

Effects of Rainfall Erosivity and Soil Erodibility on Road Networks in Ota, Ogun State, Nigeria: Laboratory Geotechnics and GIS-Based USLE Assessment

George John Solomon

Department of Civil and Environmental Engineering, Bells University of Technology, Ota, Ogun State, Nigeria.
Corresponding Authors Email: george.solomon677@gmail.com

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ABSTRACT

Road infrastructure in rapidly urbanising humid-tropical settings is increasingly exposed to water erosion, yet the joint influence of rainfall erosivity (the capacity of rainfall to erode) and soil erodibility (the susceptibility of soil to erosion) on road performance is seldom quantified in southwestern Nigeria. This study combined laboratory geotechnical testing with GIS-based soil-loss modelling to evaluate these controls for roads in Ota, Ogun State, using the Bells University of Technology road corridor as the detailed case. Disturbed soil was tested for natural moisture content, Atterberg limits, particle-size distribution and standard Proctor compaction (ASTM D2216, D4318, D6913 and D698) and classified under AASHTO M 145; erodibility, erosivity and annual soil loss were mapped in ArcGIS with the Universal Soil Loss Equation (USLE). The soil had a natural moisture content of 8.95%, a liquid limit of 31.1%, a plastic limit of 18.7% and a plasticity index of 12.4%. Maximum dry density was $1,659 \text{ kg m}^{-3}$ at an optimum moisture content of 14.5%, and density fell sharply on the wet side of optimum. Dry sieving returned only about 1% passing 0.075 mm, probably an underestimate for this aggregated tropical soil, so the AASHTO class A-2-6 is provisional. The corridor lies on the Ndasin soil series; rainfall erosivity moved from the moderate class in 2011–2020 to the high class in 2021–2024; and mapped soil loss fell in the low and moderate classes (upper class limits of about $16.5\text{--}22 \text{ t ha}^{-1} \text{ yr}^{-1}$; state-wide maximum about $24.6 \text{ t ha}^{-1} \text{ yr}^{-1}$), well above commonly cited tolerable rates. Plastic fines, a narrow compaction-moisture window, poor drainage and unprotected slopes make the corridor vulnerable to progressive surface loss. Drainage maintenance, slope step-downs, moisture-controlled compaction and soil stabilisation are recommended.

Keywords: Rainfall erosivity; soil erodibility; road deterioration; USLE; GIS; Atterberg limits; Nigeria



Highlights

- (a) Road-corridor soil in Ota is sandy-gravelly with plastic fines (LL 31.1%, PI 12.4%)
- (b) Proctor compaction is moisture-sensitive: MDD $1,659 \text{ kg/m}^3$ at OMC 14.5%
- (c) Rainfall erosivity at the corridor rose from moderate to high class (2011–2024)
- (d) Mapped USLE soil loss reaches about $22 \text{ t ha}^{-1} \text{ yr}^{-1}$, far above tolerable rates
- (e) Laboratory tests plus GIS give a low-cost screen for road-corridor erosion risk

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INTRODUCTION

Roads underpin economic growth, social development and access to health care, education and markets. Their footprint is also expanding fast: a global assessment projects very large additions to the road network by mid-century, most of them in developing nations (Laurance et al., 2014). Roads are not neutral features of the landscape. They intercept and concentrate runoff, alter hillslope hydrology and act as chronic sources of sediment (Forman & Alexander, 1998; Sidle & Ziegler, 2012). Compacted road surfaces have low infiltration capacity and readily generate Hortonian overland flow, so that even modest rainfall can produce erosive runoff on and below the road (Ziegler & Giambelluca, 1997). Field studies of unpaved and forest roads show that sediment production depends on segment length and gradient, surface condition, traffic and rainfall erosivity (Luce & Black, 1999; Ramos-Scharrón & MacDonald, 2005). Soil erosion by water is one of the most widespread forms of land degradation, with severe consequences in the tropics (Lal, 1998; Lal, 2001). Accelerated erosion generally outpaces soil formation where the protective surface is removed or disturbed (Montgomery, 2007), and recent global modelling suggests that land-use change and climate change will raise erosion pressure through the middle of this century (Borrelli et al., 2017; Borrelli et al., 2020). Poesen (2018) argues that research on erosion in the Anthropocene must pay more attention to human-disturbed, non-agricultural surfaces, of which roads are a leading example.

Two factors govern the potential for water erosion on any surface. Rainfall erosivity expresses the erosive force of rainfall, which depends on both amount and intensity, and is conventionally represented by the R-factor of the USLE and its revised form (Panagos et al., 2015). Soil erodibility expresses the inherent susceptibility of the soil to detachment and transport and is controlled by texture, organic matter, structure, aggregate stability and permeability (Bryan, 2000; Le Bissonnais, 1996; Panagos et al., 2014). Erodibility is not static on roads: Foltz et al. (2008) showed that rill erodibility of native-surface roads declines exponentially with cumulative overland-flow depth while critical shear stress stays constant, meaning that the most easily eroded material is removed first and later flows meet a more resistant surface. Rainfall erosivity is hard to quantify in West Africa because high-resolution (sub-hourly) rainfall records are scarce. Global compilations of such records exist (Panagos et al., 2017) and satellite rainfall products have been used to map erosivity across Africa (Vrieling et al., 2014), but at local scale many studies must fall back on empirical relationships based on annual or daily totals, which carry additional uncertainty (Angulo-Martínez & Beguería, 2009). The USLE family remains the most widely used framework for such data-limited applications despite its known limitations (Benavidez et al., 2018). Water also damages the road structure itself. Moisture weakens asphalt–aggregate bonding and

drives progressive stripping, cracking and potholing (Caro et al., 2008), and climate-related stressors are projected to raise pavement maintenance costs substantially (Underwood et al., 2017). In poorly drained settings, erosion of shoulders, embankments and side drains compounds these effects by removing structural support.

Despite this, few studies in southwestern Nigeria combine laboratory characterisation of road-corridor soils with spatially explicit erosivity, erodibility and soil-loss estimates. The present study addresses that gap for roads in Ota, Ogun State, and contributes a transparent, low-cost workflow that links index-test geotechnics to mapped erosion drivers where measured sediment and high-resolution rainfall data are scarce. Its objectives were to:

1. Characterise the index and compaction properties of the soil along the study road using standard laboratory tests;
2. Classify the soil and interpret its likely erodibility and behaviour under heavy rainfall;
3. Map soil erodibility (k) and rainfall erosivity (r) with gis;
4. Estimate annual soil loss with the usle for the 2015–2024 analysis period and place the results in the context of tolerable erosion rates; and
5. Recommend design and maintenance measures to improve road durability.

