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A Spatio-temporal Analysis of Traffic Flow Dynamics using UAV and GIS Integration at Elkanemi Intersection, Maiduguri, Borno State, Nigeria

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ABSTRACT
Rapid urbanization and increasing vehicle ownership have intensified traffic challenges particularly at critical intersections with poor design and limited regulation across many African cities and Nigeria is not exceptional. This study assessed the spatiotemporal dynamics of traffic flow at Elkanemi Intersection in Maiduguri, Borno State, Nigeria using an integrated Unmanned Aerial Vehicle (UAV) and Geographic Information Systems (GIS) approach. UAV-captured videos, observations, and GPS coordinates, were collected during morning, afternoon, and evening peak hours. The data were analyzed using spatial analysis tools within ArcGIS 10.8. Findings revealed significant temporal and spatial variation in traffic flow, with Mogaram Road recording the highest volume during the morning peak and Ahmadu Bello Way Westbound showing evening dominance. Tricycles emerged as the most prevalent mode across all corridors and time periods, accounting for over 55% of traffic, followed by private cars, particularly in the evening. Buses and trucks had minimal representation, while bicycle usage spiked in the afternoon, correlating with school closures. Gap acceptance analysis showed modal differences, with trucks requiring the highest gaps and tricycles exhibiting aggressive merging behavior. The study highlights the utility of UAV and GIS in urban traffic assessment and recommends integrated transport planning that accounts for modal heterogeneity, peak-hour demand, and intersection performance to improve urban mobility in rapidly growing cities.

***Keywords*: - Spatio-temporal, Traffic Flow Dynamics, UAV, GIS, Gap acceptance**

INTRODUCTION

The continuous rise in traffic flow has emerged as a major challenge for municipalities and governments across the world due to the rapid pace of urbanization, motorization, and infrastructure (Bukar et al 2025). According to the United Nations more than 55% of the global population resides in urban areas and projected to reach over 68% by 2050 (Rodriguez-Nikl, 2022; López and Flores-Garcí 2023; Saavedra et al., 2024). This urban growth exerts significant pressure on road infrastructure, resulting in traffic congestion, increased travel times, deteriorate atmosphere and increase the road accidents (Vrandani & Mathur, 2022; Faheem et al., 2024). These conditions are pronounced at most of the urban intersections, which often serve as critical nodes for intra-city transportation but are prone to inefficiencies as a result of poor design and inadequate traffic control and weak integration of data in planning processes (Kelly & Gupta, 2024; Rajesh et al., 2024; Malakshah & Amini, 2025)

Technological advancements have introduced new tools, notably Unmanned Aerial Vehicles (UAVs) and Geographic Information Systems (GIS) for traffic monitoring, congestion detection, and managing urban traffic conditions (Quamar et al., 2023; Raj et al., 2024). UAVs provide cost-effective, high-resolution aerial imagery and real-time video data, making them invaluable for observing traffic dynamics, vehicle counts, and movement trajectories ((Elloumi et al., 2019; Bashar, 2023) and GIS enables spatial visualization and analysis of transportation networks, facilitating the identification of traffic patterns, congestion hotspots, and spatial-temporal trends in road usage (Aghajani et al., 2017; Nayak & Goyal, 2024; Journal, 2024). Thus, UAV alongside with GIS technologies Provide a robust foundation for comprehensive traffic flow analysis and evidence-based urban planning (Zhang et al., 2019; Williams-Kelly, 2023; Raj et al., 2024; Kumarasinghe & Pushpakumara, 2024; Wang & Zhang, 2024; Zaiats, 2024; Bukar et al. 2025).

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Despite global advancement in geospatial traffic monitoring, the application of UAV and GIS in traffic management and monitoring remain limited across many African urban centers. In Nigeria, the most populous country in Africa, the surge in urban migration and vehicle ownership has outpaced the development of transportation infrastructure, leading to worsening congestion and increased safety challenges (Buhari et al., 2020; Otuoze et al., 2021; Faiyetole, 2023; Ogunkunbi et al., 2023; Oludele, et al 2024). This situation is also evident in Maiduguri which has undergone significant urban expansion in recent years due to internal migration and reconstruction effort. The key intersections, such as the Elkanemi Roundabout, have emerged as major traffic nodes, yet suffer from chronic congestion, unregulated vehicular flow, and poor design standards (Bukar and Kundiri, 2025)

Several studies have demonstrated the utility of UAVs in traffic monitoring, especially for extracting vehicle trajectories, estimating traffic density, and analyzing intersection performance (Butila & Boboc, 2022; Zong et al., 2022; Espadaler-Clapés et al., 2023; Sarkar & Chatterjee, 2024). Similarly, GIS-based spatial analysis has proven effective in understanding traffic flow, road network capacity, and land-use interactions (Reuben & Ejikeme, 2024; Journal, 2024 (Iranmanesh et al., 2024; Jiang et al., 2024; Khallef et al., 2025). However, the integration of UAV and GIS technologies has not been well explored in Maiduguri. Therefore, this study aims to assess the spatial analysis of traffic flow dynamics at Elkanemi Intersection in Maiduguri, using UAV and GIS techniques.

