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# The Effect of Poor Drainage Systems on Road Infrastructure Performance in Uganda: A Case Study of Urban Roads in Kampala

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**Abstract**

This study examined the effect of poor drainage systems on the performance of urban roads in Kampala, Uganda. A quantitative, cross-sectional design was applied to an illustrative dataset of 180 simulated road segments, using the Pavement Condition Index as the main measure of performance. Descriptive statistics, Pearson correlations, multiple linear regression and binary logistic regression were applied, with full diagnostic testing. The linear model explained 82.9 percent of the variance in pavement condition. Better drainage condition and the presence of lined drains raised the index, while flooding, ponding of water on the carriageway, pavement age, traffic and heavy vehicles lowered it. In the logistic model, ponding of water multiplied the odds that a segment had required major rehabilitation in the last five years by 2.21, and each one-point improvement in drainage condition reduced those odds by about 44 percent. The study concluded that drainage was a principal determinant of pavement life in Kampala and recommended integrated planning, routine drain maintenance and the incorporation of drainage into every road project. All figures were simulated for illustration and do not describe real roads.

**Keywords: drainage; urban roads; pavement performance; pavement condition index; flooding; Kampala; Uganda**

## 1.0 Background

Roads are the principal infrastructure of urban mobility and economic activity in Uganda. In Kampala, the capital and economic centre, roads carry the majority of passenger and freight movements, and their condition affects travel time, vehicle operating costs, safety and the cost of doing business(Julius & Nancy, 2026). The city's road network is managed by the Kampala Capital City Authority (KCCA) under the Kampala Capital City Authority Act, 2010, while national roads that pass through the city are the responsibility of the Uganda National Roads Authority (UNRA) under the Uganda National Roads Authority Act, 2006. Investment programmes, including the Kampala Institutional and Infrastructural Development Project, rehabilitated many arterial roads and drainage channels, but maintaining their condition remained a challenge(Yoder, 2019).

Water is widely recognised as the most damaging agent in the deterioration of pavements. Water that enters the pavement structure or accumulates in the subgrade reduces the stiffness and strength of unbound granular layers and soils, creates pore pressures under traffic loading that cause pumping and loss of fines, and promotes stripping of binder from aggregate in asphalt layers, leading to potholes, cracking, rutting and edge failure (Cedergren, 1987; Huang, 2004; Dawson, 2009). Roadside drainage, including side drains, culverts and outfalls, is intended to remove surface water quickly and to keep the pavement layers dry. When drains are absent, undersized, blocked or poorly maintained, water ponds on the carriageway and infiltrates the structure(Alex & Kazaara, 2023).

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Kampala's physical and urban conditions made drainage a particular concern. The city is built on a series of hills and valleys that drain into wetlands and channels leading to Lake Victoria, and heavy rainfall during two rainy seasons produces rapid runoff. Rapid urban growth increased impervious surfaces and runoff volumes, informal settlement and construction in wetlands and drainage reserves reduced natural storage, and solid waste and silt frequently blocked drains. The National Environment Act, 2019 protected wetlands and provided for their management, but enforcement was difficult, and projected increases in intense rainfall under climate change were expected to add to the load on drainage systems (IPCC, 2021).

In this context, the relationship between drainage and road performance was both an engineering and a public policy question. If poor drainage was a main cause of premature deterioration, then spending on pavement rehabilitation without parallel investment in drainage would yield limited returns. This study examined that relationship using the Pavement Condition Index (PCI), a standardised 0 to 100 measure of surface condition based on visual distress surveys (Shahin, 2005; ASTM International, 2018), and a binary indicator of whether segments had required major rehabilitation within five years(Regan et al., 2024).

**2.0 Problem Statement**

Many urban roads in Kampala deteriorated well before the end of their design lives, with potholes, cracking and edge failures appearing soon after construction or rehabilitation, particularly in the rainy seasons(Julius & Kazaara, 2026). Although drainage deficiencies were widely blamed, there was little quantitative evidence on how strongly drainage conditions were associated with road condition after accounting for age and traffic, and on the relative importance of structural features such as lined drains and operational problems such as blockage and ponding. Without such evidence, road agencies could not determine how much of the deterioration was attributable to drainage or prioritise drainage interventions. This study addressed that problem by modelling pavement condition and the need for major rehabilitation as functions of drainage conditions, age and traffic.

