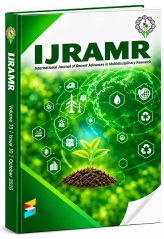
ISSN : 2350-0743

International Journal of Recent Advances in Multidisciplinary Research

Vol. 13, Issue 10, pp.12945-12953, October, 2026
https://doi.org/10.64485/ijramr.6750.10.2026



REVIEW ARTICLE

ASSESSING CLIMATE EFFECTS ON ROAD TRANSPORTATION IN WARRI AND ABRAKA, DELTA STATE, NIGERIA

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ARTICLE INFO

Article History:
Received 18th July, 2026
Received in revised form
25th August, 2026
Accepted 24th September, 2026
Published online 30th October, 2026

Keywords:

Climate Variability, Road Transport, Flooding, Pavement Performance, Delta State.

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ABSTRACT

The study examined the effect of rainfall, temperature, humidity and wind on road transportation in Warri and Abraka, Delta State, from January to December, 2024. The study also tested the hypothesis that climatic variation influences road decline. The study adopted a longitudinal quantitative design which combined monthly Nigerian Meteorological Agency records with field surveys of 85 km of arterial, secondary and feeder highways. Field teams recorded monthly logs on surface condition, pothole density, delay, flood duration, cost and accidents. The results showed at $P<0.05$ a strong relationship between precipitation and several variables (pothole density, traffic delay, repair cost, and accidents). The Road Surface Condition Index dropped from 85 to 60 in Warri and 90 to 68 in Abraka during the wet seasons, while the number of days of flood increased to 7 in Warri and 4 in Abraka. Climatic factors together accounted for 98.5% of variance in the maintenance cost ($F = 113.6$, $p < 0.001$). The results establish moisture, influenced by rainfall, as the main driver and provide a verified basis for climate-adapted design for Delta State agencies. Suggested measures included redesigning drainage to accommodate storm magnitude, using moisture-resistant surfacing and planning maintenance according to rainfall.

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Citation: Odigwe Moses, Ojoh Collins Oghenekome, Boyitie Paul Odiyirin and Arisabor Lucky, 2026. "Assessing Climate Effects on Road Transportation in Warri and Abraka, Delta State, Nigeria*" International Journal of Recent Advances in Multidisciplinary Research, 13,(10), 12945-12953.***

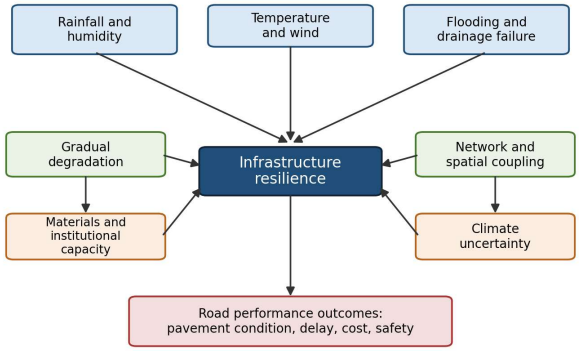
INTRODUCTION

The wet season rots the road infrastructure in southern Nigeria. The review evidence globally indicates that for each 1% increase in mean temperature, there is a 2% increase in pavement rutting, and the service life of some road sections is halved by extended moisture from precipitation (Sias *et al*., 2025). Indeed, the most exposed corridors are coastal and low-lying, where water tables are close to the surface and drainage is slow (Islam *et al*., 2021). This pressure from agriculture, water supply and public health has received national attention with few climate-specific studies of transport infrastructure (Beitelmal *et al*., 2024). Geotechnical evaluations attribute most highway collapses in the region to weak subgrades, poor drainage, and rainfall intensity acting together (Eze *et al*., 2024). Flooding is an annual occurrence throughout the routes of the Niger Delta resulting in road closures for days at a time, increased maintenance costs, and travel risk (Praharaj *et al*., 2021). A clear knowledge gap remains at the local scale. Ojeh and Ojoh (2011) attributed roughly 93% fluctuation in transit pricing in Warri to rainfall, temperature and humidity but did not go into the pavement condition, flood length and restoration cost.

There is no dataset equivalent to the Abraka or the Warri to Abraka corridor; therefore, agencies plan maintenance without the seasonal evidence. The link between weather-related delay and accident has been thoroughly demonstrated elsewhere (Su *et al*., 2023; Sadeghi & Goli, 2024) but has received limited field measurement in Delta State. The gap undermines the rationale for drainage investment and for climate-indexed budgets in the two municipalities. This study closes part of the gap by tracking climate and road performance together across a full annual cycle. Two objectives guide the work. One aim examines how rainfall, temperature, humidity, and wind relate to road surface condition and pothole density along the Warri to Abraka corridor. The other assesses how the same climatic factors influence traffic delay, flood incidence, maintenance cost, and accident frequency across the two towns. From these aims, the study tests one null hypothesis, namely, no statistically significant relationship links climatic factors to road transportation performance in Warri and Abraka. The scope comprises 12 consecutive months from January to December 2025 and three road classes and 85 km of sampled carriageway in the two settlements.