THE STUDY AREA AND METHODOLOGY

STUDY AREA

Maiduguri, the capital of Borno State, is the largest city in northeastern Nigeria. Geographically, it is situated between latitudes 11°43′N and 11°52′N and longitudes 13°05′E and 13°15′E (Figure 1b) The city covers a total area of approximately 543 km² and lies at an altitude of 345 meters above sea level (Kodiya *et al.* 2023. Maiduguri is characterized by a semi-arid climate, marked by low annual precipitation and high temperatures throughout much of the year.The study area, Elkanemi Intersection, is located between latitudes 11°49′50″N and 11°50′65″N and longitudes 13°9′0″E and 13°9′25″E. (Figure 1a) It is one of the key intersections encircling the Maiduguri Central Market.

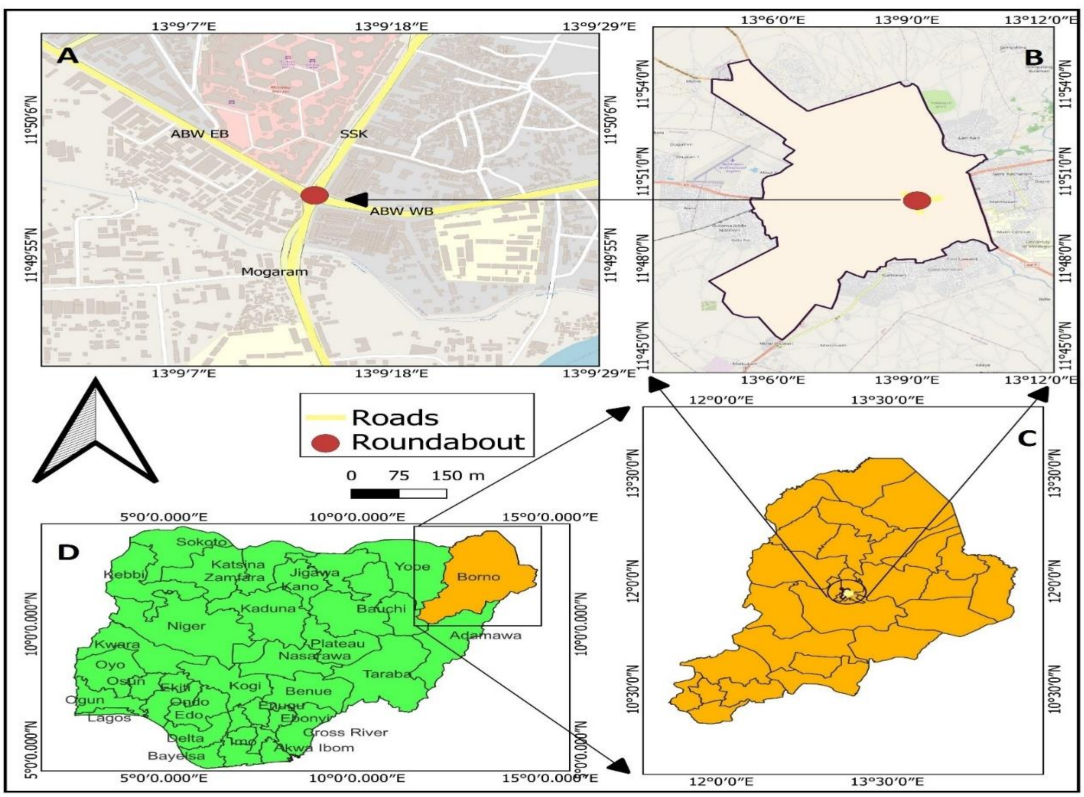

Figure: Study Araea Description: (a) Elkanemi Intersection (b) MMC Showing the Elkanemi Intersection (c) Borno State Showing MMC (d) Nigeria Showing Borno State

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MATERIALS AND METHODS

MATERIALS

Hardware: The UAV used for capturing and acquiring the live traffic flow, direction and coverage in the study area. Also, a laptop computer for processing the acquired images from the UAV, GPS data and Android Phone. The Unmanned Aerial Vehicles (DJI Phantom 4, is shown in Plate 1.

Plate 1: DJI Phantom 4

The characteristics of the UAV DJI Phantom 4 used includes flight duration of 30 minutes (One fully charged), transmission distance of 3.5km, altitude of 1000m above mean sea level, camera with resolution of 12.0 mp. To replace table 1

Table 1: Specification of the Unmanned Aerial Vehicle used

Specification
Type – DJI Phantom 4 Flight time - 25mins (one full battery) Transmission distance – 3.5km Altitude - 1000m above sea level Camera - 12.0mp

Software: Google Earth Pro Engine for capturing optical remotely sensed data, with GPS. The ArcGIS version 10.8 environment were used to perform GIS Operations which incorporate the digital image processing, spatial analyst and interpolation tools to analyse the traffic flow parameters. Microsoft Excel and Microsoft word were used for plotting charts and word-processing for the presentation respectively.

DATA SOURCE AND COLLECTION PROCEDURE

The study utilized both primary and secondary data sources. Primary data comprised UAV-based videography and photography for assessing traffic composition, high-resolution GeoEye satellite imagery (0.45 m) for accurate georeferencing, GPS-collected point coordinates and field observations conducted during peak hours. Unmanned

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Aerial Vehicles (UAVs) were specifically employed to capture traffic flow along the selected corridors during morning, afternoon, and evening peak periods within the study area. Each peak period was recorded over a two-hour duration 7:00 a.m. to 9:00 a.m., 12:00 p.m. to 2:00 p.m., and 4:00 p.m. to 6:00 p.m. Secondary data comprised traffic reports, topographic and thematic road maps, published literature, and internet-sourced information. The sets of data used for this study is presented in Table 1