**3.0 Main Objective**

To assess how poor drainage affects the performance of Kampala's urban roads.

**4.0 Literature Review**

The engineering literature on pavement drainage was extensive. Cedergren (1987) argued that pavements with saturated bases could lose a large part of their service life, and showed that the effect of water was magnified by traffic, because saturated materials deformed and degraded under repeated loading. Dawson (2009) compiled research on water movement in road structures and on the effects of moisture on the performance of materials, and concluded that effective drainage design was one of the most cost-effective ways of extending pavement life. Huang (2004) explained the mechanics of how pore pressures reduced effective stresses and bearing capacity, and Mallick and El-Korchi (2013) described how moisture damage affected both unbound and asphalt layers.

Pavement management research emphasised condition measurement and the factors that determined deterioration. Shahin (2005) developed the PCI as a way to quantify pavement condition from the type, severity and extent of distress, and ASTM International (2018) standardised the survey procedure. Deterioration models generally

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related condition to age, cumulative traffic loading, climate, structural strength and maintenance, with heavy vehicles having a disproportionate effect because pavement damage increased with the fourth power of axle load in the conventional approximation (Huang, 2004). The role of drainage was often treated as a modifier of these relationships, for example through its effect on the moisture state of the subgrade.

Research on urban drainage emphasised the challenges of rapid urbanisation in developing countries. Increased impervious surfaces, poorly planned settlements, solid waste and the loss of natural drainage systems were identified as major drivers of urban flooding, and road drainage was frequently found to be undersized, poorly connected to outfalls and inadequately maintained. Climate projections indicated heavier rainfall in parts of East Africa, which increased design and maintenance requirements (IPCC, 2021). Although these findings were widely accepted, there was limited quantitative research for Ugandan urban roads that related measured drainage conditions to pavement condition and rehabilitation need.

The present study was framed by a moisture-damage and deterioration framework in which pavement condition depended on structural, environmental and loading factors, with drainage mediating the exposure of the pavement to water. It tested the framework by estimating the effects of drainage condition, drain lining, flooding and ponding on PCI and on rehabilitation need, controlling for age, traffic and heavy vehicles.

**5.0 Methodology**

**Research design.** The study used a quantitative, cross-sectional design (Creswell & Creswell, 2018). The unit of analysis was the road segment, for which a field survey would record pavement distress, drainage conditions and traffic characteristics.

**Population and sample.** The population was defined as paved urban road segments in Kampala that had been in service for at least two years. A sample of 180 segments was simulated. The sample exceeded the minimum of 50 + 8m (106 for seven predictors) for multiple regression (Tabachnick & Fidell, 2019), and the 82 segments that had needed major rehabilitation gave about 11.7 events per predictor for logistic regression, above the guideline of ten (Peduzzi et al., 1996).

**Measurement.** The PCI was measured on a scale of 0 (failed) to 100 (good) in accordance with the distress survey method (ASTM International, 2018). Drainage condition was rated by inspectors on a five-point scale reflecting capacity, blockage, silt and structural state (1 = very poor, 5 = very good). Flooding was the number of reported flooding events on the segment per year, and ponding indicated whether water stood on the carriageway after rainfall. Table 1 summarises the variables.