The one-year window catches the full dry-wet cycle, thus the entire spectrum is considered in the analysis, rather than a single season. Warri is the centre of a dense commercial and industrial economy with significant vehicle loads, whereas Abraka is the centre of an educated and rural population with lighter traffic. The corridor connects these two. This contrast supports a comparison of climatic stress under different traffic and drainage conditions. The resulting evidence gives planners a measured basis for drainage design, material choice, and maintenance timing, and strengthens transport management under a shifting climate in Delta State.

Conceptual Framework: This study has its foundation on infrastructure resiliency. It is related to the capacity of a road network to endure climatic stress, to absorb its effect, to restore functionality, and to adjust its design over time (Sias *et al*., 2025). Resilience applies to Warri and Abraka to two tenets. The physical durability of the pavement and the continuance of the transit service in wet months. The conceptual structure employed here is clearly demonstrated in Figure 1.



Source: Authors Designed (2025).

Figure 1. Conceptual framework of climate stress and road infrastructure resilience

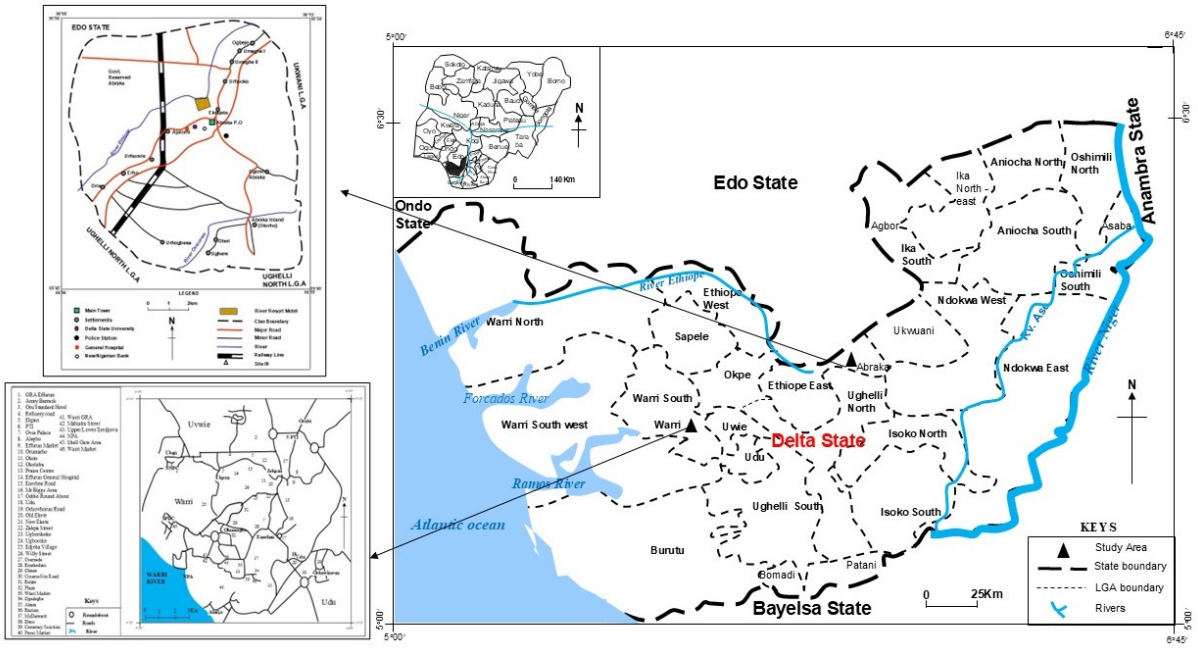
The framework evolved from an engineering practice to provide safety margins against historical peaks of load, rainfall and temperature (Sharma *et al*., 2021). Now these variables are being pushed outside their assumed constraints by climate variability. Resilience therefore needs to take into account the speed and depth of failure (not only survival) (Sias *et al*., 2025). Early resilience models have defined roadways as intact or failed. In reality, pavements deteriorate by cracking, subsidence and obstructed drainage (Eze *et al*., 2024). The idea rests on a number of assumptions. Resilience assumes that there are quantitative performance indicators, a defined baseline state, and a provable relationship between climate inputs and road outputs. The framework treats rainfall, temperature, humidity, and wind as stressors and treats surface condition, pothole density, delay, flood duration, maintenance cost, and accident frequency as response dimensions. These dimensions structure the empirical model tested later in the study.

Three processes shape resilience in the deltaic setting. Moisture-induced subgrade deterioration leads to gradual degradation, and repetitive loading increases surface flaws (Ajorlou *et al*., 2024). Spatial coupling between a road and its catchment means that even a well-drained section will flood if the inflow of runoff from upstream is faster than the outflow via the culverts (Praharaj *et al*., 2021). Network effects extend local failure outwards, with travel time on related roads increasing with delay and shutdown on an arterial route (Martín *et al*., 2021). Due to their varied reactions to water and heat, materials including asphalt, concrete, and composites make it difficult to prescribe a single treatment (Sias *et al*., 2025). Physical strength gives little protection when budget cycles, approval delays, and weak enforcement slow repair (Beitelmal *et al*., 2024). Resilience in turn goes beyond material design to governance, financing schedules, and maintenance regimens. Climate risk adds a further dimension, as future rainfall and flood patterns resist a single estimate, and robust design must hold across a variety of expected futures (Sharma *et al*., 2021). Some frameworks weight rare high-impact events and understate frequent moderate stress, while others isolate segment resilience and miss network connectivity (Martín *et al*., 2021). A defensible model derives its weights from the statistical link between climatic peaks and transport outcomes, for instance, the jump in pothole density and repair cost during rainfall maxima. The present study follows this calibrated route.The concept suits the study for three reasons. Resilience frames climate and road performance as a coupled system rather than separate problems. The framework converts abstract stress into measurable indicators fit for field survey. The approach yields outputs planners use directly, drainage priorities, material choice, and maintenance timing. Its limits deserve note, since resilience metrics remain sensitive to indicator choice and to the length of the observation window, and a twelve-month record cannot resolve multi-year trends. Positioned in this way, infrastructure resilience gives the study both theoretical grounding and practical direction for the Warri to Abraka corridor.

