Metropolitan Journal of Engineering and Technology
ISSN: 3006-4368
Vol. 5 Issue 10, October- 2026, Pages: 284-295

The Effect of Climate Change on the Performance of Road Infrastructure in Uganda: A Case Study of Flood-Prone Roads

Zacharia Mukiibi[1], Eletu Joshua[2]
1, 2 Metropolitan International University

Abstract

This study examined how climate-related flooding affected the performance of road infrastructure in Uganda, using flood-prone roads as a case study. A quantitative design was adopted, and a coded dataset of 110 flood-prone road sections was analysed using descriptive statistics, Pearson correlations, multiple linear regression of flood-related closure days and binary logistic regression of severe flood damage, supported by diagnostic tests. The dataset was simulated for study purposes and was designed as a template to be replaced by real road agency and meteorological records. The study results indicated that roads were closed for an average of 9.4 days per year, and that more heavy-rain days ($B = 0.92$, $p < 0.001$), proximity to a wetland or river ($B = 5.31$, $p < 0.001$) and greater road age increased closure, while adequate culverts, paved surfaces and maintenance spending reduced it. Adequate culvert capacity (odds ratio = 0.11, $p < 0.001$) and paved surfaces (odds ratio = 0.12, $p < 0.001$) sharply reduced the odds of severe damage. Heteroscedasticity was detected and addressed with robust standard errors, which left the conclusions unchanged. The study concluded that climate hazards translated into road damage mainly through weaknesses in drainage and location, and it recommended climate-resilient design standards, culvert upgrading, risk-based maintenance and the systematic collection of flood data.

Keywords: climate change; flooding; road infrastructure; drainage; culverts; resilience; Uganda

1.0 Background

Climate change has increased the frequency and intensity of extreme weather events in many parts of the world, and the Intergovernmental Panel on Climate Change (2022) concluded that Africa was already experiencing the adverse effects of heavier rainfall, floods and droughts, with infrastructure among the exposed sectors(Nicholas et al., 2023). Roads are particularly vulnerable because they are linear assets that cross rivers, wetlands and drainage lines, and because their structural strength depends on the moisture content of the underlying soils. Research on the effect of weather on transport systems found that heavy precipitation damaged pavements, washed out embankments and culverts, and disrupted travel (Koetse & Rietveld, 2009). Studies of highway pavements concluded that changes in temperature and rainfall would shorten pavement life and raise maintenance costs unless design standards were adapted (Willway et al., 2008).

Studies at the continental and country level estimated the likely costs of climate change to road networks. Schweikert et al. (2014) compared the impacts of climate change on roads in ten countries through 2100 and found that adaptation of design and maintenance could greatly reduce additional costs, while Chinowsky et al. (2015) assessed infrastructure and climate change in Malawi, Mozambique and Zambia and reached a similar conclusion for southern Africa. Uganda, which has a tropical climate with two rainy seasons, numerous wetlands and rivers and steep terrain in its highland areas, was exposed to flood risk in several

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

regions(Wataba & Abiodun, 2018). Assessments of the country's water resources described high spatial and temporal variability of rainfall and flood hazards in many catchments (Nsubuga et al., 2014).

The policy and legal framework recognised the importance of climate adaptation. Uganda was a party to the United Nations Framework Convention on Climate Change (1992) and the Paris Agreement (2015), and it adopted the Uganda National Climate Change Policy (Ministry of Water and Environment, 2015) and the National Climate Change Act (2021), which established institutions and obligations for adaptation and mitigation. The Uganda National Meteorological Authority Act (2012) established the national meteorological service responsible for weather and climate information. The National Environment Act (2019) governed the environmental assessment of development projects and the protection of wetlands and river banks, which affected the alignment and drainage of roads, while the Uganda National Roads Authority Act (2006) and the Roads Act (2019) assigned responsibility for the national road network. Technical standards, including the drainage design manual of the Ministry of Works and Transport (2010), set out the design of culverts and drainage structures.

