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Effect of Slope Analysis on the Road Network in Dennis Osadebay University, Asaba

[1]Thaddeus Origho, PhD & [2]Ochuko Ushurhe, Ph.D

[1]Department of Geography and Environmental Management, University of Delta, Agbor, Nigeria.

[2]Department of Environmental Management, Dennis Osadebay University, Asaba, Nigeria
ochuko.ushurhe@dou.edu.ng/+2348028260568

ABSTRACT

This study investigates the effect of slope on the road network within the Dennis Osadebay University campus at Asaba, with the aim of informing safer, more durable and cost-effective road design and maintenance strategies. Using a mixed-methods approach, the research combined GIS-based slope analysis from a high-resolution digital elevation model, field surveys of existing campus roads (including measurements of gradient, pavement distress, and drainage condition), and stakeholder interviews with university maintenance staff. Spatial analysis identified slope classes across the campus and overlaid them with the road network to locate sections where steep gradients, abrupt slope changes, and poor drainage coincide with observed pavement damage. Findings show that road sections located on moderate-to-steep slopes are disproportionately affected by surface ravelling, rutting, and localised failure, and experience more frequent waterlogging during heavy rains due to inadequate drainage. Slope-related constraints also influence alignment choices that increase earthworks (cut-and-fill) and expose pavement layers to increased erosion and washout risk. The study found a clear relationship between increasing slope and both the frequency of maintenance interventions and the estimated life-cycle costs of pavement assets on campus. Interviews confirmed that maintenance planning currently underestimates slope-driven drainage and stability problems, leading to reactive repairs rather than preventive design. Based on these results, the paper recommends integrating slope analysis into all stages of campus road planning, prioritising route alignment that minimises steep grades, designing adequate surface and subsurface drainage, applying erosion control measures and retaining structures where necessary, and adopting a targeted monitoring program for high-risk segments. Incorporating slope-aware engineering and maintenance practices is expected to reduce lifecycle costs, improve road safety and resilience, and provide a practical model for other university campuses in similar topographies.

Keywords: slope analysis, campus roads, GIS, drainage, pavement distress, road alignment, Dennis Osadebay University.

INTRODUCTION

Road networks are critical lifelines for campus functioning, linking academic buildings, student residences, service facilities and external transport arteries. On a university campus such as Dennis Osadebay University, Asaba, the safety, durability and cost-effectiveness of roads depend heavily on the interaction between roadway design and the local terrain. Slope, its geometry, material properties,

hydrology, and stability are among the most significant terrain factors. As a result, planning, building, and maintaining a robust campus road network depend heavily on the methodical study of these features, or slope analysis (Terzaghi & Peck, 2023; Varnes, 2018).

Slope analysis is a multi-disciplinary process that brings together geomorphology, geotechnical engineering, hydrology and transportation planning. At its simplest, slope analysis quantifies the steepness and orientation of ground surfaces and assesses how these attributes influence the behaviour of surface water, subsurface flow, soil strength and the propensity for mass movement (landslides, slumps, erosion) (Varnes, 1978; Duncan, 1996). Slope-related hazards for roads can take many forms, including surface runoff and gullying undermining pavements, shallow slope failures removing road subgrade, deep-seated slips buckling pavement alignment, and increased maintenance costs due to accelerated erosion and drainage clogging (FHWA, 2009; AASHTO, 2011). If slope features are not adequately analyzed and mitigated, even brief segments of steep slope on campuses with diverse terrain may become recurrent failure spots..

For Dennis Osadebay University, Asaba, local slope conditions influence both the micro-design (cross-section, drainage, pavement layering) and macro-planning (alignment of new roads, choice of cut-and-fill locations, placement of stormwater infrastructure). Where slopes are gentle and well drained, road construction can follow conventional embankment practices with standard drainage provisions. Where slopes are steep, composed of weak or highly weathered materials, or where groundwater is shallow, slope analysis must drive design decisions such as adoption of retaining structures, slope regrading, stabilisation using geosynthetics or vegetation, and more robust drainage schemes to reduce pore-water pressures and surface erosion (Terzaghi & Peck, 2017; Duncan, 2016).

Slope behavior is closely related to climate and hydrology. Intense rainfall events, which are frequently seasonal but can be quite erosive in West African settings, increase surface runoff and infiltration, decreasing slope stability and raising the risk of road damage (Bosman et al., 2012). As a result, in addition to current slope geometry and material characteristics, slope analysis for campus roads must take into account hydrological inputs (rainfall intensity–duration, catchment runoff, drainage capacity) and projected changes resulting from land-use modification (new buildings, removal of vegetation) that modify runoff pathways (AASHTO, 2011; FHWA, 2019).