The findings are intended for road engineers, planners and maintenance agencies in Nigeria and in comparable humid-tropical regions.

METHODOLOGY

Study Area

Ota lies in Ado-Odo/Ota Local Government Area of Ogun State, southwestern Nigeria (approximately 6.7° N, 3.2° E), within the humid tropical zone. Rainfall is seasonal, and the records examined show that the second half of the year receives more rainfall than the first. Ogun State is underlain mainly by Precambrian Basement Complex rocks of the West African Craton, but the study area itself lies on Quaternary–Tertiary sedimentary deposits, which are layers of sediment accumulated over time. The dominant soil unit in the study area is the Ndasin soil series (Figure 1). Ota has urbanised rapidly, with expanding built-up land, road construction and loss of vegetation cover, all of which increase runoff and sediment supply. The position of the Bells University of Technology road corridor within the State is shown in the inset of (Figure 1).

MATERIALS AND METHODS

Research Design and Site Selection

A mixed-methods case-study design was adopted.

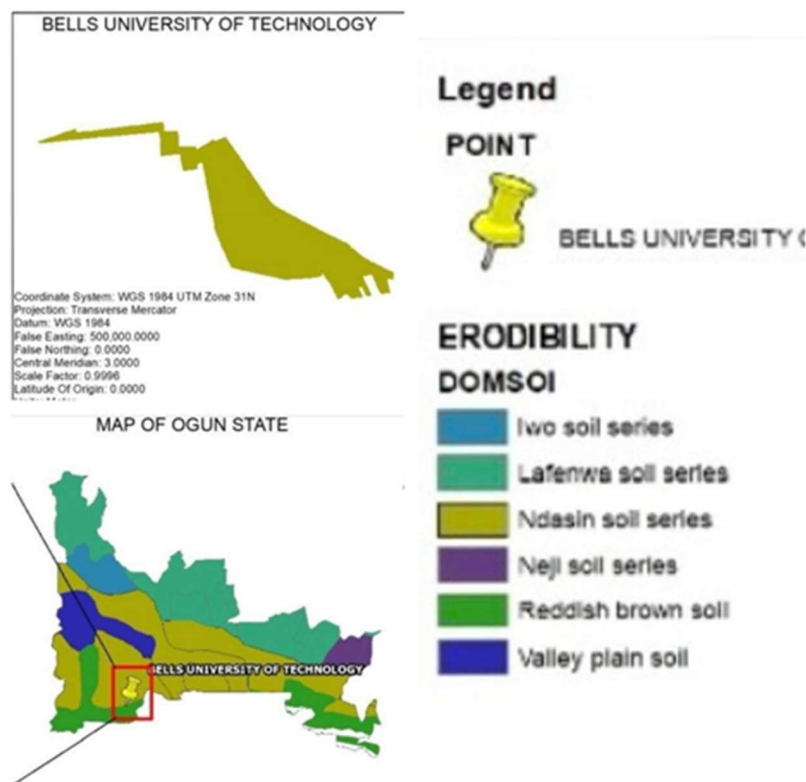


Figure 1: Dominant soil units (DOMSOI) of Ogun State used for the erodibility analysis, with the Bells University of Technology Road corridor enlarged (upper left; Ndasin soil series). Coordinate system: WGS 1984 UTM Zone 31N.

Table 1. Laboratory tests, standards and purpose

Test	Standard	Purpose
Natural moisture content	ASTM D2216	In-situ water state of the soil; phase relationships
Liquid limit, plastic limit, plasticity index	ASTM D4318; TEX-105-E	Consistency, plasticity and classification of fines
Particle-size distribution (dry sieving)	ASTM D6913	Grading and classification
Standard Proctor compaction	ASTM D698	Optimum moisture content and maximum dry density

Quantitative data came from laboratory soil tests, rainfall records, terrain data and soil-loss modelling; qualitative data came from field observation of erosion features, drainage condition, pavement defects and maintenance practice. Five roads in Ota were purposively selected using five criteria: exposure to erosion, soil properties, drainage condition, traffic intensity and history of degradation. The detailed geotechnical and USLE assessments reported here refer to the Bells University of Technology road corridor.

Soil Sampling and Laboratory Tests

Disturbed samples were collected from the road corridor, transported to the laboratory in sealed bags and tested as summarised in (Table 1). Classification followed the AASHTO system (AASHTO M 145).

Moisture Content

A representative specimen was placed in a clean, dried, pre-weighed non-corrodible container and weighed to 0.01 g. It was dried in a ventilated thermostatic oven at 110 ± 5 °C (105–115 °C) to constant mass, typically 16–24 h, and weighed again. Water content was computed as $w = (\text{mass of water} \div \text{mass of dry soil}) \times 100$.

Atterberg Limits

Air-dried soil passing the No. 40 (0.425 mm) sieve was used. For the liquid limit, about 250 g of soil was mixed with water to a uniform paste and placed in a Casagrande cup to a depth of about 8 mm. A groove was cut with the grooving tool and the cup was dropped at about two blows per second until the groove closed over 12.7 mm ($\frac{1}{2}$ in.).

The number of blows (N) and the water content were recorded for at least three trials spanning 15–40 blows, and the flow curve (water content against log N) was plotted. The liquid limit is the water content at 25 blows. For the plastic limit, about 20 g of soil was mixed with water and rolled using the TxDOT plastic-limit rolling device (3.18 mm gap) until threads crumbled at about 3 mm diameter, and the water content of the crumbled soil was determined. The plasticity index is $PI = LL - PL$.

Particle-size distribution

An oven-dried specimen was passed through a nest of sieves, with larger openings above smaller ones, a pan at the bottom and the No. 4 (4.75 mm) and No. 200 (0.075 mm) sieves always included. Sieves were cleaned with a brush, weighed empty, loaded and shaken mechanically for 10–15 min. The mass retained on each sieve was determined and converted to percentage retained and cumulative percentage passing. Percentages in this study were calculated on a 500 g specimen.