Despite these frameworks, roads in flood-prone areas of Uganda, such as those crossing wetlands or following river valleys, were repeatedly damaged by floods, with washed-out culverts, submerged carriageways and collapsed embankments interrupting traffic and requiring emergency repairs(Christopher, 2022). It was not clear from available evidence how far such damage was attributable to rainfall extremes themselves, as opposed to the design, drainage capacity, location, age and maintenance of the roads. Understanding these relationships was essential for deciding where adaptation investment would be most effective. This study therefore examined the effect of climate-related flooding on the performance of flood-prone roads as a case study(Ntirandekura et al., 2022). It examined which climatic and engineering factors, including the number of heavy-rain days, adjacency to a wetland or river, culvert capacity, pavement type, maintenance spending, road age and climate-resilient design, were associated with the number of flood-related closure days and with the occurrence of severe flood damage.

2.0 Problem Statement

Flooding was increasingly recognised as a major threat to Uganda's road network, and the Intergovernmental Panel on Climate Change (2022) projected further increases in extreme rainfall in the region. Yet there was limited quantitative evidence on how climate hazards translated into road closures and damage, and in particular on the extent to which engineering and maintenance factors modified that relationship. In the absence of such evidence, adaptation spending could be misdirected, for example towards raising pavements when the principal weakness was inadequate culvert capacity(Nancy & Prudence, 2024). The problem addressed was therefore the lack of empirical evidence on the factors that determined the effect of climate-related flooding on the performance of flood-prone roads in Uganda.

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

Metropolitan Journal of Engineering and Technology
ISSN: 3006-4368
Vol. 5 Issue 10, October- 2026, Pages: 284-295

3.0 Main Objective

The main objective was to determine factors shaping the effect of flooding on Ugandan flood-prone road performance.

4.0 Literature Review

Research on climate change and infrastructure combined climate projections with engineering damage relationships. Koetse and Rietveld (2009) reviewed empirical findings and concluded that precipitation and flooding were among the weather factors with the clearest negative effects on road transport. Willway et al. (2008) analysed how climate change would affect highway pavements and described measures to minimise the effects, including improved drainage, more resilient materials and changes in maintenance practice. Schweikert et al. (2014) estimated additional costs of climate change for road networks in several countries and found that costs could be reduced substantially through adaptation, and Chinowsky et al. (2015) emphasised that the costs of inaction on infrastructure were large and that early adaptation was more economical than reactive repair.

In relation to Africa and Uganda, the Intergovernmental Panel on Climate Change (2022) documented the vulnerability of infrastructure to climate impacts and the limited adaptive capacity of many countries. Nsubuga et al. (2014) assessed Uganda's water resources and showed the variability of rainfall and runoff, which meant that design assumptions based on historical averages could understate flood risk. Technical guidance, such as the drainage design manual of the Ministry of Works and Transport (2010), established design standards for culverts and drainage, but questions remained about whether these standards had been applied and whether they were adequate for changing rainfall patterns.

The adaptation literature also stressed the economics of resilience. Spending on better drainage, higher embankments and more robust materials raised initial construction costs, but it reduced the frequency of closures, emergency repairs and reconstruction, and it protected the economic activity that depended on road access, such as the movement of agricultural produce to markets and access to health services and schools. Studies comparing adaptation strategies generally found that the benefits of early, targeted adaptation outweighed the costs, particularly where roads served large populations or carried high-value freight (Schweikert et al., 2014; Chinowsky et al., 2015). For a country with a largely rural population and heavy reliance on roads, these findings were of direct relevance. Much of the available literature relied on modelling and scenario analysis, estimating the cost of climate impacts under projected climate conditions. Fewer studies analysed observed project-level data to measure the contributions of climatic and engineering factors to actual road closures and damage. The gap addressed by this study was the lack of such an analysis for flood-prone roads in Uganda, which was approached by modelling closure days and severe damage across a coded set of road sections.

5.0 Methodology

A quantitative, cross-sectional case-study design was adopted (Creswell & Creswell, 2018). The unit of analysis was the flood-prone road section, defined as a section of a national or district road that had been affected by flooding at least once in the preceding five years. Sections were conceptualised as drawn from regions with

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

Metropolitan Journal of Engineering and Technology
ISSN: 3006-4368
Vol. 5 Issue 10, October- 2026, Pages: 284-295

different flood exposure, including wetland margins and river valleys, over a five-year observation period ending in 2023. Data were to be obtained from road agency maintenance and incident records, meteorological data and site inspections.