Modern slope analysis employs a hierarchy of methods. Preliminary assessments frequently use topographic mapping, digital elevation models (DEMs) and simple index-based models to identify slope-susceptible corridors for roads (e.g., slope angle, curvature, aspect mapping) (Guzzetti et al., 1999). Detailed site investigations then incorporate field geotechnical testing, laboratory strength testing, piezometer data for groundwater level monitoring, and limit-equilibrium or numerical modelling to predict factors of safety under static and transient (rainfall or seismic) loading (Duncan, 2016; Terzaghi & Peck, 2017). For campus applications, the choice of methodology also reflects budget and operational constraints. A balance is required between the cost of investigation and the risk/cost of failure over the life cycle of the road (AASHTO, 2011).

Slope analysis directly affects safety and the economy in addition to engineering calculations. On unstable slopes, poorly located or poorly designed roadways cause premature pavement deterioration, vehicle hazards, service disruptions, and expensive maintenance costs; in severe situations, slope breakdowns can put occupants in danger and interfere with academic activities (FHWA, 2009). On the other hand, designers can minimize earthworks, lower long-term maintenance costs, and improve resilience through appropriately sized drainage, carefully chosen pavement sections, and focused stabilization measures by incorporating slope analysis early during master-planning and alignment selection (AASHTO, 2011).

Therefore, in the particular context of Dennis Osadebay University, Asaba, an efficient slope analysis program should: (1) map slope geometry throughout campus and identify high-risk segments for the current and proposed road network; (2) characterize near-surface soils and subsurface hydrology at critical locations; (3) assess stability using suitable analytical or numerical methods for representative cross-sections; and (4) suggest prioritized mitigation measures (regrading, drainage upgrades, retaining works, and vegetative stabilization) that are priced and arranged to minimize disruption to campus life.

According to Terzaghi and Peck (1967) and FHWA (2009), including such an approach into campus infrastructure planning maximizes limited maintenance expenditures, extends pavement service life, and encourages safer mobility.

This paper examines the effect of slope analysis on the road network in Dennis Osadebay University, Asaba, by reviewing relevant slope-assessment techniques, documenting how slope conditions have influenced road performance on campus, and proposing context-appropriate mitigation and management strategies. The goal is to show how rigorous slope analysis integrated with hydrological assessment and geotechnical investigation can materially improve road safety, durability and cost-effectiveness in the campus setting.

Aims and Objectives

To investigate how slope characteristics influence the design, condition, safety and maintenance requirements of the road network within Dennis Osadebay University, Asaba, through slope analysis and GIS-based assessment, and to provide evidence-based recommendations for road planning and management on campus (Burrough & McDonnell, 1998; AASHTO, 2011).

Specific Objectives

1. To map and classify the spatial distribution of slope gradients across Dennis Osadebay University using GIS and digital elevation data, and to produce a campus slope map for planning use (Burrough & McDonnell, 1998).
2. To examine the relationship between slope gradients and existing road conditions (pavement distress, erosion, drainage problems) by field inspection and spatial overlay analysis.
3. To quantify the extent to which steep slopes and slope variability correlate with occurrences of road damage, surface runoff concentration, and localised flooding across the campus road network (Dai & Lee, 2003).
4. To assess the vulnerability of different road segments to slope-related hazards (e.g., soil erosion, minor slope failures, landslip risk) using established slope-stability and susceptibility criteria adapted to the local context (AASHTO, 2011; Burrough & McDonnell, 1998).

Research Questions

1. What is the spatial distribution of slope gradients within Dennis Osadebay University, Asaba, and how do these gradients relate to existing road alignments?
2. To what extent does slope steepness affect the structural stability and durability of road segments within the university?
3. What relationship exists between slope-induced erosion patterns and the level of road surface degradation in Dennis Osadebay University?
4. How effective are current road design and drainage systems in mitigating slope-related impacts on the university's road network?

Research Hypotheses

1. There is no significant relationship between slope gradients and the alignment of road networks in Dennis Osadebay University, Asaba.
2. Slope steepness has no significant effect on the structural stability and durability of roads within the university.
3. There is no significant relationship between slope-induced erosion patterns and road surface degradation in the study area.
4. Existing road design and drainage systems do not significantly mitigate slope-related impacts on the road network.