Compaction

Air-dried soil passing the No. 4 sieve was compacted in a cylindrical mould in three equal layers with the standard rammer (about 25 blows per layer for the 4-in. mould, 56 for the 6-in. mould), following the Proctor approach (ASTM D698). The first test started at an assumed water content of about 8%, and water was increased in steps of about 2% for each subsequent test until the dry density fell with further wetting. For each test the compacted mass and water content were measured, bulk density was computed from the mould volume (0.0009818 m^3), and dry density was computed as $\rho_d = \rho \div (1 + w)$. The compaction curve plots dry density against water content, with its peak giving the maximum dry density (MDD) and optimum moisture content (OMC).

GIS-Based Erodibility, Erosivity and Soil-Loss Modelling

Analyses used ArcGIS 10.8 and Microsoft Excel. Input data comprised (i) soil texture and soil-unit data from field survey and FAO soil maps, (ii) a 30 m SRTM digital elevation model (Farr et al., 2007), (iii) long-term daily or monthly rainfall from meteorological stations (NIMET), with satellite products such as CHIRPS (Funk et al., 2015) as a supplement, and (iv) classified land-use/land-cover data. All layers were projected to WGS 1984 UTM Zone 31N (Transverse Mercator; central meridian 3° E ; scale factor 0.9996; false easting 500,000 m) to ensure spatial consistency.

Soil erodibility (K). K was computed in Excel from the Wischmeier and Smith (1978) relationship (Equation 1), then joined to the soil shapefile in ArcGIS by soil ID and

interpolated with IDW or Kriging (Li & Heap, 2011):

$$K = [2.1 \times 10^{-4} (12 - OM) M^{1.14} + 3.25 (S - 2) + 2.5 (P - 3)] \div 100 \quad (1)$$

where OM is organic matter (%), $M = (\% \text{ silt} + \% \text{ very fine sand}) \times (100 - \% \text{ clay})$, S is the soil-structure code and P is the permeability class. This yields K in US customary units; multiplying by 0.1317 gives SI units ($\text{t ha h ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$). The raster was classified, and legend, north arrow, scale bar and title were added before export.

Rainfall erosivity (R). Because high-resolution intensity data were unavailable, R was estimated from mean annual precipitation P (mm) with the empirical West African relationship adopted in the project methodology, which attributes it to Roose (1977) (Equation 2)

$$R = 38.5 P - 2184 \text{ (MJ mm ha}^{-1} \text{ h}^{-1} \text{ yr}^{-1}) \quad (2)$$

R was calculated for each station in Excel, imported into ArcGIS as a table, joined to the station points and interpolated by Kriging to give a continuous erosivity raster. Rainfall records of at least 10 years were used. Annual-total-based estimators approximate, but do not fully capture, the intensity component of erosivity (Angulo-Martínez & Beguería, 2009; Panagos et al., 2017). Erosivity rasters were produced for two periods, 2011–2020 and 2021–2024, and displayed in five relative classes (very low, low, moderate, high, very high).

Topography (LS)

The slope-length and steepness factors were derived from the DEM and slope data (Moore et al., 1991) using the standard USLE expressions (Wischmeier & Smith, 1978):

$$L = (\lambda \div 22.13)^m \quad (3)$$

$$S = (0.43 + 0.30 s + 0.043 s^2) \div 6.613 \quad (4)$$

where λ is slope length (m), s is slope gradient (%) and m is the slope-length exponent (0.5 for gradients of 5% or more).

Cover and support practice (C, P). C was assigned from land-cover class and P from slope class (Table 7)

Soil loss. Mean annual soil loss was estimated for each analysis epoch as (Equation 5)

$$A = R \times K \times LS \times C \times P \quad (5)$$

and expressed in $\text{t ha}^{-1} \text{ yr}^{-1}$. The resulting rasters were displayed in four classes (low, moderate, high, very high) whose limits are listed in (Table 8). Soil units, erosivity and soil loss were mapped for the whole of Ogun State, with

the Bells University of Technology corridor enlarged as an inset in each map.

RESULTS

Natural Moisture Content

The natural moisture content of the soil was 8.95% (Table 2), a moderately low in-situ water state typical of a well-drained sandy to loamy road-corridor soil in the dry-to-early-wet season.

Table 2. Natural moisture content test.

Parameter	Value
Mass of empty can (m_1)	38.0 g
Mass of wet soil + can (m_2)	128.0 g
Mass of dry soil + can (m_3)	121.0 g
Mass of water ($M_w = m_2 - m_3$)	7.5 g
Mass of dry soil	83.8 g
Water content	8.95%

Atterberg Limits

The flow-curve data (Table 3; Figure 2) gave a liquid limit of 31.1% at 25 blows. Water content decreased from 35.0% at 20 blows to 28.8% at 29 blows, and a least-squares line through the three trials returns 31.2% at 25 blows, within about 0.1 percentage point of the measured value.

Table 3: Liquid limit test.

Trial	W_1 (g)	W_2 (g)	Moisture content (%)	Number of blows
1	38	74.0	35.0	20
2	38	72.5	31.1	25
3	38	70.8	28.8	29

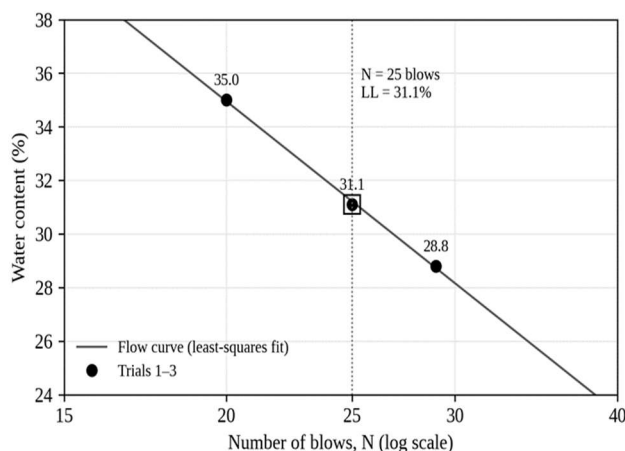


Figure 2: Flow curve for the liquid-limit test: water content against number of blows (logarithmic scale) for three trials (Table 3). The liquid limit is the water content at 25 blows (31.1%).