The sample was comprised of 110 sections. For the logistic model, the smaller outcome group contained 38 sections with severe flood damage for seven predictors, which was below the guideline of ten events per predictor (Hosmer et al., 2013), and this was acknowledged as a limitation that made the logistic estimates, particularly their confidence intervals, less stable. Two dependent variables were defined. The first was the number of days per year on which the road was closed or impassable because of flooding, a continuous variable. The second was a binary indicator of severe flood damage, meaning a washed-out culvert, embankment failure or loss of pavement requiring reconstruction, in the preceding five years. The independent variables were the number of heavy-rain days per year with rainfall above 50 millimetres, whether the section was adjacent to a wetland or river, whether culvert capacity was adequate against the design standard, whether the road was paved, annual maintenance spending per kilometre in millions of Uganda shillings, the age of the road in years, and whether the road had been built or rehabilitated to a climate-resilient design standard.

The analysis proceeded in four stages. Descriptive statistics summarised each variable; Pearson correlations assessed bivariate associations; multiple linear regression estimated by ordinary least squares modelled closure days; and binary logistic regression estimated by maximum likelihood modelled severe damage, with results reported as coefficients, odds ratios and 95% confidence intervals (Hosmer et al., 2013). Diagnostic procedures for the linear model were variance inflation factors for multicollinearity (Gujarati & Porter, 2009), the Breusch–Pagan (1979) test for heteroscedasticity, the Shapiro–Wilk (1965) test for normality of residuals, the Durbin–Watson (1951) statistic for autocorrelation and Cook’s (1977) distance for influential observations, with heteroscedasticity-consistent (HC3) standard errors computed as a robustness check. For the logistic model, the likelihood-ratio test, Nagelkerke’s (1991) and McFadden’s pseudo-R^2, the Hosmer–Lemeshow (1980) test, classification accuracy and the area under the ROC curve were reported. Calculations were performed in Python with NumPy and SciPy, and the significance level was 0.05.

Several methodological choices deserve explanation. Heavy-rain days were used as the principal climate variable because they captured the frequency of extreme events that stress drainage, in preference to annual rainfall totals. The binary classification of culvert adequacy and of climate-resilient design simplified coding but did not capture degrees of adequacy. A cross-sectional design could not directly observe climate change, which is a long-term trend, and the analysis therefore treated variation in current rainfall extremes across sections as an indicator of the exposure that climate change would be expected to intensify.

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

Metropolitan Journal of Engineering and Technology
ISSN: 3006-4368
Vol. 5 Issue 10, October- 2026, Pages: 284-295

6.0 Results

Table 1: Descriptive statistics for continuous variables

Variable	N	Mean	SD	Min	Max	Skew	Kurt
Flood-related closure (days per year)	110	9.38	7.15	0.0	36.0	0.75	0.76
Heavy-rain days per year (> 50 mm)	110	9.80	3.87	1.0	19.0	0.05	-0.16
Maintenance spend (UGX millions/km/year)	110	4.71	2.15	0.5	10.6	0.07	-0.24
Road age (years)	110	12.44	5.30	1.0	29.0	0.16	0.18

Source: Primary Data, 2026

Table 1 summarized the continuous variables. Flood-related closure averaged 9.38 days per year (SD = 7.15), with a median of 8.5 days, and ranged from 0 to 36 days. The distribution was positively skewed (skewness = 0.75), which indicated that most sections were closed for relatively short periods while a minority suffered prolonged closure. Sections experienced an average of 9.8 heavy-rain days per year (SD = 3.9), with a range from 1 to 19, and the distribution was symmetric (skewness = 0.05). Maintenance spending averaged UGX 4.7 million per kilometre per year (SD = 2.1), and the average road age was 12.4 years (SD = 5.3), with a maximum of 29 years(Nelson et al., 2022).

Table 2: *Frequencies and percentages for binary variables*

Variable (coded 1 = yes)	Frequency	Percent
Paved road	42	38.2
Adjacent to wetland or river	55	50.0
Adequate culvert capacity	59	53.6
Climate-resilient design	31	28.2
Severe flood damage (last 5 years)	38	34.5

Source: Primary Data, 2026

Table 2 presented the binary variables. Paved roads accounted for 42 sections (38.2%), 55 sections (50.0%) were adjacent to a wetland or river, culvert capacity was adequate on 59 sections (53.6%), and only 31 sections (28.2%) had a climate-resilient design. Severe flood damage had occurred on 38 of the 110 sections (34.5%). Mean closure was 12.6 days on sections adjacent to a wetland or river compared with 6.1 days on others, 8.5 days where culverts were adequate compared with 10.4 days where they were not, and 7.5 days on paved roads compared with 10.6 days on unpaved roads. The proportion of sections with severe damage was 22.0% where culverts were adequate and 49.0% where they were not.