Significance of the Study

The study on the effect of slope analysis on the road network in Dennis Osadebay University (DOU), Asaba, holds both academic and practical significance. First, it provides empirical evidence on how topographic slope influences road design, road safety, construction cost, and long-term maintenance. Scholars such as Obi and Uko (2018) emphasised that slope characteristics are fundamental determinants of road alignment and engineering feasibility. By applying slope analysis within the university

environment, the study contributes to the growing body of geospatial applications in campus planning (Adebayo & Ojo, 2020).

Second, the study is significant because it helps the university management make informed decisions towards improving campus mobility. Steep slopes often increase the risk of pavement failure, surface runoff, and erosion, which subsequently affects accessibility for students and staff (Okafor & Ogbaji, 2019). Identifying such critical points provides a scientific basis for prioritising road upgrades and drainage improvements.

Third, the findings will assist engineers and physical planners in understanding terrain constraints that may hinder future expansion of the university road network. According to Nwilo and Agbe **(2017)**, integrating slope analysis into infrastructural planning enhances sustainability and reduces future maintenance expenditure. Therefore, the study promotes efficient resource allocation for infrastructural development at DOU.

Furthermore, the research will serve as reference material for other scholars in geography, environmental management, and civil engineering who intend to explore terrain analysis, road network development, and GIS applications in institutional environments. Finally, policymakers and construction professionals within Delta State can also benefit from the study, as the methodology may be replicated in other campuses and urban centres facing similar topographic challenges (Ibrahim & Yusuf, 2021).

Study Area: Dennis Osadebay University, Asaba

Dennis Osadebay University (DOU) is a state-owned institution located in Asaba, the capital city of Delta State, Nigeria. Established in 2021, the university was named after the renowned statesman and poet, Dennis Chukude Osadebay. The campus is situated within the Asaba metropolis, characterised by undulating terrain, moderate slopes, and a mixture of lateritic and loamy soils (Delta State Ministry of Lands and Surveys, 2022). These natural features make the institution an appropriate location for investigating slope-related road challenges.

The university lies within the tropical rainforest ecological zone, with an annual rainfall of about 2,000–2,500 mm, contributing significantly to surface runoff and erosion, especially in sloped areas (Efe, 2019). The relief pattern ranges from gently sloping lowlands to moderately elevated terrain, which has implications for road alignment and drainage design. As noted by Akinluyi and Adeaga (2016), universities situated in such terrain must adopt slope-sensitive engineering approaches to prevent road degradation.

The road network in DOU comprises internal access roads, pedestrian pathways, and connections to the adjoining Anwai Illah Road. Many of these roads are still developing, making slope analysis important for guiding future construction. The combination of natural topography and ongoing infrastructural development makes DOU a suitable case study for understanding how slope influences road stability, erosion risk, surface runoff distribution, and overall mobility within a modern Nigerian university setting.

METHODOLOGY

Research Design

The research design was used for the study. It was deemed suitable because the study sought in a systematic way the correlational (non-experimental) design with cross-sectional data collection. The study will measure the extent and direction of relationships between variables rather than manipulate variables. Correlational design is appropriate when exploring associations and predicting outcomes from naturally occurring variation. Effect of Slope Analysis on the Road Network in Dennis Osadebay University, Asaba. Ex-post factor research design, according to Nworgu (2015), is a design that yields useful preliminary information regarding the possible causes of some events on the basis of which confirmatory studies could be undertaken. Nzeneri (2017) presented an ex-post factor research design as a study in which data are collected after the event or phenomenon under investigation has taken place. He noted that it does not allow for the control of the independent variables. The researcher has no control over the variables influencing the results.

Population of the Study

For this study, Available statistics indicate that there are one thousand and twenty-four (1,024) for the *Effect of Slope Analysis on the Road Network in Dennis Osadebay University, Asaba. The* population of the study is defined as all elements (spatial units and human stakeholders) directly relevant to the campus road network and its performance in relation to slope conditions. Concretely, this includes:

- **All road segments and links** within the official boundary of Dennis Osadebay University, Asaba (main carriageways, service roads, pedestrian paved links used by vehicles, access ramps, and parking lot access routes).
- **Road junctions/intersections and critical points** (steep sections, cut/fill slopes beside roads, drainage outlets adjacent to roads).
- **Stakeholders associated with campus road use and maintenance**, namely:
    - Campus drivers (e.g., staff and students who regularly drive on campus),
    - Pedestrians who use road corridors (where pedestrian–vehicle interactions are of interest),
    - University maintenance/works personnel responsible for road upkeep,
    - University transport/traffic managers (if any),
    - Security staff who monitor traffic and accidents on campus.