MATERIALS AND METHODS

The study was conducted in Warri and Abraka areas of Delta State, Nigeria. Warri is situated at 5.517° N, 5.750° E. Abraka is situated at 5.790° N, 6.100° E. Abraka and Warri stand on low deltaic land some above sea level. Also, the surface water drains slowly, and flooding can occur with severe rains (Eze *et al*., 2024). Warri is surrounded by fresh water marshes and mangroves, whilst Abraka is surrounded by natural savanna and rainforest. It is tropical and humid environment. The wet season is between March-October and dry season between November to February. Warri and Abraka have mean annual rainfalls of 2,500 mm and 2,200 mm respectively with daytime temperatures of 30°C to 32°C. Warri has extensive commercial, port and industrial activity with significant axle loads, while Abraka is a university town with rural trade. These contrasts were suitable for the study purpose of assessing climatic stress on roads under different traffic and drainage regimes. The study region is shown in Figure 2.

This study was premised on a longitudinal quantitative design in which climate and transport variables were measured over twelve successive months from January to December 2025. The design was appropriate for the research problem because road decay occurs over time and requires repeated observation, not a single snapshot (Ajorlou *et al*., 2024). The repetition of measurement on a monthly basis permitted cause-effect inference between climatic input and road response, was consistent with the resilience framework, and addressed the two objectives directly. Unlike wet-or dry-only sampling, the full-year window included all seasons.Weather data collected included precipitation, temperature, humidity & wind speed.



Source: Authors (2025).

Figure 2. Map of Study Area

Transportation statistics were pothole density, traffic delay, flood incidence, maintenance cost, accident frequency and road surface condition. Daily climate data gathered from Warri and Abraka stations of Nigerian Meteorological Agency were aggregated into monthly means. Rainfall and temperature were indicators of physical deterioration, humidity of subgrade moisture, and wind of drainage and safety exposure. The road population of the two towns consisted of 275 mapped segments within arterial, secondary and feeder classes based on the data of the Federal Ministry of Works and Delta State Ministry of Works. Stratified random sampling was used to draw 80 segments so that the sample represented the proportion of each class, construction quality and drainage condition. Computer-aided selection lowered prejudice. It sampled a length of 50 km in Warri and 35 km in Abraka with intervals of 500 m to 1 km. The sampling framework is presented in Table 1.

Table 1. Road network population and sampling framework for Warri and Abraka

City	Road Class	Population (segments)	Sample Size	Total Length (km)
Warri	Arterial	30	10	20
Warri	Secondary	60	20	20
Warri	Feeder	80	20	10
Abraka	Arterial	15	5	10
Abraka	Secondary	30	10	15
Abraka	Feeder	60	15	10
Total		275	80	85

Source: Federal Ministry of Works and Delta State Ministry of Works (2025).

Field measurement followed fixed protocols. The Road Surface Condition Index derived from International Roughness Index values read with portable profilometers at 500 m intervals, scored from 0 for failure to 100 for excellent. Field teams counted potholes per kilometre after rain and geo-referenced each with GPS. Flood depth and road-closure duration were logged from June to September with graduated rods and observation sheets.

Test vehicles timed travel between fixed points with digital stopwatches, and delay per kilometreequalled wet-season travel time divided by free-flow dry-day time. Monthly maintenance expenditure of the Delta State Ministry of Works for resurfacing, clearing of drainages and pothole repairs. Weather related accident counts were sourced from the Federal Road Safety Corps. All records entered a relational database for quality control, storage, and processing. Analysis moved from description to inference. Descriptive statistics summarised the climate and road variables. Pearson correlation measured the strength and direction of each climate-transport link, and multiple linear regression tested the joint effect of the four climatic factors on road performance, with maintenance cost as the integrating outcome. Significance held at the 5% level, and SPSS version 27 performed the computation. Correlation and regression suited interval data, small monthly samples, and the study hypothesis, and drew on the resilience model, which treats climate as the driver of graded road decline (Sias *et al.*, 2025).Reliability and validity received explicit attention. Repeated monthly measurement and cross-checking across NiMet records, field logs, and ministry accounts raised reliability, while agreement among these independent sources supported validity. On ethics, the study used institutional records with permission, disturbed no residents, and reported aggregate figures without personal data, so no individual faced risk from the fieldwork.

