. The concentration pattern of transport facilities in the state is depicted in Fig. 4.

The disparate level of concentration of transportation facilities within Adamawa State can be attributed to multiple factors. First, because Yola North and Yola South LGAs serve as the capitals of Adamawa State, they both have a significant number of tarred roads. Additionally, Yola North and Yola South LGAs are home to the majority of Adamawa State's socioeconomic resources, government agencies, and population. As a result, the government of Adamawa State focuses its efforts on road building in these two LGAs. Therefore, the high concentration of tarred roads in some LGAs in Adamawa State may contribute to their growth. However, the concentration facilities of water transportation in nine LGAs is due to the fact that only these LGAs have navigable rivers. According to Talpur et al. (2018), the transport sector is crucial for the free flow of people and goods, and is the backbone of national and regional economies. This conclusion was reinforced by Abbas et al. (2014), Balogun et al. (2019), and Xu (2019), who stated that decent roads are important for economic growth and development. Invariably, decent roads make it simple for locals to access quality medical facilities. Also, the state is characterized by a vast number of paved and deteriorating roads, including Yola-Mubi and Lafia-Ngurore Roads, which are prone to increased levels of insecurity. Consequently, incidents of armed robbery occur, leading to a general reluctance among drivers and passengers to undertake nocturnal travel along these routes (Anjorin et al. 2021). This may have encouraged the Adamawa State administration to invest in road building around the state in order to enhance inhabitants' living standards and promote the state's socioeconomic growth.

Table 4 presents a comprehensive depiction of the distribution pattern of the transport facilities and population in the state. It is noteworthy that Fufore, being the most populous LGA, possesses a significant expanse of paved roads in comparison to the kilometers of tarred roads. Moreover, Song and Demsa, despite their large population, exhibit a relatively larger proportion of paved roads as opposed to tarred roads. The state capital, which comprises Yola North and Yola South LGAs, is characterized by the presence of tarred roads. On the other hand, nine LGAs such as Numan, Demsa, Girei, and Fufore still rely on both roads and waterways for transportation. However, it is important to note that these rivers are subject to seasonality, rendering them less navigable during the dry season, especially from January to May. This specific distribution arrangement has an adverse impact on the potential for socioeconomic advancement and progress within the LGAs and the state. To illustrate, individuals residing in rural LGAs with more paved roads such as Mayo-Belya, Toungo, and Maiha, who primarily engage in agricultural activities, face difficulties when it comes to transporting their agricultural produce to urban centers. This is particularly evident during the peak of the rainy season, which occurs from July to October, when paved roads become less suitable for motorized movement due to flooding and erosion. Additionally, the seasonal nature of navigable waterways presents a transportation challenge, especially in LGAs that have access to such water bodies.

This finding aligns with the assertions made by Onu and Iliyasu (2008), who previously emphasized the detrimental effects of the inadequate state of the road infrastructure in Adamawa State on the farmers' ability to transport their produce to markets, consequently aggravating the poverty rate. Also, this concern was raised in Anjorin et al. (2021) and Galtima et al. (2020), who have observed the hurdles faced by rural residents of Adamawa State in accessing medical, educational, and banking services in urban centers, as well as the periodicity of certain markets within the state caused by transportation difficulties. The state of transportation infrastructure and its impact on the economic progress of Adamawa State closely reflect the state of roadways throughout Nigeria. As stated by Adewumi (2008), the road sector in Nigeria, despite its potential for growth, has been negatively impacted by insufficient transportation facilities and infrastructure, which has impeded economic development and hindered poverty reduction endeavours. The World Bank (2019) reveals that a significant proportion of the federal and state roads in Nigeria are in a suboptimal state, with only a negligible fraction, varying between 10% and 15%, deemed acceptable or navigable. Additionally, the report shows that Adamawa State exhibits noticeable inconsistencies in terms of rural accessibility, amounting to 12.8%. This figure is comparable to the neighbouring Taraba and Yobe States, which report percentages of 10.5% and 13.7%, respectively. However, it is important to note that disparities exist when comparing these figures to those of the southern states, such as Lagos and Imo, where the percentages are significantly higher at 49.7 and 48.3%, respectively (World Bank 2019). Therefore, in order to avoid stagnation in various areas such as the economy and social interactions, it is vital to implement a productive transportation system.

5. Conclusion

The study investigated the spatial pattern of road, water, and air transportation facilities in Adamawa State, Nigeria, and identified spatial-related challenges facing the transportation sector and the socioeconomic development of the state. Roads were identified as the most prominent transit option in the state, with a higher prevalence of paved roads compared to tarred roads. The length and density of tarred roads were greater in some of the less-populated compared to the highly-populated LGAs. Therefore, the spatial arrangement of transportation facilities leads to inadequate accessibility in the state. Consequently, the state's economic expansion is impeded by the state's inadequate transportation framework, specifically in far-flung regions where the availability of urban-centric facilities is restricted. Nevertheless, the research indicates that the lack of one form of transportation in the region can be offset by the prevalence of another, warranting Shelleng's categorization in the "Moderate Class" despite its limited number of tarred roads, as well as Madagali, Michika, and Mubi-North LGAs in the "Low Class" despite their abundance of tarred roads.

Therefore, based on the study's results, the following recommendations are made to improve the state's transport sector:

- Given the considerable concentration of paved roads within the state, it is imperative for the government to tar these roads so as to ameliorate the inconveniences related to transportation among the road users dwelling in the affected LGAs, especially during the rainy season. This measure will aid in mitigating transportation inconveniences and augmenting connectivity with commercial hubs and urban-centric facilities.
- Since the research findings suggest that densely populated LGAs tend to have fewer tarred roads compared to paved roads, and some heavily populated LGAs have fewer tarred roads than less populated areas, conducting location quotient analyses is crucial for allocating transportation facilities, particularly new roads, in LGAs. Understanding the distribution pattern of transportation facilities within the state will guide the state government's resource allocation and investment decisions towards ensuring more equitable access to transportation services.

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Additional information

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.