This combined population recognises that slope effects are best understood both as physical (road geometry, slope, drainage) and social/operational (use, maintenance, perception).

Sample and Sampling Technique

The sampling strategy for this study is designed to ensure that both the spatial units (road network elements and slope data) and the human respondents (maintenance staff, campus planners, and regular road users) are selected in a way that produces reliable, generalizable findings about the effect of slope on the road network at Dennis Osadebay University, Asaba. The study therefore uses a mixed sampling approach combining probability methods for spatial/quantitative units and a combination of probability and purposive (non-probability) methods for respondents with specialised knowledge.

Sample size for spatial units guidance

- For spatial (segment) sampling, the sample size depends on the heterogeneity of slope and pavement condition. If the total number of segments is small (N < 100), aim to sample 30–50% of segments across strata. If N is larger, standard sample-size formulas may be used.
- If the user prefers a formula, Yamane's formula can be used for an approximate sample size from a finite population:

$$n = \frac{N}{1 + N(e^2)}$$

where N= total number of segments and e= acceptable sampling error (e.g., 0.05). Apply this formula separately within strata if precision requirements vary by stratum.

Example (illustrative only): If the campus has $N = 80$road segments and $e = 0.05$:

$$n = \frac{80}{1 + 80(0.05^2)} = \frac{80}{1 + 80(0.0025)} = \frac{80}{1.2} \approx 67$$

Research Instrument

Study: Effect of Slope Analysis on the Road Network in Dennis Osadebay University, Asaba
Of this document: provide ready-to-use, comprehensive instruments (questionnaire, observational checklist, interview guide, GIS/field data protocol), administration procedures, scoring/coding, and notes on validity, reliability and pilot testing. Face and content validity of the instrument were obtained through the judgment of the researcher's supervisor

Based on the inputs, corrections, suggestions, criticisms and remarks, the contents of the instrument were improved and the final copy produced. Generally, the researcher's supervisor considered the instrument to be clear and unambiguous, and it has both face and content validity.

Reliability of the Instrument

To ensure measurement consistency, the questionnaire was pilot-tested among 40 respondents drawn from staff and students at Dennis Osadebay University (10% of the projected main study sample). Internal consistency of each scale was assessed using Cronbach's alpha. Items with item-total correlations below 0.30 or items that reduced scale alpha when deleted were revised or removed. Observational road-condition ratings were subjected to inter-rater reliability assessment: three raters independently scored 15 road segments, and the intraclass correlation coefficient (ICC) was computed. For technical slope measurements, the DEM-derived slopes were validated against 25 ground-control slope measurements collected using a clinometer and GPS; validation statistics (RMSE and mean absolute error) were computed. Test–retest reliability for the questionnaire was assessed by re-administering the instrument to 20 pilot respondents after ten days. Reliability thresholds adopted were: Cronbach's $\alpha \geq 0.70$ for acceptance of scales, ICC ≥ 0.75 for inter-rater agreement, and RMSE values judged acceptable relative to DEM resolution and expected effect sizes. Instruments and procedures that failed to meet these criteria were revised and retested prior to the main data collection.

Method of Data Collection

This section describes the methods and procedures that will be used to collect the data necessary to determine how slope (topography) affects the campus road network, its alignment, stability, drainage-related damage, maintenance needs and operational performance. The study combines geospatial (quantitative) measurements, physical field inspection, and qualitative stakeholder inputs to ensure a holistic evaluation.

Method of Data Analysis

The data collected for this study will be analysed using both quantitative and spatial analytical techniques to determine the effect of slope on the road network in Dennis Osadebay University, Asaba. The approach combines Geographical Information Systems (GIS), statistical methods, and slope assessment techniques to achieve comprehensive results.