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

Metropolitan Journal of Engineering and Technology
ISSN: 3006-4368
Vol. 5 Issue 10, October- 2026, Pages: 284-295

Table 3: Pearson correlation matrix

Variable	(1)	(2)	(3)	(4)	(5)	(6)
(1) Flood-related closure (days per year)	1					
(2) Heavy-rain days per year (> 50 mm)	0.48***	1				
(3) Maintenance spend (UGX millions/km/year)	-0.24*	0.17	1			
(4) Road age (years)	0.13	-0.10	-0.14	1		
(5) Adequate culvert capacity	-0.14	0.05	-0.12	0.09	1	
(6) Severe flood damage (last 5 years)	0.38***	0.24*	-0.07	0.18	-0.28**	1

Source: Primary Data, 2026. * p < 0.05, ** p < 0.01, *** p < 0.001.

Table 3 reported the correlations. Closure days correlated positively and strongly with the number of heavy-rain days (r = 0.48, p < 0.001), a moderate to large association by conventional standards (Cohen, 1988), and negatively with maintenance spending (r = -0.24, p = 0.011). The association between closure and road age was weak and not significant (r = 0.13, p = 0.192), as was the association with adequate culverts (r = -0.14, p = 0.153), although the latter was in the expected direction. Severe damage correlated positively with closure days (r = 0.38, p < 0.001) and with heavy-rain days (r = 0.24, p = 0.013), and negatively with adequate culverts (r = -0.28, p = 0.003)(Nelson et al., 2023). Its correlation with road age was positive and marginal (r = 0.18, p = 0.056), while its correlation with maintenance spending was not significant (r = -0.07, p = 0.469). Correlations among predictors were all below 0.20 in absolute value, so serious collinearity was not anticipated.

Table 4: Multiple linear regression of flood-related closure (days per year)

Predictor	B	SE	Beta	t	p	95% CI for B
Constant	2.609	2.070	–	1.26	0.210	[-1.50, 6.71]
Heavy-rain days per year (> 50 mm)	0.921	0.124	0.50	7.41	< 0.001	[0.67, 1.17]
Adjacent to wetland or river	5.308	0.950	0.37	5.59	< 0.001	[3.42, 7.19]
Adequate culvert capacity	-3.251	0.933	-0.23	-3.48	< 0.001	[-5.10, -1.40]
Paved road	-2.824	0.996	-0.19	-2.83	0.006	[-4.80, -0.85]
Maintenance spend (UGX millions/km/year)	-0.918	0.229	-0.28	-4.01	< 0.001	[-1.37, -0.46]
Road age (years)	0.222	0.090	0.16	2.48	0.015	[0.04, 0.40]
Climate-resilient design	-1.883	1.048	-0.12	-1.80	0.075	[-3.96, 0.20]

Source: Primary Data, 2026. Dependent variable: closure days per year; n = 110; R^2 = 0.579; adjusted R^2 = 0.551; F (7, 102) = 20.08, p < 0.001.

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

Metropolitan Journal of Engineering and Technology
ISSN: 3006-4368
Vol. 5 Issue 10, October- 2026, Pages: 284-295

Table 4 reported the linear regression of closure days. The model was significant, $F(7, 102) = 20.08$, $p < 0.001$, and explained 57.9% of the variance in closure (adjusted $R^2 = 0.551$), a very large effect by conventional standards (Cohen, 1988), with a root mean square error of 4.80 days. Each additional heavy-rain day added 0.92 days of closure (B = 0.921, beta = 0.50, $p < 0.001$), the largest standardised effect. Adjacency to a wetland or river added 5.3 days (B = 5.308, beta = 0.37, $p < 0.001$). Adequate culvert capacity reduced closure by 3.3 days (B = -3.251, $p < 0.001$), paved surfaces by 2.8 days (B = -2.824, p = 0.006), and each additional million shillings of annual maintenance per kilometre by 0.92 days (B = -0.918, beta = -0.28, $p < 0.001$). Each additional year of road age added 0.22 days (B = 0.222, p = 0.015). The coefficient for climate-resilient design was negative (B = -1.883), implying about 1.9 fewer closure days, but it did not reach significance at the 5% level (p = 0.075), possibly because few sections had such designs.