The three plastic-limit trials (Table 4) ranged from 18.1% to 19.1% and averaged 18.67%, so the plasticity index is $31.1 - 18.7 \approx 12.4\%$. This places the fine fraction in the low-to-medium plasticity range: cohesive enough to bind particles, but with limited swelling potential. On the Casagrande plasticity chart the LL–PI pair plots above the A-line ($PI = 0.73[LL - 20] = 8.1$ at $LL = 31.1\%$), in the domain of inorganic clays of low plasticity.

Table 4: Plastic limit test.

Trial	W_1 (g)	W_2 (g)	W_3 (g)	Moisture content (%)
1	38	70.5	65.2	18.8
2	38	69.8	64.5	18.1
3	38	70.4	64.6	19.1

W_1 = mass of empty can; W_2 = can + wet soil; W_3 = can + dry soil. Mean plastic limit = 18.67%. [plastic limit of 20.4% gives $PI \approx 10.7\%$, at the A-2-6 boundary ($PI \geq 11$).

Particle-Size Distribution

Dry sieving of the 500 g specimen gave the distribution in (Table 5) and the grading curve in (Figure 3).

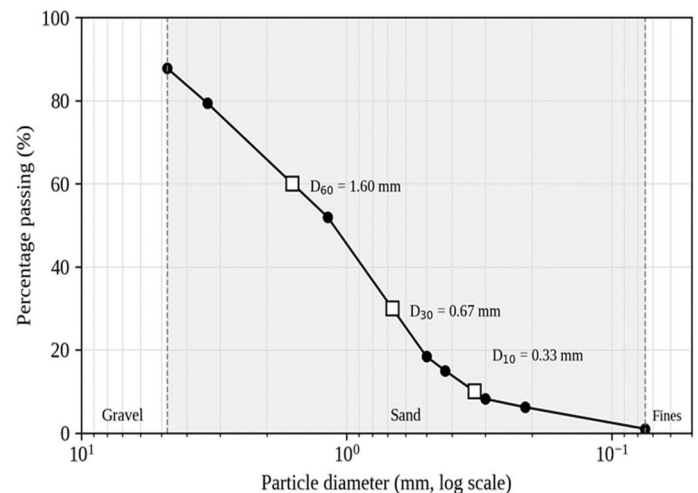


Figure 3: Particle-size distribution of the corridor soil from dry sieving (Table 5). Dashed lines mark the gravel–sand (4.75 mm) and sand–fines (0.075 mm) boundaries; squares mark D_{10} , D_{30} and D_{60} by log-linear interpolation.

About 12% of the soil was retained on the 4.75 mm sieve (gravel), roughly 87% fell in the sand range and only about 1% passed the 0.075 mm sieve (a further 0.4% was collected in the pan). The curve is smooth and gently sloping through the sand range, with $D_{10} = 0.33$ mm, $D_{30} = 0.67$ mm, $D_{50} = 1.1$ mm and $D_{60} = 1.6$ mm, giving a coefficient of uniformity $C_u = 4.9$ and a coefficient of curvature $C_c = 0.86$. Because C_u is below 6, the sand is poorly (uniformly) graded under the Unified Soil Classification criteria, and the grading is dominated by coarse to medium sand with some fine gravel.

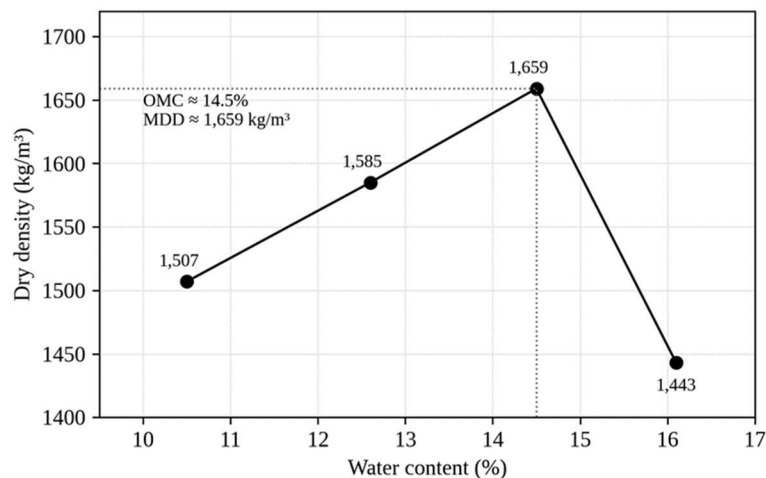
Table 5: Sieve analysis (500 g specimen).

Sieve opening (mm)	Empty mass (g)	Retained (g)	Retained (%)	Cumulative retained (%)	Passing (%)
4.75	611	61	12.2	12.2	87.8
3.35	473	42	8.4	20.6	79.4
1.18	349	137	27.4	48.0	52.0
0.500	441	168	33.6	81.6	18.4
0.425	421	17	3.4	85.0	15.0
0.300	439	34	6.8	91.8	8.2
0.212	330	10	2.0	93.8	6.2
0.075	397	26	5.2	99.0	1.0
Receiver	331	2	0.4	99.4	0.6

Table 6: Standard Proctor compaction results.

Parameter	Trial 1	Trial 2	Trial 3	Trial 4
Mass of compacted soil (kg)	1.636	1.763	1.865	1.645
Mould volume (m ³)	0.0009818	0.0009818	0.0009818	0.0009818
Moisture content (%)	10.5	12.6	14.5	16.1
Bulk density (kg/m ³)	1,666	1,785	1,899	1,675
Dry density (kg/m ³)	1,507	1,585	1,659	1,443

Trial 2 mass $1.763 \text{ kg} \div 0.0009818 \text{ m}^3 = 1,796 \text{ kg/m}^3$, not $1,785 \text{ kg/m}^3$ (a mass of 1.753 kg would give $1,785$).

**Figure 4:** Standard Proctor compaction curve (dry density against water content) from the four trials in Table 6, with the optimum moisture content (OMC $\approx 14.5\%$) and maximum dry density (MDD $\approx 1,659 \text{ kg/m}^3$) indicated.