Table 1: Datasets used for the Study

SN	Type of Data	Temporal Resolution	Spatial Resolution	Date Available	Source(s)
1.	UAV Images	Three times per day	Very High	2021	
2.	GeoEYE	16-day	0.35 m	2022	Digital Imagine
4.	GPS Point Data	Instantaneous	3 m	2023	Garmin GPS Pro

(Source: Researcher, 2023)

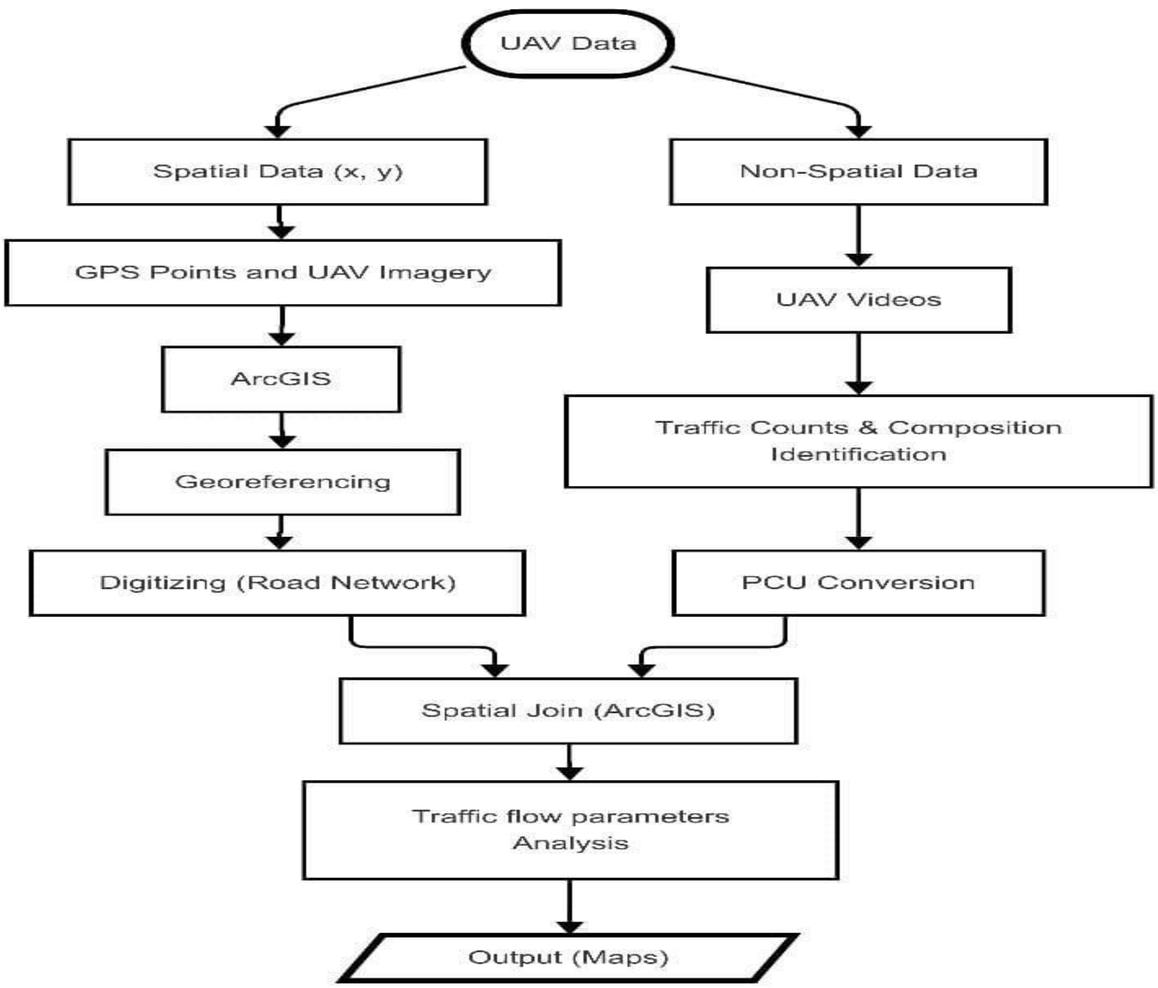

Figure 1: Methodological Flow Chart

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DATA PROCESSING AND ANALYSIS

The videography data from the memory card of the UAV was played on a laptop computer and vehicle types were identified (cars, tricycles, buses, trucks and bicycles), their composition and Gap acceptance. The classification of the vehicles and conversion to a common standard format was performed using the Microsoft Excel before being carried forward for GIS Operations in ArcGIS 10.8 Environment to achieve geospatial mapping. The ArcGIS 10.8 was used to digitize the study area's road network using Geo Eye High-Resolution satellite image with 0.35m spatial resolution and the traffic flow parameter were analyze using geoprocessing and Spatial Analyst tools.

Plate 1 Traffic situation in the study area at afternoon

Source: UAV 2021

RESULTS AND DISCUSSION

TRAFFIC FLOW

The analysis of average traffic flow across the study area reveals significant spatial and temporal variations in traffic dynamics (Figure 3). Among the observed locations, Mogaram Road recorded the highest average traffic flow during the morning peak 2249 vehicles (Figure 3a), indicating that it serves as a major entry corridor into the central Market and accommodating commuters heading towards workplaces and schools (Huang *et al.*, 2021; Zhou *et al.*, 2022). While Ahmadu Bello Way (ABW) eastbound recorded the lowest morning traffic flow 1715 vehicles (Figure 3a), demonstrating that this corridor is not a primary route during early hours. This is as a result of its function as a feeder road to the Maiduguri Central Market which remains closed during the early morning period (Omole *et al*., 2013).