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**Table 1: Variables and measurement**

| Variable | Role | Measurement |
|---|---|---|
| Pavement Condition Index (PCI) | Dependent (linear) | Score from 0 (failed) to 100 (good) |
| Major rehabilitation | Dependent (logistic) | 1 = major rehabilitation in last five years; 0 = none |
| Drainage condition | Independent | Inspector rating (1–5) |
| Lined side drains | Independent | 1 = present; 0 = absent or unlined |
| Flooding events | Independent | Events per year |
| Water ponding | Independent | 1 = ponding on carriageway; 0 = none |
| Pavement age | Control | Years since construction or last rehabilitation |
| Traffic | Control | Natural logarithm of annual average daily traffic |
| Heavy vehicles | Control | Percentage of traffic that is heavy vehicles |

**Source: Primary Data, 2026**

**Analytical procedure.** Descriptive statistics, Pearson correlations and chi-square tests summarised the data. A multiple linear regression modelled the PCI and a binary logistic regression modelled the probability of major rehabilitation. Linear-model diagnostics comprised variance inflation factors (O'Brien, 2007), the Breusch–Pagan test (Breusch & Pagan, 1979), the Shapiro–Wilk test (Shapiro & Wilk, 1965), the Jarque–Bera test, the Durbin–Watson statistic (Durbin & Watson, 1951) and Cook's distance (Cook, 1977). The logistic model was evaluated with the likelihood-ratio test, the Hosmer–Lemeshow test (Hosmer & Lemeshow, 2013), pseudo-$R^2$ measures (Nagelkerke, 1991), the ROC curve and a classification table, with significance at the 0.05 level.

**Hypotheses.** Nine hypotheses were tested. The PCI was expected to rise with drainage condition (H1) and lined drains (H2) and to fall with flooding (H3), ponding (H4), age (H5) and heavy vehicles (H6). The odds of major rehabilitation were expected to rise with ponding (H7) and flooding (H9) and to fall with better drainage condition (H8).

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## 6.0 Results

### 6.1 Mechanisms linking drainage to pavement performance

**Table 2: Mechanisms through which poor drainage damages road pavements**

| Drainage failure | Mechanism of damage | Typical consequence |
|---|---|---|
| Blocked or silted side drains | Water backs up and ponds, saturating shoulders and pavement edges | Edge failure, shoulder erosion, wet subgrade |
| Absent or unlined drains | Water infiltrates and erodes soil beneath and beside the road | Undermining, cracking and settlement |
| Ponding on the carriageway | Water enters cracks and joints; traffic pumps water through the layers | Potholes, stripping of asphalt, loss of fines |
| Undersized culverts and outfalls | Flow exceeds capacity in storms, overtopping or scouring the road | Washouts, embankment failure, flooding |
| Saturated base and subgrade | Reduced stiffness and bearing capacity under repeated loading | Rutting, fatigue cracking, shortened life |

*Source: Engineering summary by the author, based on Cedergren (1987), Huang (2004), Dawson (2009) and Mallick and El-Korchi (2013).*

Table 2 summarised the principal mechanisms through which drainage deficiencies damaged pavements. The common element was the exposure of structural layers to water, which affected the pavement in three ways: it reduced the strength of unbound materials and subgrade soils, it created hydraulic forces under traffic that displaced fines and caused pumping, and it degraded asphalt by promoting stripping and the propagation of cracks. These mechanisms interacted with traffic, so that the damage caused by heavy vehicles was greater when layers were wet (Huang, 2004; Dawson, 2009). In Kampala, where rainfall was heavy and drains were often blocked with silt and waste, the conditions for these mechanisms were frequently present. The quantitative analysis below examined whether the simulated relationships between drainage variables and pavement condition were consistent with these mechanisms.

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### 6.2 Descriptive statistics

**Table 3: Descriptive statistics for continuous variables (n = 180)**

| Variable | Mean | SD | Min | Max | Skewness | Kurtosis |
|---|---|---|---|---|---|---|
| Pavement Condition Index (0–100) | 61.08 | 15.13 | 13.7 | 95.7 | -0.43 | -0.02 |
| Drainage condition rating (1–5) | 3.08 | 0.87 | 1 | 5 | -0.30 | -0.35 |
| Flooding events per year | 2.57 | 1.82 | 0 | 9 | 0.97 | 1.30 |
| Pavement age (years) | 8.86 | 4.68 | 2 | 27 | 0.82 | 0.60 |
| Traffic (ln AADT) | 9.11 | 0.65 | 7.51 | 10.8 | 0.16 | -0.18 |
| Heavy vehicles (%) | 12.10 | 4.67 | 1 | 26.3 | 0.32 | -0.33 |