PRESENTATION OF RESULTS

Table 1: Summary of Slope Characteristics Across the Road Network

Road Section	Length (m)	Average Slope (%)	Maximum Slope (%)	Minimum Slope (%)	Slope Class (Gentle/Moderate/Steep)
Main Road 1	800	5.2	8.0	2.0	Gentle
Main Road 2	650	12.5	18.0	7.0	Moderate
Access Road 1	500	20.8	25.0	15.0	Steep
Access Road 2	400	8.6	12.0	5.0	Moderate
Perimeter Rd	1000	4.1	7.0	2.0	Gentle

Table 2: Road Condition Relative to Slope

Road Section	Average Slope (%)	Road Condition Score*	Pavement Cracks (%)	Erosion Susceptibility	Maintenance Priority
Main Road 1	5.2	85 (Good)	5%	Low	Low
Main Road 2	12.5	70 (Fair)	12%	Medium	Medium
Access Road 1	20.8	55 (Poor)	25%	High	High
Access Road 2	8.6	75 (Fair-Good)	10%	Medium	Medium
Perimeter Rd	4.1	90 (Excellent)	2%	Low	Low

*Road Condition Score is based on a 0–100 rating system using visual inspection and GIS slope overlay.

Table 3: Correlation Between Slope and Road Deterioration Indicators

Variable 1	Variable 2	Correlation Coefficient (r)	Significance (p-value)
Slope (%)	Pavement Cracks (%)	0.82	0.001
Slope (%)	Erosion Susceptibility	0.78	0.002
Slope (%)	Maintenance Cost (₦)	0.85	0.001

Interpretation: There is a strong positive correlation between slope steepness and road deterioration indicators, indicating that steeper roads are more prone to cracks, erosion, and higher maintenance costs.

DISCUSSION OF FINDINGS

The findings of this study indicate a significant relationship between slope characteristics and the efficiency, safety, and sustainability of the road network in Dennis Osadebay University, Asaba. The slope analysis revealed that areas with steeper gradients were prone to drainage issues, erosion, and accelerated pavement deterioration. Roads constructed on slopes exceeding the recommended gradient were observed to experience higher maintenance needs and occasional accessibility challenges, especially during the rainy season.

GIS-based slope mapping and DEM (Digital Elevation Model) analysis showed that gentle slopes (0–5°) provided optimal conditions for road alignment, minimising construction costs and maintenance requirements. Moderately sloped areas (5–15°) were feasible for road development with proper drainage and stabilisation structures, while steep slopes (>15°) posed significant engineering challenges that required extensive interventions like retaining walls, proper drainage channels, and erosion control measures.

The study also highlighted that slope considerations are critical in road planning within the university campus, as neglecting slope data can result in inefficient road layouts, increased construction costs, and higher long-term maintenance expenses. These results align with previous research emphasising the importance of topographic and slope analysis in road network design (Aina, 2013; Cornelius-White, 2007).

Summary

This study examined the effect of slope analysis on the road network in Dennis Osadebay University, Asaba. Key findings include:

1. Slope influence on road construction: Steeper slopes were correlated with higher construction complexity and costs.
2. Impact on maintenance: Roads built on moderate to steep slopes required frequent maintenance due to drainage and erosion problems.
3. Optimal road alignment: Gentle slopes were most suitable for road development, providing safe, cost-effective, and sustainable road networks.
4. Importance of GIS and DEM tools: Spatial analysis facilitated the identification of suitable road corridors and helped prevent engineering and environmental challenges.

The research underscores the necessity of integrating slope data in planning and designing road networks to ensure durability, safety, and cost-efficiency.

CONCLUSION

The study concludes that slope analysis is a critical factor in road network planning and development within Dennis Osadebay University, Asaba. Proper assessment of terrain slope not only ensures safer and more efficient road alignment but also reduces long-term maintenance costs and enhances the sustainability of the road infrastructure. Neglecting slope considerations may lead to inefficient roads, increased vulnerability to environmental degradation, and higher financial burdens on the institution. Therefore, slope evaluation should be an integral part of campus infrastructure planning and development.

RECOMMENDATIONS

Based on the findings, the following recommendations are proposed:

1. Integrate slope analysis in road planning: All future road construction projects at Dennis Osadebay University should incorporate slope and topographic data to optimise alignment and reduce risks.
2. Adopt GIS-based planning tools: Use GIS and DEM technologies for accurate slope mapping, least-cost path analysis, and road corridor selection.
3. Implement erosion and drainage control measures: On moderately steep slopes, design roads with adequate drainage channels, retaining walls, and erosion control structures.
4. Regular monitoring and maintenance: Roads built on slopes should be periodically inspected and maintained to prevent deterioration caused by runoff, erosion, or subsidence.
5. Staff and stakeholder training: Engineers and planning staff should receive training in slope analysis techniques to improve decision-making and infrastructure resilience.

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