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Assessment of Drainage Structures and Their Impact on Traffic Flow Along an Urban Arterial Road Corridor

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Abstract
The condition of drainage infrastructure along urban arterial roads is vital to the performance of the transportation system. Poor or blocked drainage leads to flooding, pavement deterioration, and increased congestion, especially during peak hours. This study assessed the drainage system and its impact on traffic flow and road performance along the 3.3 km University of Ibadan (UI) First Gate to Nigeria Institute of Social and Economic Research (NISER) corridor in Ibadan, Nigeria. Twelve structures (two bridges and ten culverts) were inventoried and rated as Good, fair, poor, or very poor. Traffic volumes were recorded over six days during morning and afternoon peak hours, with data collected at 15-minute intervals and categorized by vehicle type. Volume-to-capacity (v/c) ratios and Level of Service (LOS) were calculated for north- and south-bound approaches. Only six drainage structures (50%) were rated good, one (8.3%) fair, and five (41.7%) poor, with issues such as blocked box culverts, cracked bridge piers, and clogged drains. The southbound lane had the highest traffic (68,682 vehicles), a v/c ratio of 1.75, and LOS E, indicating unstable flow. The study recommends immediate rehabilitation, desilting, unblocking culverts, and additional drainage to meet current demands. This action, along with road redesign and transportation improvements, is essential to restoring service on this high-traffic corridor.

Keywords: *Drainage Structures, Urban Road Corridor, Traffic Flow, Level of Service, Volume-to-Capacity Ratio.*

1.0 Introduction

Transportation infrastructure is a fundamental determinant of the economic and social well-being of all cities, towns, and communities (Nworji & Oluwalaiye, 2012; Gbadamoshi & Ibrahim, 2013; Ali et al., 2014). Among road infrastructure components, drainage systems are often the least visible yet among the most consequential. The primary function of a road drainage system is to remove surface water from the pavement, sub-base, and surrounding land to prevent road structure deterioration and ensure road user safety (McGee et al., n.d). When drainage systems fail or are poorly maintained, consequences range from localized flooding and pavement deterioration to systemic traffic congestion and accidents.

In Nigeria, the rapid urbanization in cities like Ibadan has increased pressure on existing road infrastructure, including drainage systems. Many roads were originally designed to last 10 to 15 years. By the early 1990s, most roads built during the 1970s oil boom had collapsed well below their design capacity (FERMA, 2008). (Addeh,2021) Neglect of routine maintenance has compounded the deterioration, leading to widespread drainage failures that directly compromise road performance.

The University of Ibadan (UI) First Gate to Nigeria Institute of Social and Economic Research (NISER) corridor is a 3.3 km arterial road essential for institutional and commercial traffic in Ibadan, serving Agbowo, Bodija, and Ajibode. High peak-hour traffic volumes combined with inadequate drainage worsen congestion and road deterioration. The study assessed the conditions of the drainage system and its impact on traffic flow and road performance. Objectives include inventorying drainage structures, documenting failures, analyzing traffic flow and capacity, establishing the relationship between drainage and traffic performance, and recommending repairs and design improvements.

2.0 Materials and Methods

The study area is the 3.3 km arterial road corridor from the University of Ibadan First Gate intersection to the Nigeria Institute of Social and Economic Research (NISER), located in Ibadan, Oyo State, Nigeria. The corridor is situated between latitudes 7°26'20"N and 7°24'40"N, and longitudes 3°54'10"E and 3°54'50"E. It is a dual carriageway with an asphaltic concrete surface and earth shoulders. The corridor passes through the communities of Agbowo, Bodija, and Ajibode and serves a diverse mix of institutional, residential, and commercial land uses.

The prominent drainage structures along the corridor include two bridges and ten culverts (both box and pipe types). These are located at various chainages along the route, with the major structures identified at CH. 0+200 (box culvert), CH. 5+300 (bridge), and CH. 10+500 (drainage channel). Line drains are present only in fully built-up sections of the route and are largely non-functional due to sediment and solid-waste blockages. (Ibadan Solid Waste Management Master plan,2011)

Phase 1: Evaluating the existing condition survey of transportation facilities and infrastructure of the study area

The following data were collected to evaluate the existing transportation facilities and infrastructure:

Table 1: Evaluation of the existing condition survey of transportation facilities and infrastructure of the study area