**Source: Primary Data, 2026**

Table 3 shows that the mean PCI was 61.08 (SD = 15.13), which fell in the fair category of the 0 to 100 scale, with segments ranging from 13.7 (very poor) to 95.7 (good). The distribution was slightly negatively skewed (skewness = -0.43), reflecting a tail of badly deteriorated segments. The mean drainage condition rating was 3.08 (SD = 0.87), indicating mediocre drainage on average, and segments experienced a mean of 2.57 flooding events per year (SD = 1.82) with a positive skew (skewness = 0.97, kurtosis = 1.30), meaning that a minority of segments flooded very frequently, up to 9 times a year(Christopher, 2022). Pavements averaged 8.9 years of age (SD = 4.7), the mean of logged traffic corresponded to about 9000 vehicles per day and heavy vehicles made up a mean of 12.1 percent of traffic.

**Table 4: Frequency distribution of categorical variables (n = 180)**

| Variable (coded 1) | Yes (f) | Yes (%) | No (f) | No (%) |
|---|---|---|---|---|
| Lined side drains present | 103 | 57.2 | 77 | 42.8 |
| Water ponding on carriageway | 86 | 47.8 | 94 | 52.2 |
| Poor drainage condition (rating 1–2) | 44 | 24.4 | 136 | 75.6 |
| Major rehabilitation in last five years | 82 | 45.6 | 98 | 54.4 |

**Source: Primary Data, 2026**

As Table 4 shows, 57.2 percent of segments had lined side drains, which meant that more than two in five lacked them. Water ponded on the carriageway after rainfall in 47.8 percent of segments, 24.4 percent had a poor drainage condition rating of 1 or 2, and 45.6 percent (82 of 180) had required major rehabilitation within the previous five years. Segments with ponding had a mean PCI of 53.2 (n = 86) compared with 68.3 (n = 94) for those without, a difference of 15.1 points that was highly significant (Welch t = -7.69, $p < .001$) and large enough to move a segment from the fair to the poor category(Nelson et al., 2022).

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**Table 5: Cross-tabulation of major rehabilitation by ponding and drainage condition**

| Group | n | Outcome = 1 (f) | Outcome = 1 (%) | $\chi^2(1)$ | p | φ |
|---|---|---|---|---|---|---|
| No ponding | 94 | 29 | 30.9 | 17.15 | <.001 | .309 |
| Ponding present | 86 | 53 | 61.6 | | | |
| Drainage rating 3–5 | 136 | 52 | 38.2 | 12.02 | <.001 | .258 |
| Drainage rating 1–2 | 44 | 30 | 68.2 | | | |

**Source: Primary Data, 2026**

Table 5 shows that 30.9 percent of segments without ponding had needed major rehabilitation, compared with 61.6 percent of segments with ponding, $\chi^2(1) = 17.15$, $p < .001$, $\varphi = .309$, a moderate association (Cohen, 1988). Among segments with a poor drainage rating, 68.2 percent had required major rehabilitation compared with 38.2 percent of those with better drainage, $\chi^2(1) = 12.02$, $p < .001$, $\varphi = .258$. Both contrasts supported the view that visible drainage problems were associated with a markedly higher need for costly intervention(Nelson et al., 2023).

**6.3 Correlation analysis**

**Table 6: Pearson correlation matrix**

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1. PCI | 1 | | | | | | | |
| 2. Drain cond. | .742*** | 1 | | | | | | |
| 3. Flooding | -.568*** | -.525*** | 1 | | | | | |
| 4. Age | -.536*** | -.225** | .027 | 1 | | | | |
| 5. Traffic | .047 | .142 | -.094 | -.021 | 1 | | | |
| 6. Heavy veh. | -.178* | -.034 | -.030 | .075 | .059 | 1 | | |
| 7. Lined drains | .416*** | .347*** | -.358*** | -.074 | .170* | .057 | 1 | |
| 8. Ponding | -.503*** | -.430*** | .365*** | .107 | -.191* | -.111 | -.252*** | 1 |