RESULTS AND FINDINGS

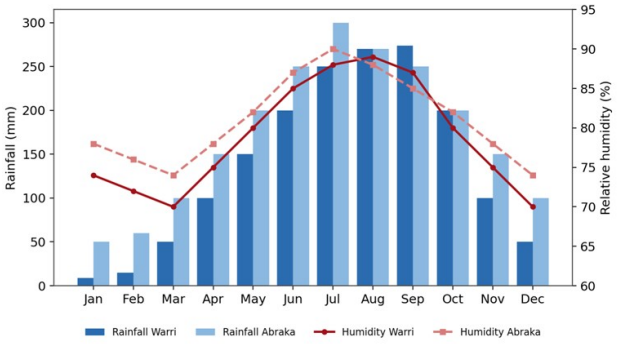
Table 2 shows the monthly weather characteristics of the two municipalities. The maximum temperature ranged from 30.0°C to 32.5°C and the minimum temperature from 23.0°C to 25.5°C in Warri and Abraka. While rainfall rose from 9 mm in January to about 274 mm in September. Succinctly, Abraka recorded the highest rainfall in July, almost 300 mm. Humidity > 85% in June-September. In the same wet months wind speed increased.

Table 2. Monthly temperature, rainfall, wind speed, and humidity for Warri and Abraka

Month	Temp Warri (Max/Min °C)	Temp Abraka (Max/Min °C)	Rain Warri (mm)	Rain Abraka (mm)	Wind Warri (km/h)	Wind Abraka (km/h)	RH Warri (%)	RH Abraka (%)
Jan	31.5/24.5	31.0/24.0	9	50	5.1	6.8	74	78
Feb	32.0/25.0	31.5/24.5	15	60	5.3	6.9	72	76
Mar	32.5/25.5	32.0/25.0	50	100	5.3	7.1	70	74
Apr	32.0/25.0	32.5/25.5	100	150	5.0	7.1	75	78
May	31.5/24.5	32.0/25.0	150	200	4.8	6.8	80	82
Jun	31.0/24.0	31.5/24.5	200	250	5.4	7.6	85	87
Jul	30.5/23.5	31.0/24.0	250	300	6.4	8.8	88	90
Aug	30.0/23.0	30.5/23.5	270	270	6.8	9.1	89	88
Sep	30.5/23.5	31.0/24.0	274	250	6.0	7.9	87	85
Oct	31.0/24.0	31.5/24.5	200	200	4.9	6.3	80	82
Nov	31.5/24.5	32.0/25.0	100	150	4.1	5.3	75	78
Dec	32.0/25.0	32.5/25.5	50	100	4.4	5.9	70	74

Source: Nigerian Meteorological Agency (NiMet) stations, Warri and Abraka. Note. Values are monthly means.

This is in line with regional findings of constant rainfall and humidity as contributors to pavement deterioration (Eze *et al*., 2024), confirming prolonged moisture loading over heat as the dominant stressor on local roadways. The high humidity during the rainy season is a sign of long-term saturation of the subgrade, which causes deterioration of the road layers and creates the conditions for the mentioned surface failures in the attached tables (Sias *et al*., 2025).



Source: NiMet (2025)

Figure 3. Seasonal rainfall (bars) and relative humidity (lines) in Warri and Abraka

Figure 3 confirms the seasonal connection of rainfall and humidity in both towns. The paired rise suggests prolonged moisture loading, rather than short storm bursts, the exposure pattern earlier review studies have linked to progressive pavement deterioration in humid corridors (Sias *et al*., 2025). Table 3 presents the Road Surface Condition Index over the year. Warri dropped from 85 in January to 60 in August, while Abraka went down from 90 to 68 in the same period, after both cities recovered as rain reduced in September. The simultaneous drop with the rainfall peak indicates that moisture, not traffic, is the main agent of degradation, as two towns with differing traffic loads dropped together. Warri held the lower index throughout, which points to heavier axle loading and weaker drainage as compounding factors. Abraka retained higher scores, a sign of firmer subgrade and lighter use. Not a sudden decline but a graduated fall fits the resilience concept of a progressive degradation and is consistent with studies that moisture intrusion lowers load bearing capability for months (Sias *et al*., 2025). Flooded flexible pavement sensitivity investigation records the same stiffness loss after subgrade moisture increase that corroborates the wet-season dip (Ajorlou *et al*., 2024). The result supports scheduling resurfacing ahead of the wet peak in both towns.

Table 4 shows the number of potholes per km: Warri has also risen from 2.1 in January to 6.5 in August (down from October), and Abraka is up from 1.5 to 4.2 (down from October). The graph shows the distribution of rainfall responsible for the mechanism of surface disintegration via infiltration and drainage failure. The largest number was in Warri every month, and this pattern represented the concentrated runoff and higher traffic on the previously wet layers. Again, it's the gradual monthly increases, not rapid surge, that indicate steady deterioration, not instant failure. These results align with geotechnical data of high rainfall on weak subgrades that accelerates pothole formation in humid Nigerian corridors (Eze *et al*., 2024). Data from global reviews reveal a noticeable increase in surface rutting and cracking when moisture from precipitation shortens the pavement service life, a process comparable with the density rise reported here (Sias *et al*., 2025).