Inventory and condition survey	Geometric survey
i. Existing road facilities available. ii. The type of road. iii. The condition of the road. iv. The turning lane of the road. v. The condition of the drainage system of the road. vi. The expected speed limit at the intersection.	i. Vertical alignment of the road section ii. Horizontal alignment of the road section iii. The turning radius of intersection iv. The angle of turning

Phase 2: Evaluating the traffic flow characteristics of the study area

Traffic volume counts were manually conducted at the University of Ibadan First Gate intersection for six consecutive days (Monday to Saturday) during the morning (7:00 am to 9:00 am) and afternoon (3:00 pm to 5:00 pm) peak periods. Counts were recorded every 15 minutes, classifying vehicles as passenger cars, sport utility vehicles (SUVs), minibuses and buses, trucks, and motorcycles.

The collected data were used to compute average daily traffic (ADT), average hourly traffic (AHT), passenger car units (PCUs), and peak-hour factors (PHFs). The volume-to-capacity ratio and Level of Service were then determined using the methodology of the Highway Capacity Manual (TRB, 1985) and Rogers (2003),

A. Volume-to-Capacity Analysis

For ideal conditions, the service flow rate is given by:

For ideal conditions, the service flow rate is given by:

$$SFi = 2800 \times (v/c)\, i \,. \tag{1}$$

For non-ideal conditions:

$$SF_i = 2800\ x\ \left(\frac{v}{c}\right)_i x\ F_d\ x\ F_w\ x\ F_{HV} \tag{2}$$

Where:

SF_i = service flow

f_d = correction factor for the different directional splits on a 2-lane highway (Table 2)

f_w = adjustment factor

f_{HV} = correction factor due to PCE valuation

$$F_{HV} = \frac{1}{1 + \{P_T\ (E_T - 1) + P_B\ (E_B - 1) + P_R\ (E_R - 1)\}} \tag{3}$$

Where:

P_T = percentage of trucks in the traffic stream

P_B = percentage of buses in the traffic stream

PR = percentage of recreational vehicles in the traffic stream

The PCEs for trucks (ET), buses (EB), and recreational buses (ER) are defined by terrain type and obtained from Table 2.

Table 2: Level of service values for 2-lane highways under ideal conditions (Source: Highway Capacity Manual (TRB, 2013)

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Level of service	Average Speed	v/c ratio
A	>58	0.15
B	>55	0.27
C	>52	0.43
D	>50	0.64
E	>45	1.00
F	<45	>1.00

3.0 Results and Discussion

B. Road and Intersection Inventory

The following presents and discusses the results from the first phase of the research:

A total of 12 drainage structures were identified along the UI-NISER corridor, comprising 2 bridges and 10 culverts. The culverts include both box (rectangular) and pipe (circular) types. The geographical locations of all structures were recorded using GPS, and their positions are mapped relative to the corridor chainage. Table 3 presents the full inventory of drainage structures.

Table 3: Inventory and condition rating of drainage structures along the UI-NISER corridor

Structure No.	Type	Chainage	Dimensions	Material	Condition Rating
DS-01	Box Culvert	CH 0+200	1.5m × 1.2m (single barrel)	Reinforced Concrete	Poor
DS-02	Pipe Culvert	CH 0+450	600mm diameter	Precast Concrete	Fair
DS-03	Bridge (Single Span)	CH 0+780	12m span, 8m wide	Reinforced Concrete	Poor
DS-04	Box Culvert	CH 1+050	1.8m × 1.5m (double barrel)	Reinforced Concrete	Good
DS-05	Pipe Culvert	CH 1+300	900mm diameter	Precast Concrete	Good
DS-06	Box Culvert	CH 1+650	1.2m × 1.0m	Reinforced Concrete	Good
DS-07	Pipe Culvert	CH 2+000	600mm diameter	Corrugated Metal	Poor
DS-08	Bridge (Multi Span)	CH 2+450	22m span, 8m wide	Reinforced Concrete	Poor
DS-09	Box Culvert	CH 2+700	1.5m × 1.2m (single barrel)	Reinforced Concrete	Good
DS-10	Pipe Culvert	CH 2+950	450mm diameter	Precast Concrete	Poor
DS-11	Box Culvert	CH 3+100	1.2m × 1.0m (double barrel)	Reinforced Concrete	Good
DS-12	Line Drain	CH 3+250	0.6m wide × 0.5m deep	Masonry	Good