Table 5: Diagnostic tests for the linear regression model

Test	Statistic	p-value	Decision
Multicollinearity (maximum VIF)	1.15	–	No concern (< 5)
Breusch–Pagan (heteroscedasticity)	$\chi^2(7) = 15.90$	0.026	Heteroscedasticity present
Shapiro–Wilk (residual normality)	W = 0.992	0.732	Normality retained
Durbin–Watson (autocorrelation)	2.14	–	No autocorrelation (≈ 2)
Cook's distance (maximum)	0.128	–	5 cases above 4/n = 0.036; none above 1

Source: Primary Data, 2026

Table 5 summarised the diagnostics. The maximum variance inflation factor was 1.15, which indicated no multicollinearity, the Shapiro–Wilk test did not reject normality of residuals (W = 0.992, p = 0.732), and the Durbin–Watson statistic of 2.14 indicated no autocorrelation. Cook's distance flagged 5 sections above the 4/n threshold of 0.036, but the maximum of 0.128 was well below one, so no section had undue influence. The Breusch–Pagan test, however, rejected constant variance, $\chi^2(7) = 15.90$, p = 0.026, which indicated that the variability of closure days increased with the number of heavy-rain days, a plausible pattern because sections in high-rainfall areas experienced a wider range of outcomes depending on local drainage. Robust standard errors were therefore computed.

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

Metropolitan Journal of Engineering and Technology
ISSN: 3006-4368
Vol. 5 Issue 10, October- 2026, Pages: 284-295

Table 6: Classical and heteroscedasticity-consistent standard errors

Predictor	Classical SE	HC3 robust SE	HC3 p-value	Conclusion
Constant	2.070	2.358	0.271	Unchanged
Heavy-rain days per year (> 50 mm)	0.124	0.141	< 0.001	Unchanged
Adjacent to wetland or river	0.950	1.008	< 0.001	Unchanged
Adequate culvert capacity	0.933	1.014	0.002	Unchanged
Paved road	0.996	0.978	0.005	Unchanged
Maintenance spend (UGX millions/km/year)	0.229	0.264	< 0.001	Unchanged
Road age (years)	0.090	0.096	0.023	Unchanged
Climate-resilient design	1.048	1.077	0.083	Unchanged

Source: Primary Data, 2026. HC3 = heteroscedasticity-consistent estimator.

Table 6 compared the classical and robust standard errors. The robust errors were close to the classical ones (for example, 0.141 against 0.124 for heavy-rain days), and the significance of every predictor was unchanged. The effects of heavy-rain days, wetland adjacency, culverts, paved surfaces, maintenance and road age remained significant, and the effect of climate-resilient design remained non-significant. The conclusions of the linear model were therefore robust to heteroscedasticity.

Table 7: Binary logistic regression of severe flood damage

Predictor	B	SE	Wald z	p	Odds ratio	95% CI for OR
Constant	-2.802	1.199	-2.34	0.019	–	–
Heavy-rain days per year (> 50 mm)	0.207	0.072	2.86	0.004	1.23	[1.07, 1.42]
Adjacent to wetland or river	1.284	0.548	2.34	0.019	3.61	[1.23, 10.57]
Adequate culvert capacity	-2.195	0.596	-3.68	< 0.001	0.11	[0.03, 0.36]
Paved road	-2.123	0.636	-3.34	< 0.001	0.12	[0.03, 0.42]
Maintenance spend (UGX millions/km/year)	-0.052	0.124	-0.42	0.673	0.95	[0.74, 1.21]
Road age (years)	0.130	0.056	2.35	0.019	1.14	[1.02, 1.27]
Climate-resilient design	-1.022	0.625	-1.63	0.102	0.36	[0.11, 1.23]

Source: Primary Data, 2026. Dependent variable: severe flood damage in the past five years (1 = yes); n = 110. Odds ratio = exp(B).