Table 3: Road Surface Condition Index (RSI) in Warri and Abraka

Month	Warri RSI	Abraka RSI
Jan	85	90
Feb	84	89
Mar	82	88
Apr	80	85
May	75	80
Jun	70	78
Jul	65	70
Aug	60	68
Sep	65	70
Oct	70	75
Nov	78	80
Dec	82	85

Source: Field measurement (2025).
Note: RSI scaled from 0 (failure) to 100 (excellent).

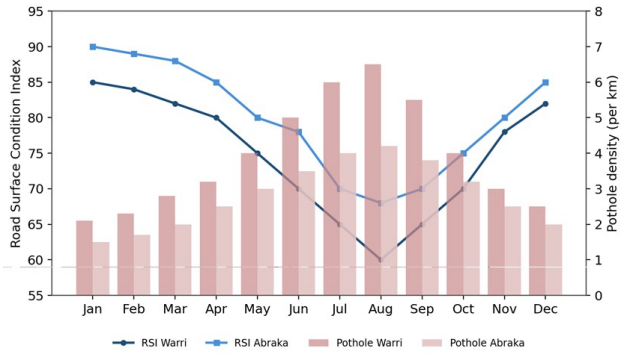
Table 4. Pothole density (number per km) in Warri and Abraka

Month	Warri	Abraka
Jan	2.1	1.5
Feb	2.3	1.7
Mar	2.8	2.0
Apr	3.2	2.5
May	4.0	3.0
Jun	5.0	3.5
Jul	6.0	4.0
Aug	6.5	4.2
Sep	5.5	3.8
Oct	4.0	3.2
Nov	3.0	2.5
Dec	2.5	2.0

Source: Field measurement (2025); Note: Counts recorded after rainfall events

The kind of pothole growth enhances vehicle operating expense and crash risk; therefore, our data supports the argument for rainfall-indexed repair before flaws escalate to structural damage.

Figure 4 sets surface condition against pothole density and exposes an inverse mirror. As the Road Surface Condition Index dips toward its August trough, the pothole bars climb to their yearly high in both towns. The two series move in near-perfect opposition, which marks moisture-driven breakup as the shared mechanism behind falling quality and rising defects. Warri holds the weaker surface and the denser potholes throughout, a gap consistent with heavier loading over saturated subgrades reported for weak Nigerian soils (Eze *et al*., 2024).



Source: Field measurement (2025).

Figure 4. Road Surface Condition Index (lines) and pothole density (bars) in Warri and Abraka

Table 5 presents the traffic delay index (minutes/km). Warri delay increased from 1.2 in January to 3.2 in August and Abraka from 0.9 to 2.1 but both declined after September. The rise is linked to rainfall and the increase of potholes, showing how surface breakdown and standing water hinder movement. Warri exhibited a larger delay for each month, corresponding with heavier flows encountering a more degraded surface. Because of the concentration of delay on arterial links, local failure propagated through the network and increased journey length on connected roadways. Such propagation is in line with the network feature of the resilience concept and corresponds with broader findings that wet-weather conditions increase incident-related delay (Su *et al*., 2023). Comparative network study reveals that delay on a damaged arterial propagates to related roads and reduces whole-corridor accessibility, supporting the concentration pattern described here (Martín *et al*., 2021). The research links physical decay with lost time and fuel and supports weather responsive traffic management and drainage clearance during the wet months to safeguard corridor throughput.

Table 5. Traffic delay index (minutes per km) in Warri and Abraka

Month	Warri	Abraka
Jan	1.2	0.9
Feb	1.3	1.0
Mar	1.5	1.2
Apr	1.8	1.3
May	2.0	1.5
Jun	2.5	1.8
Jul	3.0	2.0
Aug	3.2	2.1
Sep	2.8	1.9
Oct	2.2	1.7
Nov	1.5	1.3
Dec	1.3	1.1

Source: Field measurement (2025). Note: Delay per km = wet-season travel time / free-flow dry-day time.

Table 6 shows flood incidence in days per month. Warri reached seven flood days in August and Abraka four, with events clustered from May to September in step with rainfall and humidity peaks. The dry months of January through March recorded none. The higher exposure in Warri indicates inferior drainage capacity and limited stormwater control in a denser populated environment. Flooding is a compound stressor because it saturates pavement layers and shuts pathways, simultaneously driving structural degradation and network disturbance. Simultaneous flooding of different routes at the same time reduces redundancy and collapses connectivity, a well documented concern for deltaic road systems (Praharaj *et al*., 2021). Research on transport along the coast also shows increased exposure where low elevation and shallow water tables hinder drainage, which encourages greater flood counts found in Warri (Islam *et al*., 2021). Drainage redesign and hydrological planning would make the biggest difference in clustering signals. Pre-season culvert clearing for the May to September period is a way to reduce closure days and safer wet season traffic. Table 7.

Table 6. Flood incidence (days per month) in Warri and Abraka

Month	Warri	Abraka
Jan	0	0
Feb	0	0
Mar	0	0
Apr	1	0
May	2	1
Jun	4	2
Jul	6	3
Aug	7	4
Sep	5	3
Oct	3	2
Nov	1	1
Dec	0	0

Source: Field measurement (2025).