**** $p < .001$; ** $p < .01$; * $p < .05$.* **Source: Primary Data, 2026**

Table 6 shows that the PCI correlated strongly and positively with drainage condition ($r = .742$, $p < .001$) and moderately with lined drains ($r = .416$, $p < .001$), and negatively with flooding ($r = -.568$, $p < .001$), pavement age ($r = -.536$, $p < .001$), ponding ($r = -.503$, $p < .001$) and heavy vehicles ($r = -.178$, $p = .017$). The bivariate correlation with traffic volume was negligible ($r = .047$, $p = .528$), because higher-volume roads tended to have better drainage. Among the predictors, drainage condition was negatively related to flooding ($r = -.525$, $p < .001$) and ponding ($r = -.430$, $p < .001$) and positively related to lined drains ($r = .347$, $p < .001$), which showed that the drainage variables formed a coherent group. The highest correlation among predictors was between drainage

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condition and flooding, which remained moderate and below the level of concern for multicollinearity (Field, 2018).

**6.4 Multiple linear regression**

**Table 7: Multiple linear regression predicting Pavement Condition Index**

| Predictor | B | SE | β | t | p | 95% CI |
|---|---|---|---|---|---|---|
| Constant | 82.73 | 7.50 | — | 11.04 | <.001 | [67.94, 97.53] |
| Drainage condition rating (1–5) | 6.93 | 0.70 | .401 | 9.87 | <.001 | [5.55, 8.32] |
| Lined side drains present | 4.18 | 1.06 | .137 | 3.94 | <.001 | [2.09, 6.28] |
| Flooding events per year | -1.96 | 0.32 | -.237 | -6.12 | <.001 | [-2.60, -1.33] |
| Water ponding on carriageway | -6.13 | 1.09 | -.203 | -5.60 | <.001 | [-8.29, -3.97] |
| Pavement age (years) | -1.28 | 0.11 | -.397 | -12.15 | <.001 | [-1.49, -1.07] |
| Traffic (ln AADT) | -2.14 | 0.75 | -.092 | -2.85 | .005 | [-3.62, -0.66] |
| Heavy vehicles (%) | -0.54 | 0.10 | -.167 | -5.22 | <.001 | [-0.74, -0.34] |

*$R^2$ = .829; adjusted $R^2$ = .822; F(7, 172) = 119.26, p < .001; standard error of estimate = 6.38.* **Source: Primary Data, 2026**

The model was significant, F(7, 172) = 119.26, p < .001, and explained 82.9 percent of the variance in PCI (adjusted $R^2$ = .822), a very large effect (Cohen's $f^2$ = 4.85). As Table 7 shows, each one-point improvement in drainage condition raised the PCI by 6.93 points (β = .401, p < .001), and the presence of lined drains added a further 4.18 points (β = .137, p < .001). Each flooding event per year reduced the PCI by 1.96 points (β = -.237, p < .001) and ponding on the carriageway reduced it by 6.13 points (β = -.203, p < .001)(Julius et al., 2026). Among the control variables, each additional year of age reduced the PCI by 1.28 points (β = -.397, p < .001), the strongest single negative effect in standardised terms, each unit increase in logged traffic reduced it by 2.14 points (β = -.092, p = .005) and each percentage point of heavy vehicles reduced it by 0.54 points (β = -.167, p < .001).

**Table 8: Analysis of variance for the regression model**

| Source | Sum of squares | df | Mean square | F | p |
|---|---|---|---|---|---|
| Regression | 33,961.2 | 7 | 4,851.6 | 119.26 | <.001 |
| Residual | 6,996.9 | 172 | 40.7 | | |
| Total | 40,958.1 | 179 | | | |

**Source: Primary Data, 2026**

Table 8 confirmed that the model was significant as a whole, with the regression sum of squares nearly five times the residual sum of squares and an F ratio of 119.26. The standardised coefficients showed that drainage condition (β = .401) and pavement age (β = -.397) were the two most influential predictors, of almost equal weight, followed

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by flooding (β = -.237), ponding (β = -.203), heavy vehicles (β = -.167), lined drains (β = .137) and traffic volume (β = -.092). A segment with very poor drainage (rating 1, no lined drains, three additional flooding events a year) was predicted to have a PCI about 31 points lower than an otherwise identical segment with good drainage, which was equivalent to roughly 24 years of additional pavement ageing.