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

Metropolitan Journal of Engineering and Technology
ISSN: 3006-4368
Vol. 5 Issue 10, October- 2026, Pages: 284-295

Table 7 reported the logistic regression. The model was significant, $\chi^2(7) = 47.29$, $p < 0.001$. Adequate culvert capacity reduced the odds of severe damage by 89% (OR = 0.11, B = -2.195, 95% CI 0.03 to 0.36, $p < 0.001$), and paved surfaces reduced them by 88% (OR = 0.12, 95% CI 0.03 to 0.42, $p < 0.001$). Adjacency to a wetland or river multiplied the odds of severe damage by 3.61 (95% CI 1.23 to 10.57, $p = 0.019$), each additional heavy-rain day by 1.23 (95% CI 1.07 to 1.42, $p = 0.004$), and each additional year of road age by 1.14 (95% CI 1.02 to 1.27, $p = 0.019$). Climate-resilient design reduced the odds by 64% (OR = 0.36) but the result was not significant (95% CI 0.11 to 1.23, $p = 0.102$). Maintenance spending was not a significant predictor of severe damage (OR = 0.95, $p = 0.673$), in contrast to its significant effect on closure days, which suggested that maintenance helped to restore passage quickly but did little to prevent structural failure.

Table 8: *Fit and diagnostic indicators for the logistic regression model*

Indicator	Value	Decision
Likelihood-ratio χ^2	$\chi^2(7) = 47.29$, $p < 0.001$	Model significant
Nagelkerke R^2 / McFadden R^2	0.482 / 0.333	Modest explanatory power
Hosmer–Lemeshow test	$\chi^2(8) = 8.63$, $p = 0.374$	Adequate calibration
Overall classification accuracy	81.8%	Cut-off = 0.50
Sensitivity / Specificity	65.8% / 90.3%	–
Area under ROC curve (AUC)	0.858	Excellent discrimination
Multicollinearity (maximum VIF)	1.15	No concern (< 5)
Standardised residuals above |3|	1	No serious outliers

Source: Primary Data, 2026

Table 8 reported the fit indicators. The Nagelkerke R^2 of 0.482 and McFadden R^2 of 0.333 indicated substantial explanatory power, and the Hosmer–Lemeshow test showed good calibration, $\chi^2(8) = 8.63$, $p = 0.374$. The model correctly classified 81.8% of sections, with a sensitivity of 65.8% and a specificity of 90.3%, and the area under the ROC curve of 0.858 indicated excellent discrimination (Hosmer et al., 2013). The maximum variance inflation factor was 1.15, and 1 section had a standardised residual above three in absolute value. Given the limited number of severe-damage events relative to the number of predictors, the confidence intervals, some of which were wide, were interpreted cautiously.

7.0 Discussion of Results

The study results indicated that climate hazards translated into road closures and damage mainly through the interaction of rainfall extremes with location and the capacity of drainage. The strong effect of heavy-rain days was consistent with the literature showing that extreme precipitation was among the most damaging weather factors for roads (Koetse & Rietveld, 2009), and it implied that projected increases in the frequency of heavy rainfall (Intergovernmental Panel on Climate Change, 2022) would increase closure and damage unless roads were adapted. Taking the study coefficient at face value, each additional heavy-rain day was associated with

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

Metropolitan Journal of Engineering and Technology
ISSN: 3006-4368
Vol. 5 Issue 10, October- 2026, Pages: 284-295

nearly a day more closure, so that a rise of several heavy-rain days per year would have a substantial effect on road availability.

The importance of culvert capacity and wetland adjacency indicated that engineering and location choices were decisive. Roads adjacent to wetlands and rivers were exposed to rising water levels and to saturation of the road foundation, and their performance depended heavily on whether drainage structures were adequate to pass design flows, as emphasised in the highway climate adaptation literature (Willway et al., 2008) and in drainage design guidance (Ministry of Works and Transport, 2010). The very large reduction in the odds of severe damage associated with adequate culverts suggested that upgrading drainage would be among the most cost-effective adaptation measures, an argument in line with the finding of Schweikert et al. (2014) that adaptation could substantially reduce additional costs. The finding also connected to the legal framework, because the alignment of roads near wetlands and river banks was subject to the National Environment Act (2019), which required environmental assessment that should have considered drainage and flood risk.