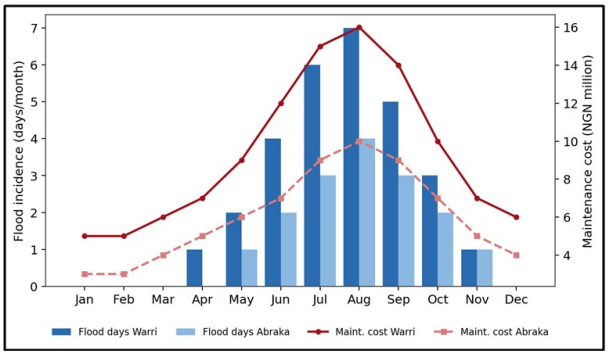
Monthly cost of road maintenance in million naira. Warri spending grew from 5 in January to 16 in August and Abraka from 3 to 10 before falling off with the drop in rainfall. The cost curve includes the physical damage seen in the previous figures, because resurfacing, drainage clearance and pothole repair all increase with moisture load. Warri's increased spend implies frequent intervention over a busier, wetter network. The threefold rise during the wet season reveals the cost of reactive repair. Agencies spend more chasing repeated damage. The pattern corroborates global findings that climatic stress increases pavement maintenance budgets and adaptive methods reduce life-cycle cost (Yao *et al*., 2024). A Nigerian case assessment shows similar climate-driven stress on transport infrastructure budgets with limited adaptation, supporting the quantified wet-season cost increase herein (Beitelmal *et al*., 2024). Proactive drainage modifications and moisture resistant surfacing would halt deterioration and minimise the rise in the wet season. Rainfall-indexed maintenance is a change from reactive to planned and presents Delta State with a quantifiable save over repeated seasons.

Table 7: Road maintenance cost (million naira per month) in Warri and Abraka

Month	Warri	Abraka
Jan	5	3
Feb	5	3
Mar	6	4
Apr	7	5
May	9	6
Jun	12	7
Jul	15	9
Aug	16	10
Sep	14	9
Oct	10	7
Nov	7	5
Dec	6	4

Source: Delta State Ministry of Works (2025). Note. Covers resurfacing, drainage clearance, and pothole repair.

Figure 5 aligns flood incidence with maintenance cost and reveals a direct wet-season link. The flood bars and spending lines rise together from May, peak in August, and recede after September in step. The overlap marks flooding as the cost driver, since saturated layers and blocked drainage force repeated repair. Warri carries both the higher flood count and the steeper cost line, matching evidence showing recurring flooding lifts roadway repair burden on low-lying networks (Praharaj *et al*., 2021).



Source: Field measurement and Delta State Ministry of Works (2025).

Figure 5. Flood incidence (bars) and road maintenance cost (lines) in Warri and Abraka

Table 8 reports weather-related road accidents per month. Warri peaked at 42 in August and Abraka at 32, with counts climbing through the wet season and falling toward December. The rise coincides with lower surface condition and higher pothole density, which links crash risk to physical decay and standing water. Reduced skid resistance, hidden defects under water, and longer stopping distances raise hazards on wet, broken surfaces. Warri's higher totals follow its heavier traffic and greater flood exposure.

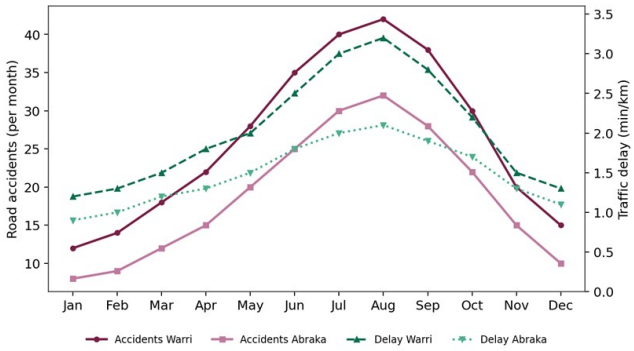
Table 8. Weather-related road accident frequency (per month) in Warri and Abraka

Month	Warri	Abraka
Jan	12	8
Feb	14	9
Mar	18	12
Apr	22	15
May	28	20
Jun	35	25
Jul	40	30
Aug	42	32
Sep	38	28
Oct	30	22
Nov	20	15
Dec	15	10

Source: Federal Road Safety Corps (2025).
Note: Weather- and road-related incidents only.

The pattern translates pavement failure into a safety cost and is consistent with research that poor surface quality and unfavourable weather jointly increase accident frequency (Sadeghi & Goli, 2024). A Nigerian time-series model of weather and road traffic accidents shows the similar wet-season rise in crash numbers (Adams, 2025) that supports the August peak seen here. The study underscores the human stake in road resiliency. Better drainage, surface repair and real-time wet season maintenance would reduce exposure, so safety advantages are a direct return on climate-adapted road management in both communities. Figure 6 relates accident frequency to traffic delay and shows the two climbing in tandem across the wet months.

Both peak in August, when broken surfaces, standing water, and reduced skid resistance raise hazard and slow flow at once. The parallel movement ties safety loss to the same moisture stress driving physical decay, an association of weather-and-surface studies report for wet, degraded roads (Sadeghi & Goli, 2024). Warri records the higher counts on both measures, in line with its heavier traffic and greater flood exposure.