Compaction Characteristics

Dry density increased from $1,507 \text{ kg/m}^3$ at 10.5% water content to a peak of $1,659 \text{ kg/m}^3$ at 14.5% , then fell to $1,443 \text{ kg/m}^3$ at 16.1% (Table 6; Figure 4). The soil therefore has an OMC of about 14.5% and an MDD of about $1,659 \text{ kg/m}^3$, taken from the observed peak of four points. The dry-side gain was about 38 kg/m^3 per percentage point of water, whereas the wet-side loss was about 135 kg/m^3 per percentage point (216 kg/m^3 , or 13% , over only 1.6 percentage points), so the soil is highly sensitive to moisture during construction. The natural moisture content (8.95% ; Table 2) lies about 5.5 percentage points below OMC, so the material would need to be wetted before compaction.

Soil Classification and Interpretation

The measured liquid limit (31.1%) and plasticity index (12.4%) show that the fines are plastic but not highly so. Under AASHTO M 145, soils with 35% or less passing 0.075 mm , $LL \leq 40\%$ and $PI \geq 11\%$ fall in group A-2-6 (silty or clay gravel and sand); if the fines content exceeded 35% the same limits would give A-6 (clayey soil), and the A-7 groups would require $LL \geq 41\%$, which was not measured. Because the dry-sieved fines content (about 1% ; Figure 3) points to A-2-6, that class is adopted provisionally. Two cautions apply. First, dry sieving without washing tends to underestimate the silt-and-clay fraction of aggregated tropical soils, because fines remain coated on or cemented to coarser grains. A washed sieve analysis (ASTM D1140) and, if needed, a hydrometer test (ASTM D7928) is

required to confirm the fines content and hence the final group. Second, the Atterberg limits are determined on the fraction passing 0.425 mm (15% of the sample here), so they describe a minor but behaviourally important part of the soil. In practice the corridor soil is best described as a sandy to gravelly material with plastic fines. Such soils infiltrate readily when loose, but their low cohesion makes the surface vulnerable to detachment once compacted wheel paths, concentrated flow or poor drainage develop.

Erodibility and Erosivity Patterns

Soil Units and Erodibility

The corridor lies wholly within the Ndasin soil series (Figure 1), the dominant soil unit of the study area and one of the most extensive units in Ogun State; the other mapped units are the Iwo, Lafenwa and Neji soil series, reddish-brown soils and valley-plain soils. Erodibility was therefore assigned from the properties of this series rather than resolved at the scale of individual road segments.

Rainfall Erosivity

Erosivity increased between the two analysis periods (Figures 5 and 6). For 2011–2020 the corridor falls in the moderate erosivity class, whereas for 2021–2024 it falls in the high class. At state scale, erosivity in both periods rises from very low in the north to high and very high in the east. Because R was derived from annual rainfall totals, the upward shift reflects rising rainfall amount; changes in rainfall intensity could not be resolved with the available data. The study area has also urbanised rapidly, which raises runoff and sediment supply but does not itself change rainfall erosivity, so the trend in (Figures 5 and 6) is interpreted as a rainfall signal.

USLE Soil Loss

For the sample calculation, a slope length $\lambda = 643$ m, a gradient $s = 5.1\%$ and $m = 0.5$ give $L = (643 \div 22.13)^{0.5} = 5.39$ and $S = (0.43 + 0.30 \times 5.1 + 0.043 \times 5.1^2) \div 6.613 = 3.078 \div 6.613 = 0.465$, so $LS = 5.39 \times 0.465 = 2.51$. The P-factor values by slope class are given in (Table 7). Annual soil loss was mapped for three epochs labelled USLE 15, USLE 20 and USLE 25 in the GIS output (Figures 7–9), which correspond to the 2015, 2020 and 2025 map epochs. Across Ogun State, soil loss ranged from 0 to between 24.2 and 24.6 t ha⁻¹ yr⁻¹ (Table 8). The corridor lies in the low and moderate classes in all three maps. In 2015 the western arm and upper part of the corridor fall in the moderate class and the south-eastern body in the low class (Figure 7); in 2020 and 2025 the low class occupies progressively more of the corridor, and by

2025 only the western end remains in the moderate class (Figures 8 and 9).

DISCUSSION

Soil Properties and Erodibility

The corridor soil combines a granular skeleton with a small but plastic fine fraction (LL 31.1%, PI 12.4%; Figures 2 and 3). Soil erodibility is governed by texture, organic matter, structure, aggregate stability and permeability (Bryan, 2000; Le Bissonnais, 1996). In the Wischmeier nomograph sense, a sandy soil with little silt would be expected to have low to moderate K , because it infiltrates readily and offers little fine material for detachment and transport, whereas plastic fines supply cohesion that raises resistance to detachment. The vulnerability of this corridor therefore lies less in intrinsic erodibility than in how the surface behaves once it is compacted, sealed or concentrated by wheel paths and drains. K -factor predictions from soil properties also carry substantial uncertainty (Torri et al., 1997), and the nomograph equation was developed for temperate soils (Panagos et al., 2014), so K should be treated as an indicative ranking rather than an absolute value. The grading data reinforce this reading. With $C_u = 4.9$ and $C_c = 0.86$ the sand is uniformly rather than well graded, a condition that favours infiltration when loose but leaves few fines to fill voids and bind the surface. The compaction results are practically important. The sharp decline in dry density from 1,659 to 1,443 kg/m³ when water content rose from 14.5% to 16.1% (Figure 4) shows a narrow window for achieving good density. Soil compacted wet of optimum is weaker and, if left unsealed, more easily disturbed by traffic. Compaction at or near OMC raises strength but lowers infiltration, so a well-compacted surface sheds more runoff, which is exactly the mechanism that makes roads efficient runoff generators (Ziegler & Giambelluca, 1997). Good compaction must therefore be paired with good drainage.