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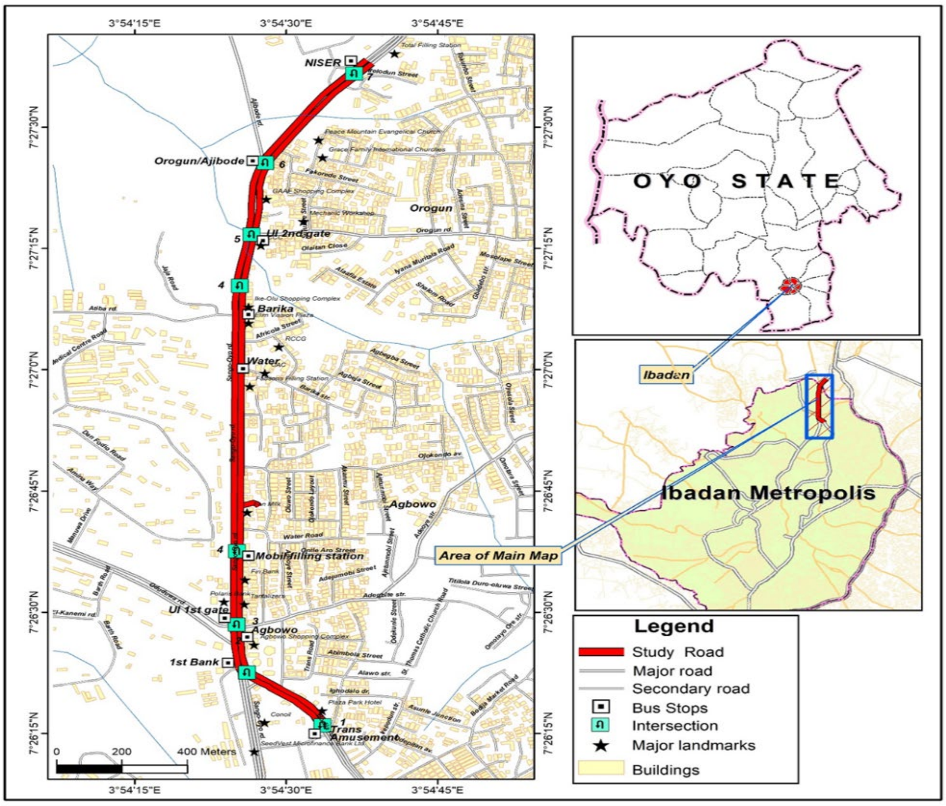

Figure 1: Map of study area showing observed intersection and Bus Stops

Condition survey of the road and bus stops

The road condition survey showed that maintenance is irregular. Widespread distress includes potholes, surface cracks, delineation, and shoving, as shown in Plate 1. Most of the bus stops were observed in deplorable condition, as shown in Plate 2.

Plate 1: Pavement distress observed on the road

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Plate 2: Bus-stop condition survey

C. Condition Survey of Drainage Structures

Six drainage structures along the route are in good condition; one is fair, and five are in poor condition. Plate 3 depicts the blocked end of the box culvert at CH. 0+200, and Plate 3, the cracked pier of the bridge at CH. 5+300. Others include blocked drainage structures at CH. 10+500. These poor conditions of the drainage structures could have contributed to the observed flooding on the route.

Plate 3: Drainage condition survey

D. Summary of Condition Ratings

Table 4: Summary of drainage structure condition ratings

Condition Rating	Number of Structures	Percentage (%)	Recommended Action
Good	**6**	**50.0**	**Routine maintenance**
Fair	**1**	**8.3**	**Preventive maintenance within 12 months**
Poor	**5**	**41.7**	**Rehabilitation within 6 months**
Very Poor	**0**	**0.0**	**Emergency intervention (None at present)**
Total	**12**	**100.0**	

E. Traffic Volume Analysis

Traffic volume counts conducted over six days revealed significantly high vehicle volumes on both the northbound (UI road approach) and southbound (Agbowo approach) arms of the intersection. The southbound approach recorded a total of 68,682 vehicles over the six-day survey period, while the northbound approach recorded a total of 39,199 vehicles. Motorcycles dominated the traffic composition on the southbound approach (35.3% of straight movements), while passenger cars dominated the northbound approach (65.4% of straight movements).

Converting vehicle counts to Passenger Car Units (PCUs) using the Passenger Car Equivalent (PCE) factors stipulated in the Federal Ministry of Transportation (2013) Highway Manual Design (Volume 1), the following Average Daily Traffic (ADT) and Average Hourly Traffic AHT values were derived.