Source: Field measurement and Federal Road Safety Corps (2025).

Figure 6. Road accident frequency (solid lines) and traffic delay (dashed lines) in Warri and Abraka

Table 9 provides the distribution of each variable throughout the 12 months. Rainfall had the highest range with Warri ranging from 9 mm to 274 mm, mean 139 mm and a coefficient of variation of roughly 71% demonstrating the substantial seasonality. The greatest relative variation in flood days was over 100% indicating a strong wet-season concentration. Temperature stayed stable, with variation below 3%, so heat played a minor role beside moisture. Road indicators mirrored the climate spread, as pothole density, delay, cost, and accidents each carried variation above 30%, while surface condition moved less because it recovered after the peak. Warri exceeded Abraka on every damage measure, consistent with heavier load and weaker drainage. The pronounced rainfall variance echoes hydrological evidence showing design records now understate wet-season extremes in a warming climate, which supports treating the spread as a structural stressor rather than noise (Sharma *et al*., 2021). The descriptive picture frames the correlation and regression tests reported next and shows road performance responds to a seasonal climate signal rather than random monthly variation.

Table 10 presents Pearson correlations between the four climatic factors and the six road indicators for both towns. Rainfall had the strongest and most persistent correlations: positive with density of potholes, delay, days of flood, maintenance cost and accidents; negative with surface condition, all significant at the 1% level. The similar pattern was amplified by humidity. In Warri, rainfall was linked with accidents with r = 0.985 and pothole density with r = 0.965. Abraka returned comparable values, with rainfall and pothole density at r = 0.987. Temperature correlated negatively with the damage measures, since cooler months coincided with heavier rain. Wind held moderate positive links, in line with its role during storm periods. The consistently high values suggest a strong link between moisture and road degradation (Praharaj *et al*., 2021). Adaptive-maintenance study also reveals the same dominating rainfall signal on asphalt condition, which confirms the intensity and direction of the coefficients reported here (Yao *et al*., 2024).

Table 9. Descriptive statistics of climate and road transport

Variable	Minimum	Maximum	Mean	SD	CV (%)
Rainfall, Warri (mm)	9.0	274.0	139.00	98.36	70.8
Rainfall, Abraka (mm)	50.0	300.0	173.33	84.46	48.7
Temperature, Warri (°C)	26.5	29.0	27.83	0.75	2.7
Temperature, Abraka (°C)	27.0	29.0	28.08	0.63	2.3
Humidity, Warri (%)	70.0	89.0	78.75	7.07	9.0
Humidity, Abraka (%)	74.0	90.0	81.00	5.51	6.8
Wind, Warri (km/h)	4.1	6.8	5.29	0.78	14.8
Wind, Abraka (km/h)	5.3	9.1	7.13	1.10	15.4
RSI, Warri	60.0	85.0	74.67	8.46	11.3
RSI, Abraka	68.0	90.0	79.83	7.79	9.8
Pothole/km, Warri	2.1	6.5	3.91	1.51	38.7
Pothole/km, Abraka	1.5	4.2	2.82	0.93	32.8
Delay (min/km), Warri	1.2	3.2	2.02	0.71	35.0
Delay (min/km), Abraka	0.9	2.1	1.48	0.41	27.5
Flood days, Warri	0.0	7.0	2.42	2.54	105.1
Flood days, Abraka	0.0	4.0	1.33	1.44	107.7
Maint. cost (NGN m), Warri	5.0	16.0	9.33	4.01	42.9
Maint. cost (NGN m), Abraka	3.0	10.0	6.00	2.41	40.2
Accidents, Warri	12.0	42.0	26.17	10.76	41.1
Accidents, Abraka	8.0	32.0	18.83	8.53	45.3

Source: Authors' computation (2025). Note: SD = standard deviation; CV = coefficient of variation.

Table 10. Pearson correlation between climatic factors and road transport indicators

Indicator	Temperature	Rainfall	Wind	Humidity
Warri				
RSI	0.924**	-0.985**	-0.720**	-0.953**
Pothole	-0.893**	0.965**	0.786**	0.964**
Delay	-0.891**	0.970**	0.800**	0.965**
Flood	-0.940**	0.957**	0.802**	0.973**
Maint. cost	-0.919**	0.970**	0.783**	0.969**
Accident	-0.876**	0.985**	0.725**	0.965**
Abraka				
RSI	0.574	-0.940**	-0.602*	-0.872**
Pothole	-0.530	0.987**	0.688*	0.922**
Delay	-0.556	0.979**	0.705*	0.917**
Flood	-0.733**	0.905**	0.706*	0.908**
Maint. cost	-0.595*	0.959**	0.716**	0.903**
Accident	-0.595*	0.979**	0.733**	0.938**

Source: SPSS Computation Output. Note. Pearson r, two-tailed, N = 12. * p < .05; ** p < .01.