Rainfall Erosivity and Climate

The shift of the corridor from the moderate class in 2011–2020 to the high class in 2021–2024 (Figures 5 and 6) is consistent with regional and global evidence that erosion pressure is increasing. Modelling indicates that erosion and runoff respond strongly to changes in precipitation (Nearing et al., 2005), and global projections point to higher erosion in the coming decades, with land-use change and climate both contributing (Borrelli et al., 2017; Borrelli et al., 2020). Erosivity varies strongly across space and time in Africa (Vrieling et al., 2014), and the stronger rainfall in the second half of the year in Ogun State means that peak-season rainfall, not annual mean rainfall, should drive drainage design. The R -factor used here was derived from annual totals, which cannot capture storm intensity; measurements from high-resolution rain gauges, as used

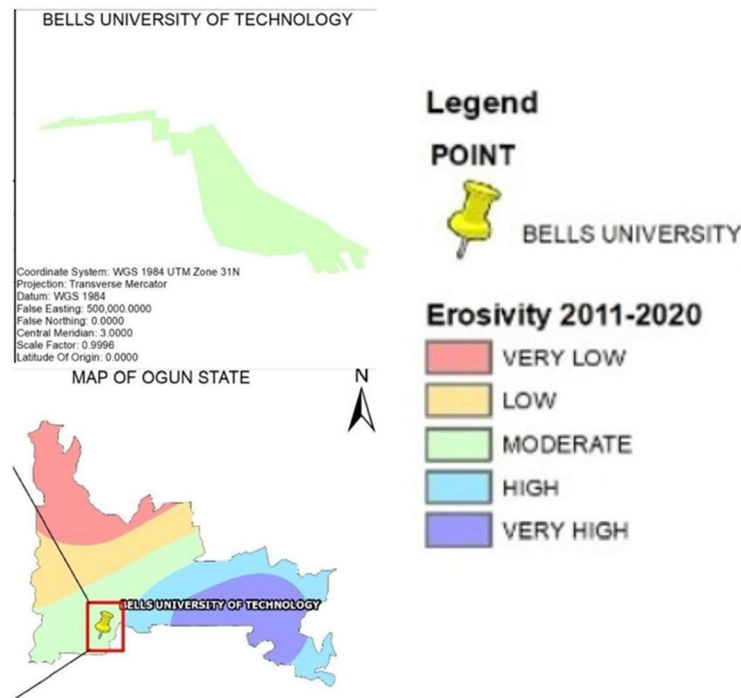


Figure 5: Rainfall erosivity classes for 2011–2020 across Ogun State, with the Bells University of Technology Road corridor enlarged (upper left; moderate class).

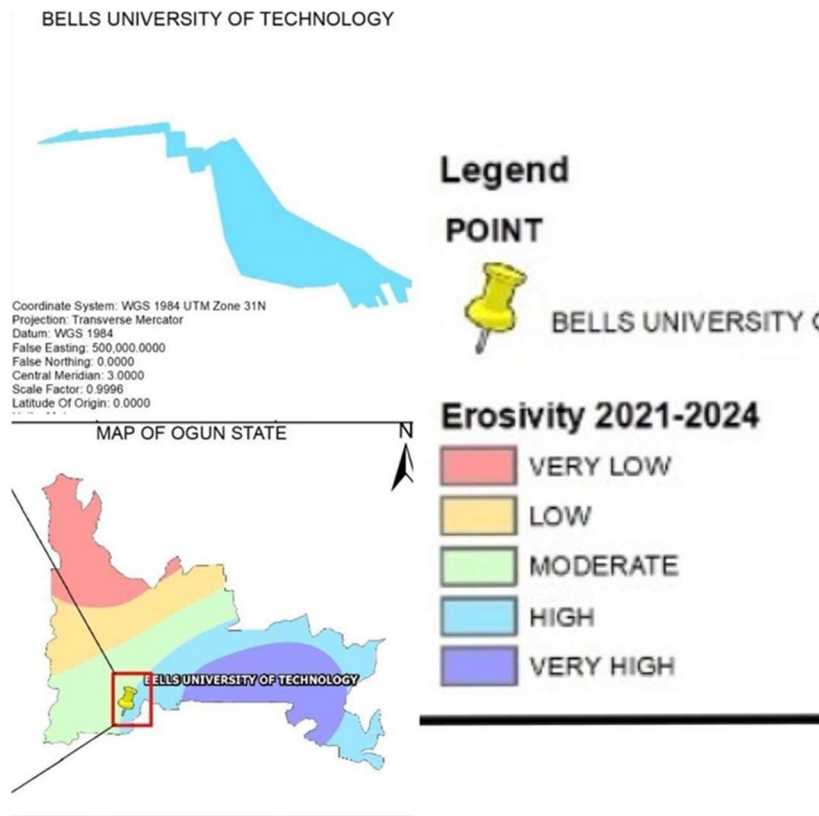


Figure 6: Rainfall erosivity classes for 2021–2024 across Ogun State, with the Bells University of Technology road corridor enlarged (upper left; high class).

Table 7: Support-practice (P) factors by slope class.

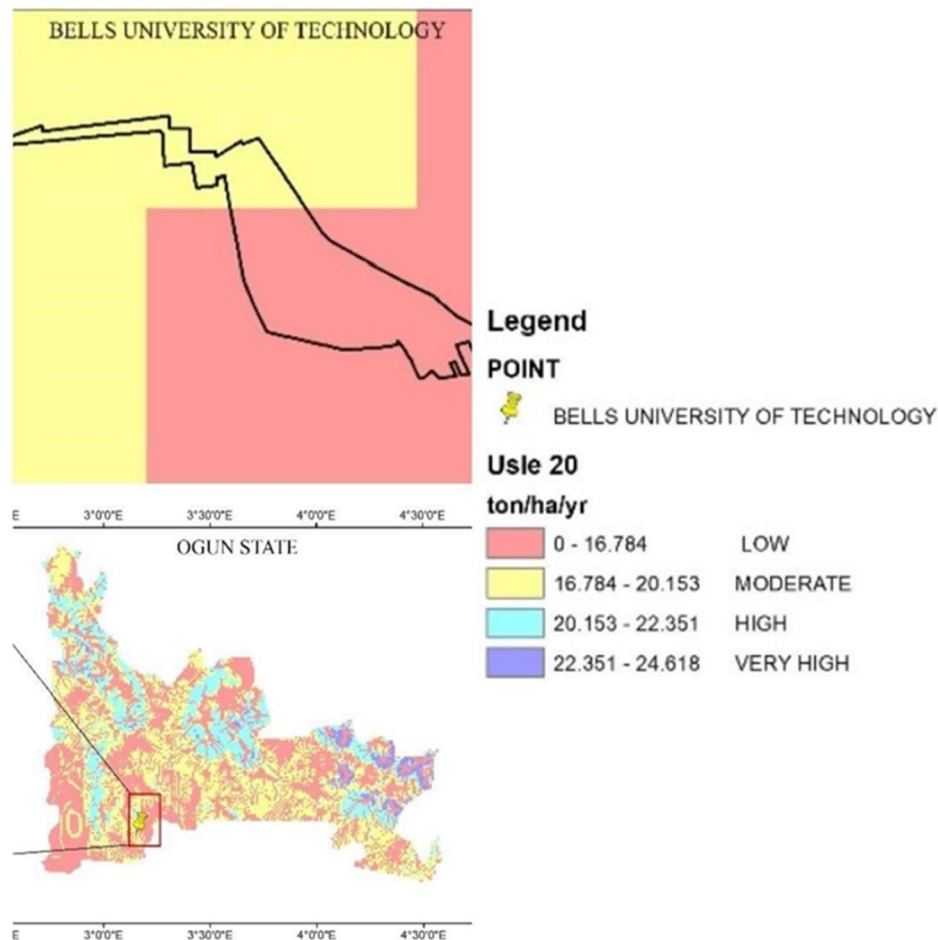
Slope class	Slope range (%)	Contour	Strip cropping	Terracing
1 (very gentle)	0.00–7.00	0.55	0.27	0.10
2 (gentle)	7.01–14.00	0.60	0.30	0.12
3 (moderate)	14.01–21.00	0.80	0.40	0.16
4 (steep)	21.01–28.00	0.90	0.45	0.18
5 (very steep)	> 28.00	1.00	0.50	0.20