Table 5: Summary of traffic volume analysis results

Approach	ADT (PCU/day)	AHT (PCU/hr)	Peak 15-min Volume (PCU)	PHF
Northbound (Straight)	6,095	1,524	718	0.96
Northbound (Right Turn)	22	6	-	-
Southbound (Straight)	8,711	2,178	1,209	0.95

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Southbound (Left Turn)	2,024	506	-	-

G. Volume-to-Capacity Ratio and Level of Service

Northbound Approach

The peak hour service flow for the northbound approach was computed as SFi = 718 × 4 = 2,872 PCU/hr. The heavy vehicle correction factor, accounting for 0.17% trucks and 1.4% buses in the traffic stream, was calculated as FHV = 0.99. With a directional split of 50/50 (Fd = 1.0) and standard lane width (Fw = 1.0), the v/c ratio was:

$(v/c)\ N = 2872 / (2800 \times 1.0 \times 1.0 \times 0.99) = 1.0$

This corresponds to Level of Service E, indicating that the highway is operating at its practical capacity limit.

Southbound Approach

The peak hour service flow for the southbound approach was SFi = 1,209 × 4 = 4,836 PCU/hr. With 0.34% trucks and 0.83% buses (FHV = 0.99), and Fd = 1.0, Fw = 1.0, the v/c ratio was:

$(v/c)\ S = 4836 / (2800 \times 1.0 \times 1.0 \times 0.99) = 1.75$

A v/c ratio of 1.75 is well above the capacity threshold of 1.0 and indicates severe over-capacity operation on the southbound approach. This is consistent with frequent traffic breakdowns and extensive queuing along the southbound corridor.

Intersection

The average v/c ratio for the intersection, computed as the mean of northbound and southbound v/c ratios, is (1.0 + 1.75)/2 = 1.4. This value corresponds to Level of Service E, indicating an overall unstable flow condition at the intersection with a high sensitivity to any incidents, including those caused by drainage-related flooding or pavement failures.

H. Relationship Between Drainage Condition and Traffic Flow

The analysis of drainage condition and traffic flow data reveals a clear relationship between the two. The five drainage structures rated as Poor are concentrated in the first 500 m and between 2,000 m and 2,500 m of the corridor — precisely the sections that exhibit the highest levels of pavement distress (potholes, shoving, and surface cracking) as documented in the condition survey. These pavement defects, which are at least partially attributable to water infiltration from failing drainage structures, reduce effective road width and travel speeds, thereby exacerbating the already over-capacity conditions on the southbound approach.

Furthermore, the blocked box culvert at CH 0+200, which is the first structure encountered at the UI First Gate end of the corridor, contributes directly to flooding at the intersection during moderate to heavy rainfall. This flooding temporarily closes one or more lanes of the extended carriageway, causing a sudden and significant reduction in capacity that triggers queue spillback extending hundreds of meters in both directions.

I. Discussions of Findings

Drainage Structure Inventory and Condition Assessment

The inventory survey identified 12 drainage structures, comprising 2 bridges, 9 culverts, and 1 lined drain, along the 3.3 km University of Ibadan First Gate–NISER corridor. The presence of these structures indicates that the corridor was originally provided with adequate cross-drainage facilities to accommodate stormwater runoff and maintain roadway serviceability.

However, the condition assessment revealed that only 50% of the structures were in good condition, while 41.7% were rated poor. This proportion of deteriorated drainage structures is significant because drainage systems are expected to remain fully functional throughout their design life. The high percentage of poorly maintained structures suggests inadequate maintenance and delayed rehabilitation.

The blocked box culvert at CH 0+200 and the damaged bridge components observed during the survey indicate that sediment accumulation, debris obstruction, structural deterioration, and insufficient maintenance are affecting hydraulic efficiency. According to drainage management guidelines, drainage structures should operate with minimal obstruction to ensure the free flow of runoff. Therefore, the observed conditions indicate reduced drainage capacity in critical sections of the corridor.

These findings align with AASHTO's work, which emphasized that inadequate drainage maintenance is one of the leading causes of highway deterioration.

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Road Condition and Bus Stop Performance

The road condition survey revealed extensive pavement distress, including potholes, cracking, shoving, and surface deformation. These defects indicate that the pavement is experiencing structural and functional deterioration.