In the afternoon, the highest traffic was observed along the Shehu Sanda Kura (SSK) corridor 2136 vehicles (Figure 3b), attributed to market-related activities occurring during midday hours (Mulíček & Osman, 2018; Ayo-Odifiri, 2023). Conversely, Ahmadu Bello Way (ABW) westbound had the lowest afternoon traffic 1866 vehicles (Figure 3b), this reflecting reduced of mid-day traffic generators along that corridor.

During the evening peak, Ahmadu Bello Way Westbound experienced the highest traffic flow 2190 vehicles (Figure 3c), highlighting its significance as a major outbound for commuters leaving the central Market and nearby institutions. While Ahmadu Bello Way eastbound again showed relatively low traffic 1836 (Figure 3c), corroborating the observation that this corridor remains consistently less trafficked throughout the day.

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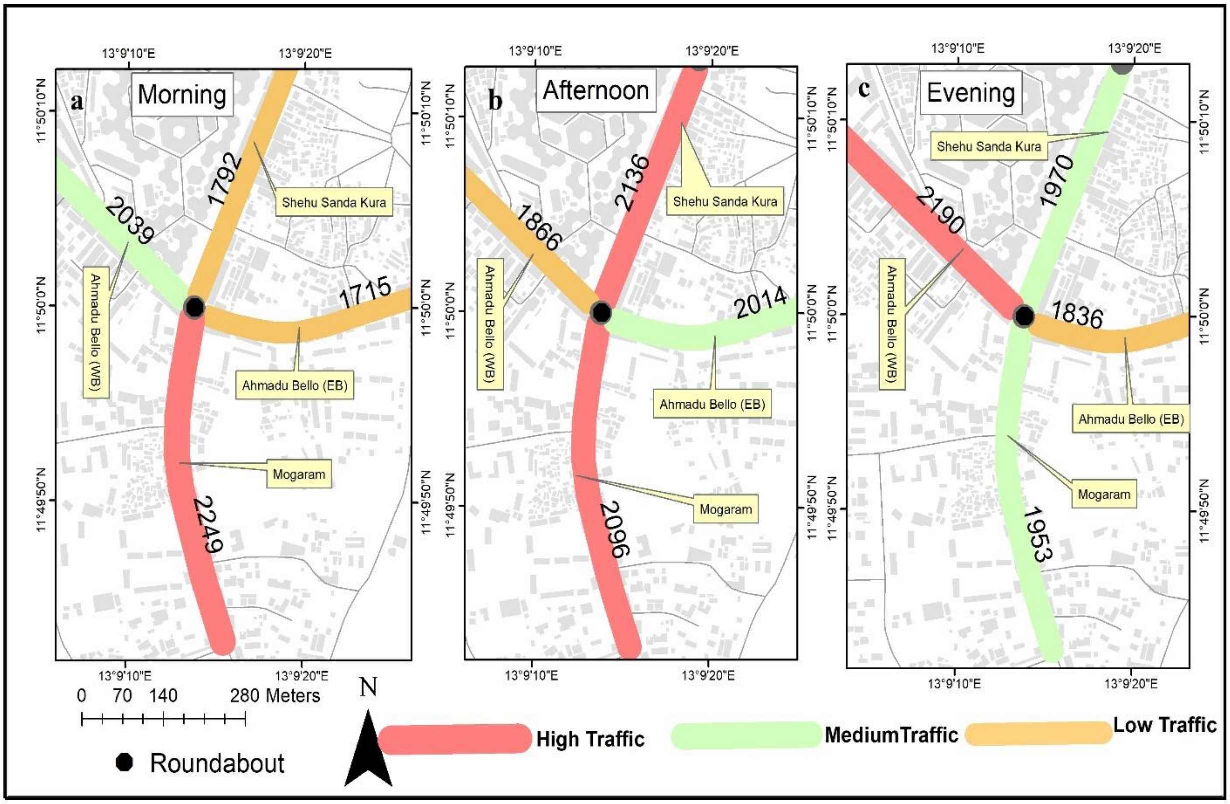

Figure 3: Traffic Flow Map: (a) Morning (b) Afternoon (c) Eveving

TRAFFIC COMPOSITION

The results of the average of traffic composition are depicted in Figure 4-6 and the average Proportion presented in Figure 7-10. The traffic in the area mainly consisted of Tricycles, Cars, Buses, Bicycles and Trucks This observation agreed with research findings by (Adams et al 2014; Bukar & Kundiri, 2025).