Table 8: Soil-loss class limits ($\text{t ha}^{-1} \text{yr}^{-1}$) in the three USLE maps (Figures 7–9).

Class	USLE 15	USLE 20	USLE 25
Low	0–18.236	0–16.784	0–16.473
Moderate	18.236–21.896	16.784–20.153	16.473–19.787
High	21.896–23.284	20.153–22.351	19.787–21.944
Very high	23.284–24.347	22.351–24.618	21.944–24.171
Classes present in the corridor	Low, moderate	Low, moderate	Low, moderate

Class limits are as printed in the legend of each map.

The upper limits of the low and moderate classes fell from 18.2 to 16.5 $\text{t ha}^{-1} \text{yr}^{-1}$ and from 21.9 to 19.8 $\text{t ha}^{-1} \text{yr}^{-1}$ between the first and last maps, whereas the state-wide maximum varied only between 24.2 and 24.6 $\text{t ha}^{-1} \text{yr}^{-1}$. Because the class limits differ among the maps, a change in class cannot be read directly as a change in absolute soil loss.

**Figure 8:** USLE annual soil loss ($\text{t ha}^{-1} \text{yr}^{-1}$), map USLE 20 (2020 epoch), for Ogun State with the road corridor enlarged (upper left). Class limits are given in Table 8.

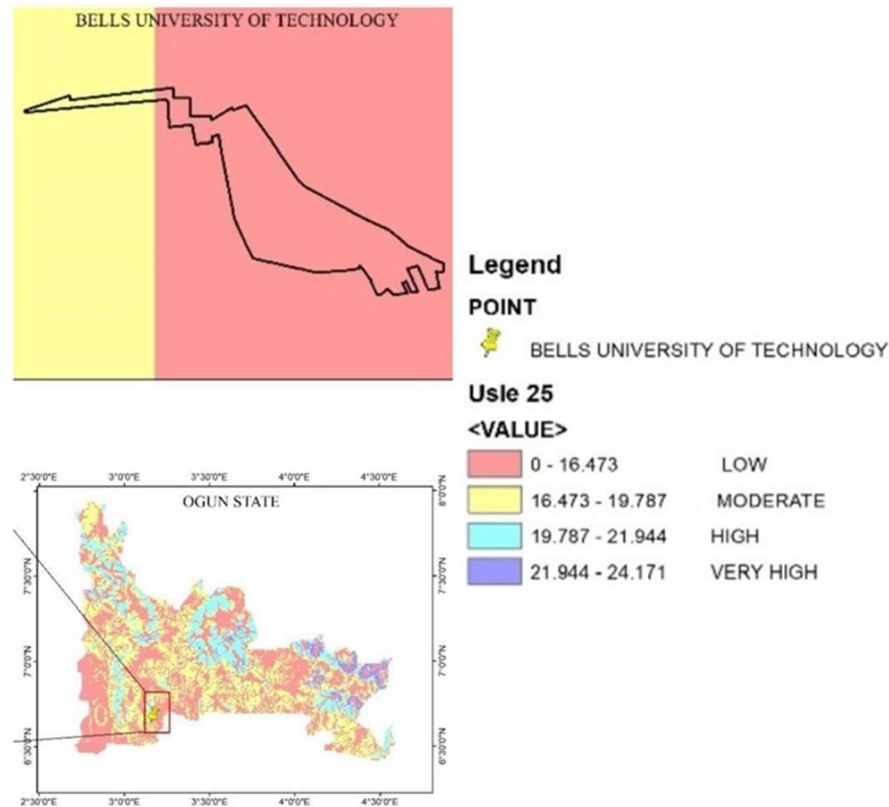


Figure 9: USLE annual soil loss ($\text{t ha}^{-1} \text{yr}^{-1}$), map USLE 25 (2025 epoch), for Ogun State with the road corridor enlarged (upper left). Class limits are given in Table 8.

in global erosivity assessments (Panagos et al., 2017), would improve the estimates.

Soil-Loss Magnitudes in Context

Three points temper the interpretation of (Figures 7–9). First, the low, moderate, high and very high labels are relative classes whose limits change from map to map (Table 8); they are not engineering or agronomic thresholds. Second, in absolute terms even the upper limits of the low class ($16.5\text{--}18.2 \text{ t ha}^{-1} \text{yr}^{-1}$) are more than an order of magnitude above the roughly $1 \text{ t ha}^{-1} \text{yr}^{-1}$ often adopted as the upper bound of tolerable erosion, a value derived for European conditions from soil-formation rates (Verheijen et al., 2009). That benchmark is not directly transferable to humid-tropical road corridors, but it shows that “low” in the map legend should not be read as negligible. Third, the rise in erosivity class between 2011–2020 and 2021–2024 is not mirrored by a steady rise in soil-loss class, and the state-wide maxima are almost identical ($24.2\text{--}24.6 \text{ t ha}^{-1} \text{yr}^{-1}$). Because soil loss is the product of R , K , LS , C and P , an increase in R would be offset only if C or P , the rainfall inputs or the interpolation differed between epochs. Using fixed cover and common class limits across epochs would allow a like-for-like

comparison. Until then the soil-loss maps are best read as a spatial ranking within each epoch, not as evidence for or against a temporal trend, although continued urban expansion and loss of vegetation cover would be expected to push more of the corridor into higher classes.