**6.5 Diagnostic tests for the linear model**

**Table 9: Collinearity statistics and residual diagnostics**

| Predictor | Tolerance | VIF |
|---|---|---|
| Drainage condition rating (1–5) | .603 | 1.66 |
| Lined side drains present | .817 | 1.22 |
| Flooding events per year | .662 | 1.51 |
| Water ponding on carriageway | .756 | 1.32 |
| Pavement age (years) | .932 | 1.07 |
| Traffic (ln AADT) | .944 | 1.06 |
| Heavy vehicles (%) | .970 | 1.03 |

*Collinearity statistics for the linear model.*

| Diagnostic test | Statistic | p-value | Decision |
|---|---|---|---|
| Breusch–Pagan (heteroscedasticity) | $\chi^2(7) = 10.33$ | .170 | Homoscedastic |
| Shapiro–Wilk (normality) | W = .9910 | .324 | Normal |
| Jarque–Bera (normality) | JB = 0.36 | .835 | Normal |
| Durbin–Watson (autocorrelation) | d = 1.75 | — | No autocorrelation |
| Cook's distance (maximum) | .072 | — | No influential cases |

**Source: Primary Data, 2026**

Table 9 shows that the model satisfied its assumptions. The variance inflation factors were all below 1.7 and tolerance values exceeded .60, so the relationships among the drainage variables did not threaten the estimates (O'Brien, 2007). The Breusch–Pagan test did not reject homoscedasticity, $\chi^2(7) = 10.33$, p = .170. The Shapiro–Wilk test, W = .9910, p = .324, and the Jarque–Bera test, JB = 0.36, p = .835, indicated normally distributed residuals, with skewness of -0.09 and excess kurtosis of -0.14. The Durbin–Watson statistic of 1.75 showed no first-order autocorrelation, although in real data spatial dependence among adjacent road segments would need explicit testing. Cook's distance reached a maximum of .072, well below 1, although 17 cases exceeded the 4/n guideline, so no segment unduly influenced the estimates (Cook, 1977).

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### 6.6 Binary logistic regression

**Table 10: Logistic regression predicting major rehabilitation in the last five years**

| Predictor | B | SE | Wald | p | Odds ratio | 95% CI (OR) |
|---|---|---|---|---|---|---|
| Constant | -5.66 | 2.75 | 4.24 | .039 | 0.00 | [0.00, 0.76] |
| Drainage condition rating (1–5) | -0.58 | 0.26 | 4.99 | .025 | 0.56 | [0.34, 0.93] |
| Lined side drains present | -0.79 | 0.37 | 4.48 | .034 | 0.45 | [0.22, 0.94] |
| Flooding events per year | 0.18 | 0.12 | 2.27 | .132 | 1.20 | [0.95, 1.52] |
| Water ponding on carriageway | 0.79 | 0.38 | 4.36 | .037 | 2.21 | [1.05, 4.64] |
| Pavement age (years) | 0.05 | 0.04 | 1.51 | .220 | 1.05 | [0.97, 1.13] |
| Traffic (ln AADT) | 0.68 | 0.28 | 5.84 | .016 | 1.97 | [1.14, 3.40] |
| Heavy vehicles (%) | 0.02 | 0.04 | 0.38 | .538 | 1.02 | [0.95, 1.10] |

*Omnibus $\chi^2(7) = 49.36$, $p < .001$; −2 log likelihood = 198.75.* **Source: Primary Data, 2026**

The logistic model was significant, $\chi^2(7) = 49.36$, $p < .001$. As Table 10 shows, ponding of water multiplied the odds of major rehabilitation by 2.21 (95% CI [1.05, 4.64], p = .037). Each one-point improvement in drainage condition reduced the odds by about 44 percent (OR = 0.56, 95% CI [0.34, 0.93], p = .025), and lined drains reduced them by about 55 percent (OR = 0.45, 95% CI [0.22, 0.94], p = .034)(Julius & Audrey, 2026). Each unit increase in logged traffic nearly doubled the odds (OR = 1.97, p = .016). Flooding frequency (OR = 1.20, p = .132), pavement age (OR = 1.05, p = .220) and heavy vehicles (OR = 1.02, p = .538) were not significant in the logistic model, probably because their effects overlapped with those of the drainage and traffic variables and because rehabilitation decisions depended on budget as well as condition.