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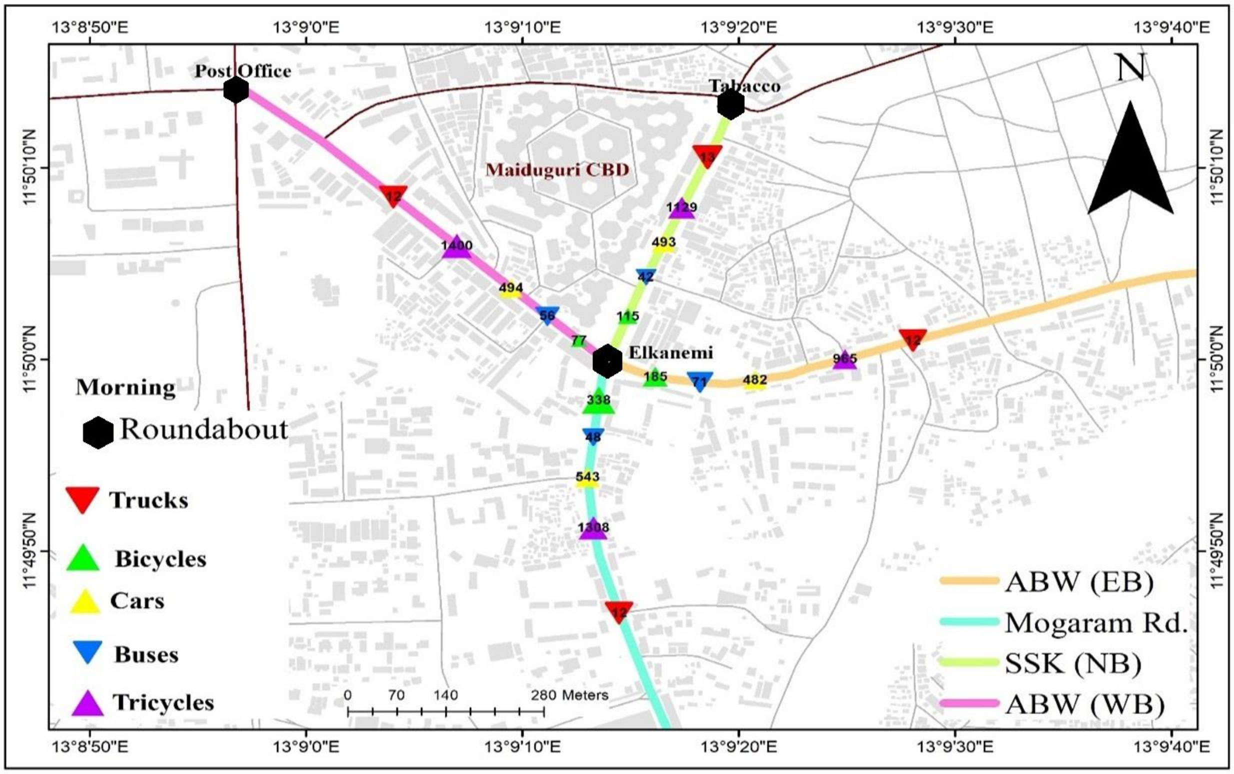

Figure 4: Traffic compositions at Elkanemi intersection during morning peak hour

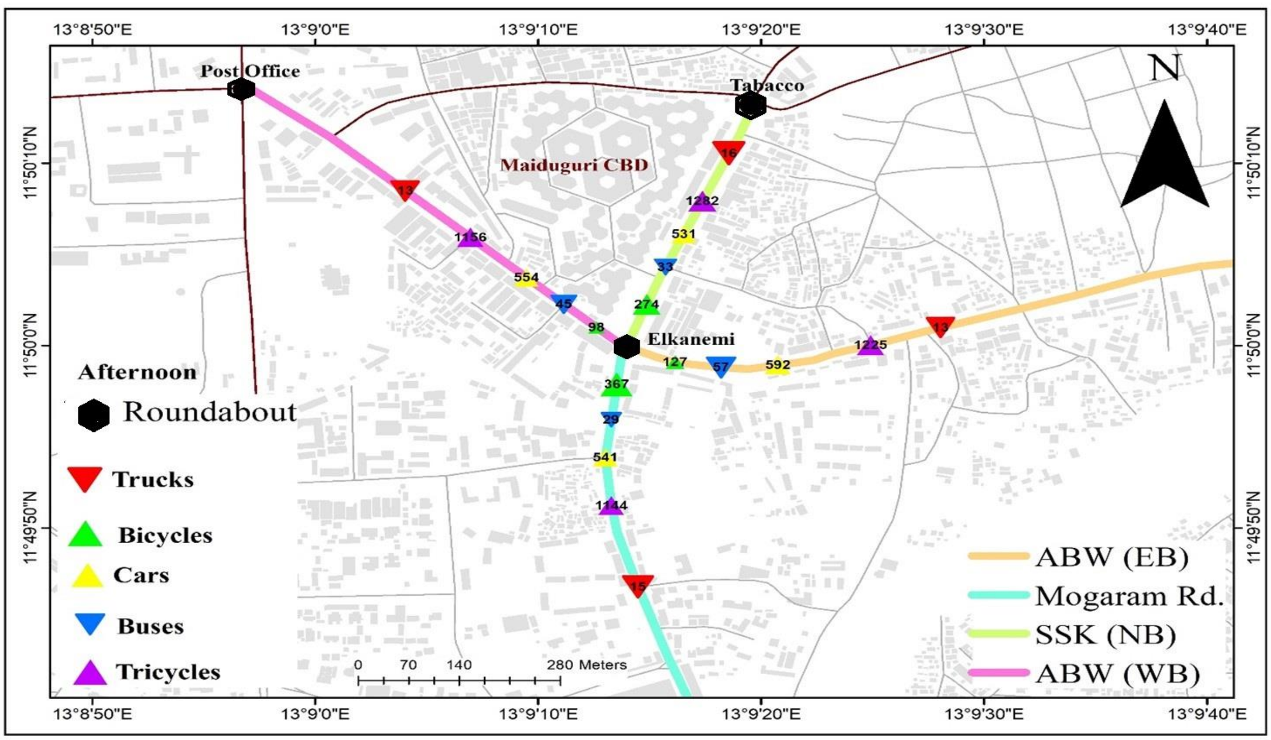

Figure 5: Traffic compositions at Elkanemi intersection during afternoon peak hour