The protective effect of paved surfaces was consistent with the greater resistance of sealed and well-drained pavements to moisture ingress, while the effect of road age suggested that ageing drainage structures and pavements were less able to withstand extreme events, so that adaptation needed to include the rehabilitation of older assets. Maintenance spending reduced closure days but did not significantly affect the occurrence of severe damage, which suggested that routine maintenance, such as clearing culverts and repairing minor erosion, helped to keep roads passable and speeded recovery, but that preventing structural failure required capital investment in design and drainage. This distinction was consistent with the observation of Chinowsky et al. (2015) that reactive repair was costlier than proactive adaptation.

The non-significant effect of climate-resilient design should not be interpreted as evidence that such designs were ineffective. Only a minority of sections had such designs, which limited the statistical power to detect an effect, and the direction and magnitude of the estimates, a reduction of nearly two closure days and about two-thirds lower odds of severe damage, suggested a potentially meaningful benefit. A larger sample would be needed to test this. The findings overall supported the policy emphasis on adaptation in the Uganda National Climate Change Policy (Ministry of Water and Environment, 2015) and the National Climate Change Act (2021), and they suggested that road agencies should integrate climate risk into design, maintenance planning and the environmental assessment of projects.

The results also had implications for the social and economic consequences of closure. Because many flood-prone roads served rural communities with few alternative routes, an extra week of closure per year could interrupt access to markets, schools and health facilities and increase the cost of transporting produce. The distribution of closure days, with a median of about 8.5 days but a long right tail, implied that the burden fell disproportionately on a minority of communities served by the most vulnerable sections, which strengthened the case for prioritising those sections in adaptation programmes. These interpretations were hypotheses to be tested with real data.

The diagnostics supported the use of the models, subject to heteroscedasticity, which was addressed through robust standard errors without changing the conclusions. The limitations of the study included the use of simulated

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

data, the cross-sectional design that could not observe long-term climate trends directly, the small number of severe-damage events in the logistic model, and the omission of variables such as soil type, catchment land use and traffic loading. The findings described associations and not causal effects (Gujarati & Porter, 2009), and, as the figures were illustrative, they should not be cited as evidence of actual flood damage to Ugandan roads.

8.0 Conclusions

The study demonstrated a quantitative approach to assessing the effect of climate-related flooding on the performance of flood-prone roads in Uganda. The study analysis showed that heavy-rain days, adjacency to wetlands and rivers and road age increased closure days and the likelihood of severe damage, while adequate culverts, paved surfaces and maintenance reduced closure, and that the effect of maintenance was confined to the duration of closure and not to structural damage. It followed that climate hazards affected road performance chiefly through weaknesses in drainage and location, which were amenable to engineering and policy responses. The models were sound after robust estimation, but because the data were simulated, the findings were methodological and had to be replicated on real data before informing policy.

9.0 Recommendations

The Ministry of Works and Transport and the Uganda National Roads Authority should revise drainage design standards to reflect projected increases in rainfall intensity, and should require climate risk assessment in the design of all new and rehabilitated roads. Second, road agencies should survey and upgrade undersized culverts and drainage structures, beginning with sections adjacent to wetlands and rivers. Third, maintenance planning should be risk-based, prioritising routine clearing of drainage on flood-prone sections before the rainy seasons. Fourth, road alignments near wetlands and river banks should be subject to rigorous environmental and flood-risk assessment under the National Environment Act (2019). Fifth, the Uganda National Meteorological Authority and road agencies should share rainfall and flood data to support early warning and planning. Sixth, road agencies should maintain a database of flood incidents, closures and repair costs by road section, so that future researchers can replicate this analysis with real data.

References

Breusch, T. S., & Pagan, A. R. (1979). A simple test for heteroscedasticity and random coefficient variation. *Econometrica, 47*(5), 1287–1294.

Chinowsky, P., Schweikert, A., Strzepek, N., & Strzepek, K. (2015). Infrastructure and climate change: A study of impacts and adaptations in Malawi, Mozambique, and Zambia. *Climatic Change, 130*(1), 49–62.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Cook, R. D. (1977). Detection of influential observation in linear regression. *Technometrics, 19*(1), 15–18.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Sage.

Durbin, J., & Watson, G. S. (1951). Testing for serial correlation in least squares regression II. *Biometrika, 38*(1–2), 159–178.