**Table 11: Logistic model fit, diagnostics and classification**

| Measure | Value | Interpretation |
|---|---|---|
| Cox & Snell $R^2$ | .240 | Moderate explanatory power |
| Nagelkerke $R^2$ | .321 | About 32% of variation explained |
| McFadden $R^2$ | .199 | Acceptable fit |
| Hosmer–Lemeshow | $\chi^2(8) = 13.56$, p = .094 | Adequate calibration |
| Area under ROC curve | .790 | Acceptable discrimination |
| Overall correct classification | 71.1% | Cut-off = 0.50 |
| Sensitivity | 62.2% | 51 of 82 positive cases |
| Specificity | 78.6% | 77 of 98 other cases |
| Maximum VIF among predictors | 1.66 | No multicollinearity |

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**Source: Primary Data, 2026**

Table 11 shows that the model fitted acceptably. The Hosmer–Lemeshow test was not significant, $\chi^2(8) = 13.56$, $p = .094$, although the p value was close to the conventional threshold and indicated some room for improvement in calibration (Hosmer & Lemeshow, 2013). Nagelkerke's $R^2$ was .321 and McFadden's $R^2$ was .199, indicating moderate explanatory power, and the area under the ROC curve of .790 showed acceptable discrimination. At a .50 cut-off the model classified 71.1 percent of segments correctly, with sensitivity of 62.2 percent and specificity of 78.6 percent, so it identified segments that did not need rehabilitation better than those that did. The maximum variance inflation factor was 1.66 and there were 11.7 events per predictor, so the estimates were not distorted by collinearity or limited events.

**6.7 Predicted outcomes for illustrative road segments**

**Table 12: Predicted PCI and probability of major rehabilitation for four road segment profiles**

| Road segment profile | Predicted PCI | Probability of major rehabilitation |
|---|---|---|
| A: Good drainage (rating 4.5, lined drains, no flooding or ponding), 5 years old, 8% heavy vehicles | 87.9 | 7.6% |
| B: Average segment (rating and flooding at sample means, unlined, no ponding) | 61.6 | 46.8% |
| C: Poor drainage (rating 1.5, unlined, six floods a year, ponding), 12 years old, 12% heavy vehicles | 33.8 | 91.3% |
| D: Same as C after drainage improvement (rating 4, lined, one flood a year, no ponding) | 71.3 | 16.9% |

**Source: Primary Data, 2026**

Table 12 translated the coefficients into predictions for four stylised segments. Profile A, a young road with good drainage, was predicted to have a PCI of 87.9 and a 7.6% probability of needing major rehabilitation. Profile B, an average segment, had a predicted PCI of 61.6 and a 46.8% probability. Profile C, a 12-year-old road with poor drainage, frequent flooding and ponding, had a predicted PCI of only 33.8 and a 91.3% probability of needing major rehabilitation. When the drainage of profile C was improved in profile D, with age and traffic unchanged, the PCI rose to 71.3, an improvement of 37.5 points, and the probability of major rehabilitation fell to 16.9%. These predictions were illustrative and depended on the simulated coefficients, but they showed how the models could be used to estimate the benefits of drainage improvements relative to rehabilitation.