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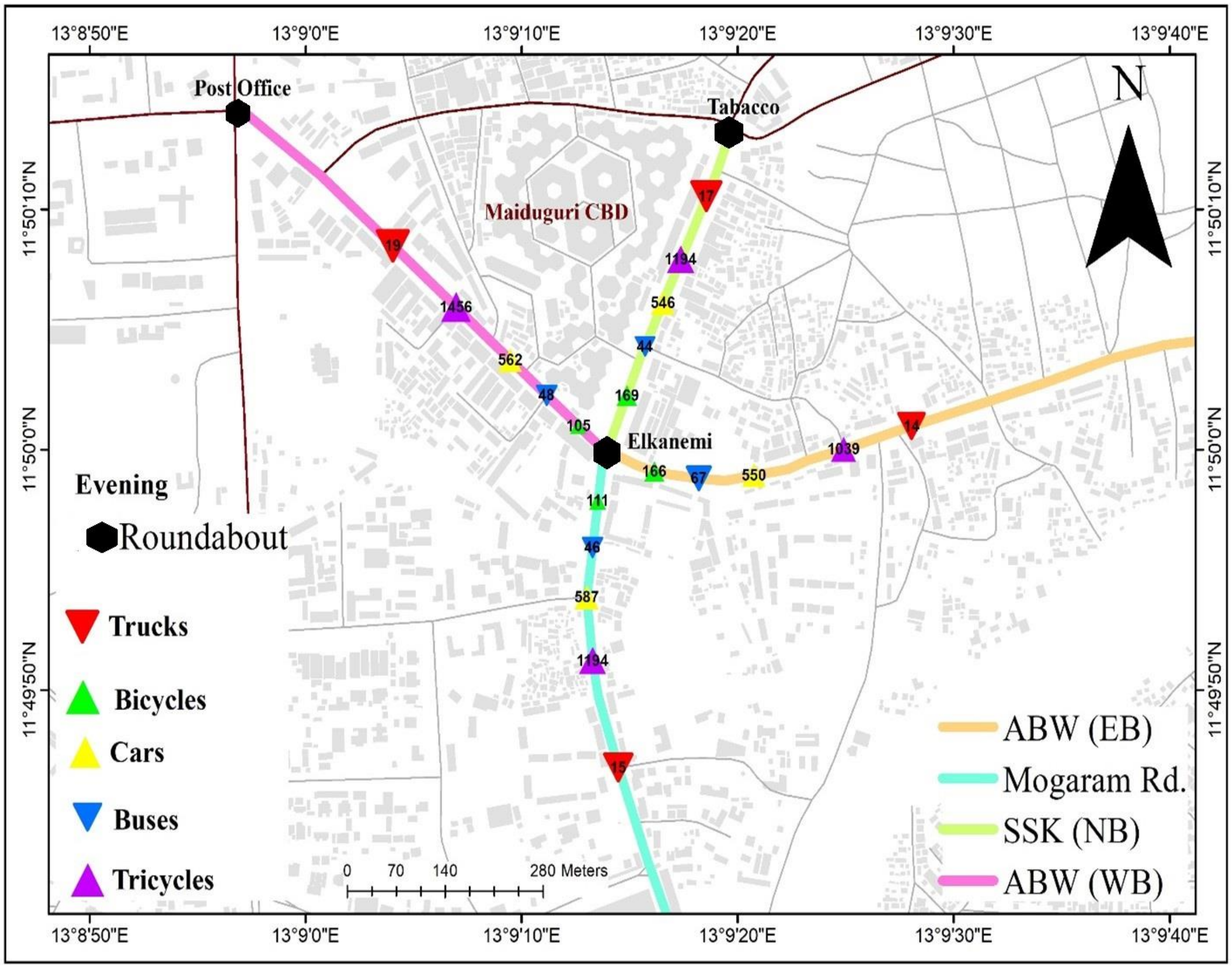

Figure 6: Traffic compositions at Elkanemi intersection during evening peak hour

The analysis of traffic composition across the four selected corridors of the intersection reveals a clear dominance of tricycles across all time periods. Tricycles accounted for more than 55% of the total traffic and peaking at 69% (1400 tricycles) along ABW West Bound in the morning (Figures 4 and 8). This pattern reflects the increasing reliance on tricycle due to limited transportation options and comfort and flexibility, especially for short-distance intra-urban movement (Toanchina, 2019; Kpacha et al., 2022). These findings are consistent with Adams et al. (2014); Jing et al. (2019) who reported that tricycles and bicycles dominate intersections.

Cars emerged as the second most common vehicle type, typically comprising 24–30% of traffic, with higher percentage observed in the evening (Figures 7,8 and 10) indicating their greater use for private, home-bound commuting. These findings are consistent with previous studies that highlight the growing reliance on personal automobiles for urban commuting (Xiao et al. 2022; Gao & Zhu, 2022; Saeidizand & Boussauw, 2023; Lv et al., 2020). Notably, bicycle use was relatively low but showed a temporary surge in the afternoon especially on Shehu Sa..da Kura Road and Mogaram Road, reaching up to 18% (Figure 10). This increase corresponds with school closures where bicycles are a common mode of transport for students and pupils returning home. This pattern supports findings by Mokitimi & Vanderschuren, (2017); Risimati et al., (2021); Okoro & Lawani, (2022) who emphasized the functional importance of non-motorized transport in African cities where modal diversity and infrastructure limitations force co-use of roads by multiple transport types.