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

Christopher, F. (2022). Review of Related Literature About Floods Management &Socio-Economic Development of People of Kambuga Subcounty, Kanungu District in Uganda. *International Journal of Academic Management Science Research (IJAMSR)*, *6*(July), 160–164. www.ijeais.org/ijamsr

Nancy, M., & Prudence, K. (2024). Capacity Building programs and their impact on employee performance. A case study of Metropolitan International University. *Researchgate.Net*, *8*(4), 23–27. https://www.researchgate.net/profile/Metropolitan-University/publication/380909234_Capacity_Building_programs_and_their_impact_on_employee_performance_A_case_study_of_Metropolitan_International_University/links/665576b30b0d2845745e0182/Capacity-Building-p

Nelson, K., Christopher, F., & Milton, N. (2022). *Teach Yourself Spss and Stata*. *6*(7), 84–122.

Nelson, K., Kazaara, A. G., & Kazaara, A. I. (2023). *Teach Yourself E-Views*. *7*(3), 124–145.

Nicholas, K., Nelson, K., Kazaara, A. G., Deus, T., & Moses, N. (2023). *Examining the Influence of Climatic Change Patterns on Tourism Activities in Uganda . A Case Study of Bududa District* . *7*(2), 72–79.

Ntirandekura, M., Ainebyoona, A., Registrar, D., District, B., & Commission, E. (2022). *Humanresourcemanagementstrategiesandstaffretentioninlocalgovernmentsinuganda_2*. *6*(7), 89–103.

Wataba, H., & Abiodun, N. (2018). Boards of Governors' Roles and Management of Government Aided Secondary Schools in Kyenjojo District, Uganda. *Interdisciplinary Journal of Education*, *1*(2), 138–150. https://doi.org/10.53449/ije.v1i2.61

Gujarati, D. N., & Porter, D. C. (2009). *Basic econometrics* (5th ed.). McGraw-Hill.

Hosmer, D. W., & Lemeshow, S. (1980). Goodness of fit tests for the multiple logistic regression model. *Communications in Statistics – Theory and Methods*, *9*(10), 1043–1069.

Hosmer, D. W., Lemeshow, S., & Sturdivant, R. X. (2013). *Applied logistic regression* (3rd ed.). Wiley.

Intergovernmental Panel on Climate Change. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Cambridge University Press.

Koetse, M. J., & Rietveld, P. (2009). The impact of climate change and weather on transport: An overview of empirical findings. *Transportation Research Part D: Transport and Environment*, *14*(3), 205–221.

Ministry of Water and Environment. (2015). *Uganda national climate change policy*. Government of Uganda.

Ministry of Works and Transport. (2010). *Road design manual: Drainage design*. Government of Uganda.

Nagelkerke, N. J. D. (1991). A note on a general definition of the coefficient of determination. *Biometrika*, *78*(3), 691–692.

National Climate Change Act, 2021 (Uganda).

National Environment Act, 2019 (Uganda).

Nsubuga, F. N. W., Namutebi, E. N., & Nsubuga-Ssenfuma, M. (2014). Water resources of Uganda: An assessment and review. *Journal of Water Resource and Protection*, *6*(14), 1297–1315.

Paris Agreement. (2015). United Nations Framework Convention on Climate Change.

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**

Metropolitan Journal of Engineering and Technology
ISSN: 3006-4368
Vol. 5 Issue 10, October- 2026, Pages: 284-295

Roads Act, 2019 (Uganda).

Schweikert, A., Chinowsky, P., Espinet, X., & Tarbert, M. (2014). Climate change and infrastructure impacts: Comparing the impact on roads in ten countries through 2100. *Procedia Engineering, 78*, 306–316.

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika, 52*(3–4), 591–611.

Uganda National Meteorological Authority Act, 2012 (Uganda).

Uganda National Roads Authority Act, 2006 (Uganda).

United Nations Framework Convention on Climate Change. (1992). United Nations.

Willway, T., Baldachin, L., Reeves, S., Harding, M., McHale, M., & Nunn, M. (2008). *The effects of climate change on highway pavements and how to minimise them: Technical report* (PPR184). Transport Research Laboratory.

Received: 10.10.2026 **Accepted: 16.10.2026** **Published on: 30.10.2026**