Roads as Sediment Sources and the Dynamics of Road Erodibility

Road surfaces concentrate flow and deliver sediment efficiently, and unpaved or disturbed roads are consistently found to be among the most erosive land surfaces (Luce & Black, 1999; Ramos-Scharrón & MacDonald, 2005; Sidle & Ziegler, 2012). Foltz et al. (2008) found that rill erodibility of native-surface roads falls exponentially as cumulative overland-flow depth increases while critical shear stress remains unchanged. This implies that after the first erosive events the loosest material is stripped away, which has two consequences for this study: models that ignore the change tend to over-predict long-run sediment yield, and roads that are regraded or disturbed (for example after maintenance) reset the supply of erodible material and become highly erodible again. Quantified runoff and sediment export from reopened roads (Foltz et al., 2009) illustrates that disturbed surface

return quickly to a high-erosion state.

Implications for Pavement Performance

Water that infiltrates through cracks and edges, or that erodes shoulders and embankments, weakens the structure from below, and moisture damage in asphalt arises through well-understood adhesive and cohesive failure mechanisms (Caro et al., 2008). Climate-related stressors will increase the cost of keeping pavements serviceable (Underwood et al., 2017). On roads in Ota, poorly maintained drains and absence of erosion control at slope breaks are therefore likely to accelerate potholing and edge failure.

Mitigation Measures

Drainage Maintenance

Drains carry water away from the surface and subgrade, limit flooding and reduce erosion. Effective maintenance includes inspection after heavy rainfall to find blockages and debris build-up, regular cleaning of streets and the surrounding environment so that solid debris does not block drains, and public awareness, since community participation sustains these efforts.

Step-Downs on Steep Slopes

A step-down is an engineering technique that breaks a steep road or drainage line into intermittent horizontal platforms, reducing the effective gradient and the velocity of flow. It is particularly useful in hilly terrain. Because soil loss increases with slope length and steepness (Luce & Black, 1999), shortening continuous slope lengths with cross-drains and step-downs is also the most direct way to reduce the LS term.

Soil Stabilization

Stabilisation improves strength, resistance to erosion and load-bearing capacity. For erosion control it typically involves compaction by rollers or tampers at OMC and the addition of binders or cohesive material such as clay or gravel. Lime treatment, for example, improves the engineering behaviour of clay-bearing soils through cation exchange, flocculation and pozzolanic reaction (Bell, 1996) and would be an option where the fines content is confirmed to be significant.

Limitations

Several limitations should be borne in mind. (i) The tests used a single composite sample, so spatial variability along the corridor is not captured. (ii) Dry sieving may underestimate fines, and the classification is therefore provisional. (iii) R was derived from annual precipitation

rather than rainfall intensity (Angulo-Martínez & Beguería, 2009), and the erosivity maps compare periods of unequal length (ten and four years) in relative classes whose numerical limits are not reported. (iv) The slope length of 643 m is long for the USLE, which was calibrated on much shorter slopes, and long lengths tend to inflate LS unless the slope is segmented at drainage breaks (Benavidez et al., 2018). (v) The USLE estimates sheet and rill erosion only and excludes gully erosion and mass movement (Benavidez et al., 2018), and it does not model erosion of the road surface itself. (vi) Class limits differ among the soil-loss maps, which prevents direct temporal comparison. (vii) Model outputs were not validated against measured sediment yield. Despite these limits, the integrated laboratory and GIS approach gives a practical, low-cost screening tool for road-corridor erosion risk.

CONCLUSIONS

1. Soil along the study corridor is a sandy to gravelly material with plastic fines. Natural moisture content was 8.95%, the liquid limit 31.1%, the plastic limit 18.7% and the plasticity index about 12.4%. The sand is uniformly graded ($C_u = 4.9$, $C_c = 0.86$), and the soil is provisionally classed A-2-6 under AASHTO, pending a washed sieve analysis to confirm the fines content.
2. Compaction is moisture-sensitive. Maximum dry density is about $1,659 \text{ kg/m}^3$ at an optimum moisture content of about 14.5%, density falls sharply on the wet side of optimum, and the natural moisture content is about 5.5 percentage points below optimum, so construction and maintenance must control moisture closely.
3. Rainfall erosivity at the corridor moved from the moderate class in 2011–2020 to the high class in 2021–2024, and Ogun State receives more rainfall in the second half of the year than in the first. Drainage and road design should therefore be based on peak-season rainfall.
4. Mapped USLE soil loss falls in the low and moderate classes, with class upper limits of about $16.5\text{--}22 \text{ t ha}^{-1} \text{ yr}^{-1}$ and a state-wide maximum near $24.6 \text{ t ha}^{-1} \text{ yr}^{-1}$. These rates are far above commonly cited tolerable erosion rates, although class limits differ among the maps and a temporal trend in soil loss cannot be resolved.
5. The study area is underlain by Quaternary–Tertiary sedimentary deposits within a state whose wider geology is dominated by the Precambrian Basement Complex. Without adequate drainage, slope control and erosion-resistant materials, roads in this setting will progressively lose surface material and deteriorate.

RECOMMENDATIONS

1. Give priority to drainage: keep drains free-flowing, remove sediment and debris after storms, and design channels to carry peak-season flows without deposition.
2. Break up steep or long slopes with step-downs, cross-drains or properly built embankments to shorten effective slope length and reduce flow velocity.
3. Compact subgrade and base layers at or near the optimum moisture content and verify density against the maximum dry density.
4. Consider stabilisation (for example lime or other binders, or gravel and clay additions) where wash-sieve and hydrometer tests confirm a significant fines fraction.
5. Confirm the soil classification with wet sieving (ASTM D1140) and hydrometer analysis, and test more samples along the corridor.
6. Replace annual-total estimates of erosivity with high-resolution rainfall data, segment slope lengths at drainage breaks, apply common class limits and fixed cover across epochs, and validate soil-loss estimates with field sediment measurements.
7. Extend the investigation to road spans longer than 1 km and to additional road sections across Ota.

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