Buses and trucks were minimally represented, generally contributing less than 5%(Figures 7-10) of the total traffic volume. These patterns support the findings of Joubert (2010) Dawda, (2024); Bukar and Kundiri (2025).

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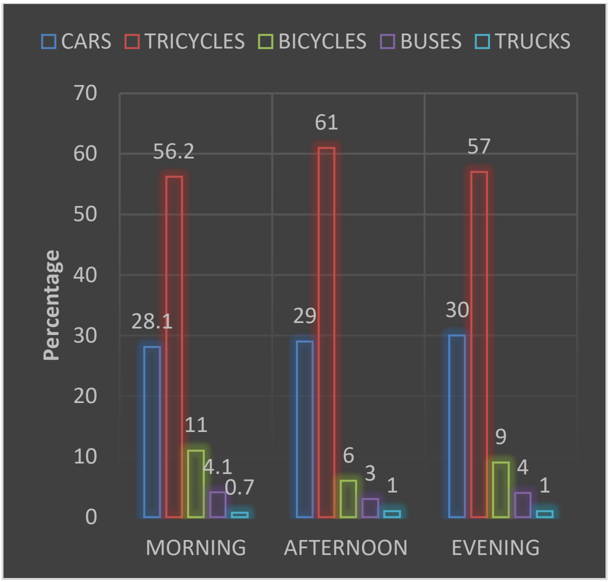

Figure 7:Traffic Composition along ABW EB

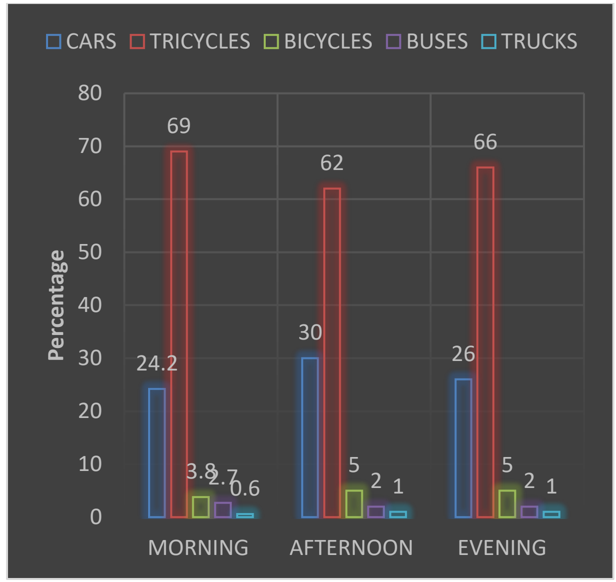

Figure 8; Traffic Composition along ABW WB

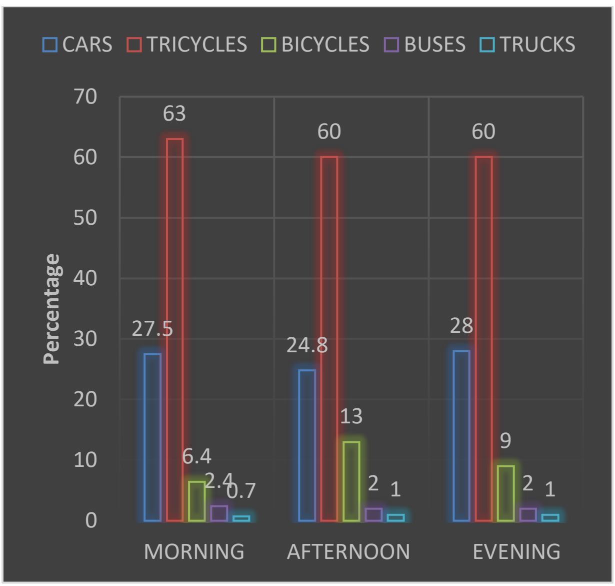

Figure 9: Traffic Composition along SSK

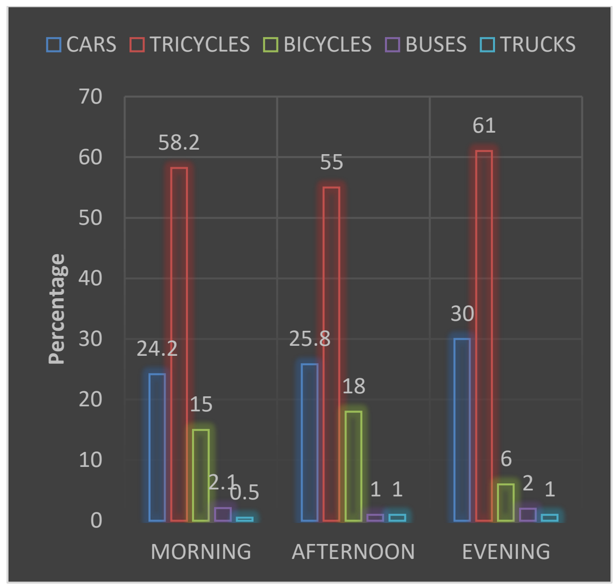

Figure 10: Traffic Composition along Mogaram Road

GAP ACCEPTANCE

Gaps are measured in time (Seconds). However, due to heterogeneous and indiscipline driver behavior, there exist a wide variation of accepted gaps (Pal & Chunchu, 2019; Mohan & Chandra, 2021; Bhatt, & Shah, 2022; Li et al., 2024). Figure 11, present the gap acceptance values across different vehicle types and road corridors at the El-Kanemi Intersection during morning, afternoon, and evening peak hours. Gap acceptance reflects the time, and space a driver is willing to wait, with higher values often indicating low-moving traffic behavior (Vinchurkar et al., 2020; Das et al., 2020; Deepthi & Ramesh, 2021).