Table 11. Regression of road maintenance cost on climatic factors, Warri Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	
1	0.992	0.985	0.976	0.619	
ANOVA					
Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	173.987	4	43.497	113.604	0
Residual	2.68	7	0.383		
Total	176.667	11			
Coefficients					
Predictor	B	Std. Error	Beta	t	Sig.
(Constant)	8.689	28.269		0.307	0.767
Rainfall	0.026	0.006	0.633	4.159	0.004
Temperature	-0.506	0.759	-0.095	-0.667	0.526
Humidity	0.068	0.128	0.12	0.531	0.612
Wind	1.094	0.367	0.214	2.981	0.02

Source: SPSS Computation Output. Note: Dependent variable: road maintenance cost, Warri. Predictors: rainfall, temperature, humidity, wind. $F(4, 7) = 113.60$, $p < .001$.

The similarity of the two opposing towns suggests that climate, driven by rainfall, is the controlling factor in the performance of roads along the corridor. Table 11 reports the regression test of the study hypothesis, with Warri maintenance cost as the outcome and the four climatic factors as predictors. The model explained 98.5% of the monthly variance in cost, with an adjusted R-square of 0.976 and a significant overall fit, $F(4, 7) = 113.60$, $p < 0.001$. Rainfall carried a significant positive coefficient, $B = 0.026$, $p = 0.004$, and wind added a further significant effect, $B = 1.094$, $p = 0.020$, while temperature and humidity showed no independent significance once rainfall entered the model. The result rejects the null hypothesis of no relationship between climatic factors and road transportation performance. Rainfall stands as the dominant driver, with wind a secondary contributor during storm months. The strong joint effect confirms climatic variation, rather than traffic alone, governs the wet-season rise in repair cost, and validates the resilience model used throughout the study (Sias *et al*., 2025). A Nigerian assessment reaches a parallel conclusion, tracing most regional highway cost to rainfall and drainage failure acting together, which corroborates the dominance of the rainfall coefficient in this model (Beitelmal *et al*., 2024).

DISCUSSION OF RESULTS

The findings indicate the significant and quantifiable relationship between climatic fluctuation and road performance in Warri and Abraka. Rainfall was the major factor, correlated >0.95 with pothole density, delay, cost and accidents in both towns, and accounting for most of the increase in maintenance expenditure during the wet-season. These results extend Ojeh and Ojoh (2011) who connected climate to transit fares in Warri, but show that the same climatic signal applies to pavement condition, flooding and safety. They also localise worldwide evidence that moisture halves pavement life and rises maintenance expenses (Sias *et al*. 2025).

The comparison across two settlements adds interpretive weight. Warri, with greater traffic and poorer drainage was more deteriorated and more expensive to maintain compared to Abraka. This is consistent with data that traffic load and drainage condition worsen climatic degradation (Eze *et al*., 2024). The synchronous decline of two towns with different traffic patterns is evidence that the common factor is moisture, not traffic stress. Flooding further enhanced the effect by saturating layers and restricting paths, in line with documented network disruption along Niger Delta corridors (Praharaj *et al*., 2021).

Both towns have roads that are not resilient with poor drainage and reactive repairs. Rainfall-indexed maintenance, moisture-resistant surfacing and drainage systems would slow degradation and minimise expense consistent with adaptive methods shown to lessen life-cycle burden elsewhere (Yao *et al*., 2024). The evidence gives Delta State agencies a measured basis for climate-adapted road planning.

CONCLUSION

This study measured how climate shapes road transportation in Warri and Abraka across a full annual cycle. Rainfall, reinforced by humidity and wind, drove lower surface condition, denser potholes, longer delay, more floods, higher cost, and more accidents, with decay sharpest between June and September. Warri suffered greater strain than Abraka under heavier traffic and weaker drainage, and climatic factors together explained 98.5 percent of maintenance-cost variance, so the study rejected the null hypothesis. The findings carry direct implications for practice. Low road resilience due to poor drainage and reactive repair characterises both towns. Moving to climate-adapted design reduces repair expense, closure days and crash exposure during successive wet seasons. The evidence presents six technical actions for the transport policy of Delta State: Link maintenance budgets to seasonal rainfall estimates and set aside repair money in advance; Require moisture-resistant surface on flood-prone roadways; Reconfigure drainage systems to reflect today's storm strength; Establish a mandatory pre-season culvert clearing program; Strengthen subgrade and impose axle-load control on main roads; Incorporate climatic data into road asset management to help inform planning and maintenance decisions. Future work should increase the length of the record beyond one year to resolve multi-year trends, test the performance of materials under controlled saturation, and develop resilience metrics for deltaic networks. The study has provided the first matched seasonal data set for the corridor and a validated approach, relating climate directly to road performance so providing planners with measured foundation for resilient transport investment in Delta State.

Declaration: This research is original and has not been submitted, published, or presented elsewhere. The authors collected and analysed all data as part of an independent study.

Funding: No funding was received for this study.

Data Availability: The datasets generated and analysed during the study are available from the corresponding author on reasonable request, subject to confidentiality restrictions. Supporting materials needed to replicate the analyses are available on request.

Acknowledgement: The authors thank the Abraka communities for their support during fieldwork, Professor Efe Sunday for guidance, and the staff of the Department of Geography, Delta State University, Abraka, for technical assistance.

Data sources: Nigerian Meteorological Agency (2025). Annual climate summary. Abuja: NiMet. Delta State Ministry of Works (2025). Road maintenance and expenditure records. Asaba: Delta State Government Press. Federal Road Safety Corps (2025). Weather- and road-related accident records, Delta State Command.

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