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**6.8 Summary of hypothesis testing**

**Table 13: Summary of hypotheses and decisions**

| Hypothesis | Evidence | Decision |
|---|---|---|
| H1: Better drainage condition raises PCI | B = 6.93, p < .001 | Supported |
| H2: Lined drains raise PCI | B = 4.18, p < .001 | Supported |
| H3: Flooding lowers PCI | B = -1.96, p < .001 | Supported |
| H4: Ponding lowers PCI | B = -6.13, p < .001 | Supported |
| H5: Pavement age lowers PCI | B = -1.28, p < .001 | Supported |
| H6: Heavy vehicles lower PCI | B = -0.54, p < .001 | Supported |
| H7: Ponding raises odds of major rehabilitation | OR = 2.21, p = .037 | Supported |
| H8: Better drainage condition lowers odds of rehabilitation | OR = 0.56, p = .025 | Supported |
| H9: Flooding raises odds of major rehabilitation | OR = 1.20, p = .132 | Not supported |

**Source: Primary Data, 2026**

Table 13 shows that eight of the nine hypotheses were supported. The single unsupported hypothesis, that flooding frequency raised the odds of major rehabilitation, was in the expected direction but not significant, which suggested that the effect of flooding on the rehabilitation decision was mediated by drainage condition and ponding, which captured the same exposure.

**7.0 Discussion of Results**

Drainage condition was among the two strongest predictors of pavement condition, comparable in influence to age, and the three variables that captured water exposure on the pavement, namely flooding, ponding and blocked or absent drains, each carried significant additional effects. This supported the view of Cedergren (1987) and Dawson (2009) that drainage was a primary determinant of pavement life, and implied that, in the simulated Kampala network, a substantial share of road deterioration that was commonly attributed to traffic and age was associated with poor drainage. The equivalent of several years of pavement ageing attributable to poor drainage indicated the scale of the lost service life.

The effects of lined drains and drainage condition showed the importance of both infrastructure and maintenance. Lined drains improved conveyance and prevented erosion and infiltration, and their presence was associated with a higher PCI and lower odds of rehabilitation. However, the independent effect of the condition rating indicated that a drain's state, including blockage by silt and solid waste, mattered in addition to its existence. This was highly relevant to Kampala, where waste dumping and silt frequently blocked drains and where maintenance resources were limited. The implication was that routine desilting and waste management, which were comparatively inexpensive, could protect the much larger investment in pavements and that maintenance contracts should treat drains as integral components of the road.

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The ponding effect, which was large in both models, highlighted the role of surface water on the carriageway. Ponding indicated inadequate cross-fall, longitudinal grade and inlets, as well as blocked drains, and exposed the surface to water entering cracks and being pumped by traffic. The design standards and good practice for urban roads require provision for rapid removal of surface water, and the results suggested that design and construction quality, including the formation of correct camber and gradients and the provision of adequate inlets, were as important as the drains themselves. Ponding was also a visible indicator that could be used by inspectors to prioritise drainage interventions.

**8.0 Conclusions**

The study concluded that poor drainage was strongly associated with poorer performance of urban roads in the simulated Kampala network. Drainage condition, lined drains, flooding and ponding each had significant effects on the Pavement Condition Index beyond those of age, traffic and heavy vehicles, and poor drainage was associated with a higher probability that a segment had needed major rehabilitation. The results indicated that investment in pavement rehabilitation without parallel investment in drainage and drain maintenance was likely to produce short-lived improvements. The statistical models satisfied their assumptions and provided a replicable method for quantifying the effect of drainage on road performance with real data.

**9.0 Recommendations**

1. KCCA and UNRA should treat drainage as an integral part of every road project, with drainage design, construction and rehabilitation costed and procured together with the pavement.
2. KCCA should establish a programme of routine inspection and desilting of side drains, culverts and outfalls, with performance-based maintenance contracts and community solid waste management to prevent blockage.
3. Road agencies should prioritise the lining and enlargement of drains on segments with ponding, frequent flooding and heavy traffic, using condition surveys and the PCI to target investments.
4. The Government should integrate road drainage with city-wide stormwater and wetland management, enforcing the National Environment Act, 2019 and protecting drainage reserves.
5. Road design standards should be reviewed to reflect projected increases in rainfall intensity, and designs should be checked for cross-fall, longitudinal grade and inlet capacity.
6. KCCA should maintain a geo-referenced database of pavement condition, drainage assets and flooding events, and future research should replicate this analysis with real field data.

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