Trucks consistently yield the highest gap acceptance across all roads during morning hour (Figure 11a), with 10.20 seconds on Ahmadu Bello Way (Eastbound) and 8.42 seconds on the Westbound, showing their need for larger merging space due to their size and slower acceleration (Sarvi & Kuwahara, 2008; Bhatt, & Shah, 2022). Bicycles and buses also show relatively higher gap acceptance on Mogaram Road at 7.21 seconds (Figure 11a) indicating a cautious

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approach. While tricycles exhibit the lowest gap acceptance values indicating they often engage in more aggressive merging maneuvers. (Doddapaneni et al., 2018; Schleinitz et al., 2020; Vinchurkar et al., 2020). In the afternoon, a slight decline in gap acceptance is observed across most vehicle types, particularly among tricycles on Ahmadu Bello Way Westbound, where the value drops to just 1.25 seconds (Figure 11b). This trend indicates a higher level of risk-taking, possibly due to midday time pressure. Despite this, trucks maintain relatively high gap acceptance value of 10.17 seconds on Mogaram Road (Figure 11b). During the evening hours, gap acceptance tends to rise again, especially for trucks, which reach their peak at 13.17 seconds on Mogaram Road, the highest recorded across all periods (Figure 11c). While tricycles and cars remain fairly stable.

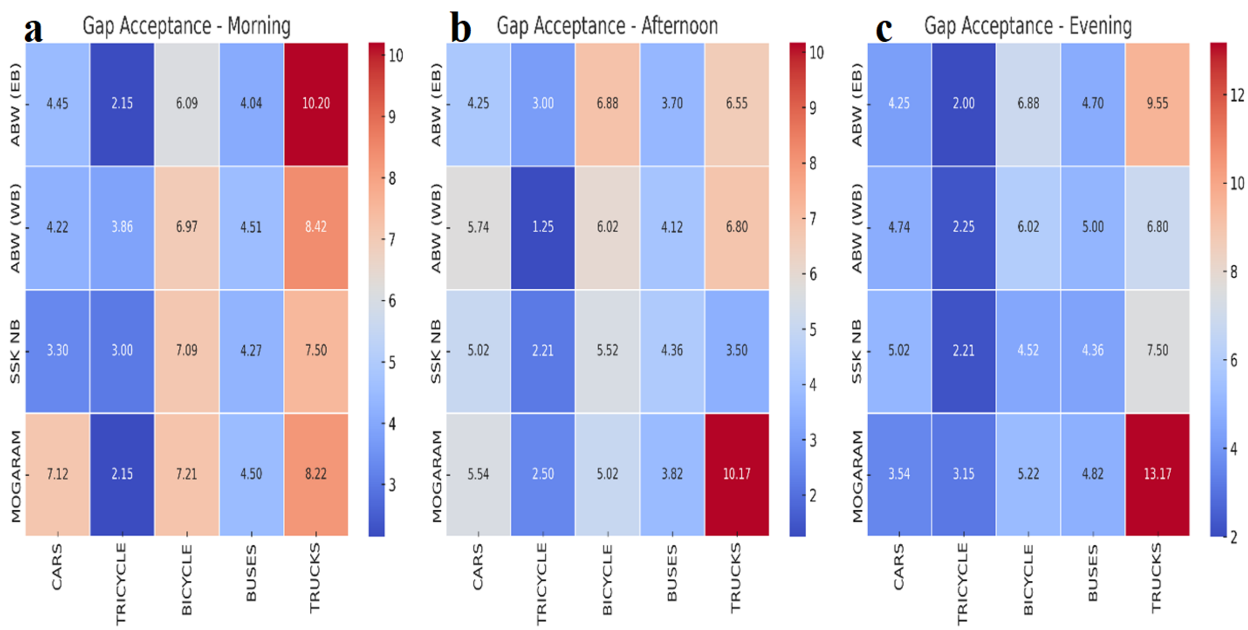

Figure 11: Gap Acceptance at Elkanemi intersection: (a)Morning (b)Afternoon (c)Evening

CONCLUSION

The study revealed a significant spatiotemporal variation in traffic dynamics at Elkanemi Intersection, Maiduguri, with Mogaram Road recording the highest morning flow due to commuter and market-bound traffic while Shehu Sanda Kura Road and Ahmadu Bello Way Westbound experienced peak volumes in the afternoon and evening, respectively. Tricycles dominated traffic composition across all corridors and periods showing their importance in short-distance urban mobility amid limited public transport options. Private cars constituted the second most prevalent mode, particularly during evening hours, consistent with home-bound commuting trends., while bicycle usage, though generally limited, exhibited a marked increase in the afternoon which attributable to student movement during school closure periods. However, buses and trucks were marginal contributors across all corridors, reflecting limited formal transit and freight activities in the area. Gap acceptance behavior further revealed modal differences, with trucks exhibiting the highest accepted gaps due to operational constraints, and tricycles the lowest which indicates an increased in risk-taking during congested hours. These findings align with previous researches in urban centers of developing nations and substantiate the necessity for integrated transport planning that accounts for modal heterogeneity, time-based demand fluctuations, and the operational characteristics of dominant vehicle types to modernize the mobility.

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