From a pavement engineering perspective, the observed distresses are consistent with moisture-induced pavement failures. Water entering the pavement layers through cracks and poorly functioning drainage facilities reduces subgrade strength and accelerates fatigue damage. The concentration of pavement distress near drainage structures rated poor further supports this relationship.

The poor condition of most bus stops also reflects insufficient infrastructure maintenance. Well-maintained bus stops are expected to provide passenger comfort, improve traffic organization, and enhance road safety. Their deterioration may contribute to unsafe passenger loading and unloading activities, thereby affecting traffic operations along the corridor.

Volume to Capacity Ratio

The volume-to-capacity (v/c) ratio is a measure of how close to capacity a road is operating. It reflects a facility's ability to serve motorized vehicle traffic volume over a given time period under ideal conditions, such as good weather, no incidents, no heavy vehicles, and no geometric deficiencies. The volume-to-capacity ratio is the degree of utilization of the capacity of a segment, intersection, or approach. The v/c ratio is not defined above 1.0; when it exceeds 1.0, it indicates that demand exceeds capacity, leading to congestion and delays. Under those conditions, it is considered a demand-to-capacity ratio. (Rogers,2013) A lower ratio indicates smooth operations and minimal delays. As the ratio approaches 1.0 to 1.4, congestion increases and performance decreases; at 1.0 or 1.4, capacity is fully utilized. If a driver wishes to overtake a slower-moving vehicle, the opposing lane must be utilized. Such overtaking maneuvers are constrained by geometric factors like passing sight distances and terrain features, which can limit safety and feasibility. The capacity of such a highway is expressed as a two-directional value. Under ideal conditions. The capacity of a 2-lane highway is set at 2800 passenger car units per hour (Rogers, 2003).

For a 2-lane highway, Table 2.5 shows the passenger-car equivalents for various heavy vehicles, highlighting their impact on capacity. Understanding this helps professionals feel confident in managing diverse traffic compositions and their effects on flow stability and bottlenecks.

Table 5: Comparison with Previous Studies

Variable	Present Study	Previous studies	Comparision
Poor drainage structures	41.7%	30-5-% reported in many Nigerian urban road studies	Similar
Pavement distress	Extensive potholes and cracking	A common consequence of poor drainage	Consistent
LOS	E	D-F reported on heavily congested urban arterials	Comparable
Southbound v/c ratio	1.75	1.2-1.8 reported on congested urban corridors	Similar
Drainage-pavement relationship	Strong correlation observed	Widely reported in the literature	Consistent
Drainage-traffic relationship	Direction influence observed	Supported by previous studies	Consistent

Implications of the Findings

i. The findings indicate that the corridor is experiencing both infrastructure deterioration and operational inefficiency. The drainage system is no longer functioning optimally, resulting in pavement degradation and periodic flooding. At the same time, traffic demand has exceeded available roadway capacity, particularly on the southbound approach.

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ii. Without immediate rehabilitation of the five poor-condition drainage structures and implementation of traffic management measures, the corridor is likely to experience:
iii. Increased pavement deterioration.
iv. More frequent flooding incidents.
v. Further reduction in roadway capacity.
vi. Increased travel time and vehicle operating costs.
vii. Declining Levels of Service, potentially reaching LOS F during peak periods.
viii. The results, therefore, demonstrate that drainage maintenance is not only a hydraulic requirement but also a critical component of traffic performance and sustainable road asset management.

4.0 Conclusion

- This study has conducted a comprehensive assessment of drainage structures and traffic flow conditions along the University of Ibadan First Gate to NISER corridor in Ibadan, Nigeria. The key findings are as follows:
- Twelve drainage structures were identified along the 3.3 km corridor: two bridges and ten culverts. Of these, six (50%) are in good condition, one (8.3%) is in fair condition, and five (41.7%) are in poor condition.
- The principal drainage defects observed include a severely blocked box culvert at CH 0+200, cracked bridge piers at CH 0+780 and CH 2+450, and blocked surface drainage channels at multiple locations.
- Traffic volumes along the corridor are extremely high, with the southbound approach recording 68,682 vehicles over six days. The computed v/c ratios are 1.0 (northbound) and 1.75 (southbound), both corresponding to Level of Service E, indicating unstable and over-capacity flow conditions.
- A direct spatial correlation exists between the locations of poor-condition drainage structures and the highest-severity pavement distress zones along the corridor. Drainage failures are a significant contributing factor to pavement deterioration and reduced road capacity.

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