

INTEGRATED ASSESSMENT OF PAVEMENT CONDITION USING VISUAL INSPECTION AND DRAINAGE QUALITY INDEX IN RAJSHAHI CITY

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ABSTRACT

The durability and service life of flexible pavements are strongly influenced by both surface condition and drainage efficiency. In developing regions such as Bangladesh, insufficient drainage conditions lead to faster pavement degradation, causing cracks, potholes, rutting and road markings which reduce service life and increase maintenance costs. This study proposes an integrated evaluation that combines visual inspection with the Drainage Quality Index (DQI) to assess flexible pavement conditions. Field surveys were carried out on selected segments of national, regional and zilla roads within Rajshahi city. Visual inspection was used to record cracking, potholes, rutting and road markings; while DQI was calculated based on five key drainage factors. As such: surface water ponding, side drain condition, cross slope, culverts and erosion. Each parameter was scored and categorized into good, fair, and poor conditions. The results indicate that pavements with poor DQI consistently showed greater surface deterioration compared to well-drained pavements. A strong relationship was observed between drainage condition and pavement deterioration. Pavement durability is strongly influenced by drainage condition. Traffic volume, axle load, subgrade condition and pavement age were systematically evaluated to quantify their effects on pavement deterioration also. The findings highlight that integrating visual inspection with DQI provides a more detailed information for pavement evaluation and can help road authorities in prioritizing maintenance and find which road sections require immediate repair.

Keywords: *Visual Inspection; Drainage Quality Index (DQI); Road Surface Distress; Pavement Condition Assessment; Pavement Maintenance.*

1 INTRODUCTION

The development of a city like Rajshahi depends upon transportation system and the transportation system will be well developed when the condition and serviceability of flexible pavements are strong. Pavements here face heavy traffic, monsoon rainfall and varying maintenance practices (Hasan et al.,2024). Flexible pavements deteriorate over time due to surface distresses such as cracks, potholes, rutting and patches which reduce service life and increase maintenance costs. Therefore, accurate pavement evaluation is crucial to ensure safety, serviceability and cost- effective maintenance (Rifai & Hastuti, 2023).

Visual inspection is a systematic and widely adopted method for identifying pavement distresses, including cracks, potholes, rutting and other surface deformations (Chang,2020). The Drainage Quality Index (DQI) is a quantitative tool used to evaluate the effectiveness of drainage systems, including surface water ponding, side drain condition, cross slope, culverts and erosion control. Integrating DQI with visual inspection provides more accurate data which helps how to plan road surface maintenance (Khan and Rahman,2021).

In Rajshahi city most of the roads are constructed and maintained by Roads & Highway Department (RHD) and Rajshahi City Corporation (RCC). In this city deteriorations of flexible pavements occurred every year due to poor quality of drainage condition and lack of proper maintenance in a correct time (Rajshahi Roads & Highway Department,2023-2024). Lack of proper maintenance occurs when visual inspection is rarely conducted. On the other side drainage condition of the road surface rarely assess by the authorities in this city, which leads to seasonal water logging specially in monsoon season (Imran,2025). The improper and unplanned drain construction has made impact on surface condition also. Most of the time pavement evaluation is conducted through outlook of the road surface without proper visual inspection and drainage efficiency is rarely investigated. This study integrates visual inspection with the Drainage Quality Index (DQI) to assess national, regional, zilla roads in Rajshahi city. Therefore, this study aims to provide detailed information to identify roads in need of immediate repair (Florida Department of Transportation,2025).

2 METHODOLOGY

2.1 Study Area

The study was conducted across selected national, regional and zilla roads within Rajshahi city, covering both urban and peri-urban sections. Approximately fifteen kilometers of road segments, including national highway named Rajshahi Town By-pass Road(N603), regional highway named Ujanpara-Bijoy nagar Road(R681) and zilla road named Arani-Bagatipara Road(Z6020) were selected for the investigation. Detailed data were collected at every five kilometers interval along the selected road segments. In general those selected segments are located in different parts of Rajshahi city, ensuring geographical variation. Rajshahi Town By-pass Road(N603), Ujanpara-Bijoy nagar Road(R681) and Arani-Bagatipara Road(Z6020) segments connect Rajshahi city with the Natore, Chapai Nawabganj and Naogaon districts and lie within a similar climate zone. These segments represent a wide range of traffic volumes, from high to low and exhibit varying surface conditions, including both well-maintained and deteriorated pavements. Hence, the selection of these road segments ensures a representative and methodologically sound evaluation of pavement performance across diverse traffic levels, surface conditions, and pavement ages under comparable climatic conditions. Preliminary field observations were carried out before the selection of these segments also.

2.2 Visual Inspection

On-site investigations were carried out along the selected segments of national highway (N603), regional highway (R681), and zilla road (Z6020). Each road was divided into smaller sections to facilitate systematic data collection. At first the total length of the road was initially inspected for the study also. A visual inspection was conducted to record pavement distresses such as cracking (alligator, block, edge, transverse, longitudinal), potholes, rutting, surface deformation and road markings. According to the AASHTO Pavement Condition Index (PCI) manual, the formulas for evaluating cracking, rutting and potholes are presented in Equations 1-4.

Alligator, Block & Transverse cracks-

$$Crack \% = \frac{Total\ crack\ area}{Total\ pavement\ area} \quad (1)$$

Longitudinal & Edge cracks-

$$Crack \% = \frac{Crack\ length}{Section\ length} \quad (2)$$

Rutting Depth-

$$Rut\ Depth = \frac{Height\ of\ crown}{Height\ of\ rut} \quad (3)$$

Potholes Calculation-

$$Pothole\ Density = \frac{Total\ potholes\ in\ segment}{Segment\ length\ in\ km} \quad (4)$$

In accordance with the AASHTO Pavement Condition Index (PCI) manual, the distress scoring was performed based on the criteria summarized in Table 1.

Table 1. Pavement Condition Classification According to PCI Manual

Distress Scoring	Condition	Description	Visual Observation
85-100	Excellent	No visible distress	Smooth surface, no cracks or potholes
70-85	Good	Few minor cracks	Slight surface wear
55-70	Fair	Moderate cracking, light rutting	Small patches or minor potholes
40-55	Poor	Numerous cracks and patching	Noticeable rutting and raveling
25-40	Very Poor	Severe cracks, deformation	Large potholes, unsafe surface
10-25	Serious	Extensive damage, structural failure	Large broken areas
0-10	Failed	pavement completely failed	Totally broken and unusable surface

2.3 Drainage Condition Assessment

The drainage condition of the selected road segments was evaluated through on-site investigation, considering surface water ponding, side drain condition, cross slope adequacy, condition of culverts and erosion. Each parameter was rated using the Drainage Quality Index (DQI). In the selected road segments, continuous side drains are largely absent due to rural and agricultural land-use characteristics, where drainage is commonly managed through cross-drainage structures such as culverts rather than longitudinal side drains. While the absence of side drains limits continuous surface runoff collection, the presence of functional culverts provides partial drainage capacity and prevents prolonged water stagnation in many locations. Accordingly, the Drainage Quality Index (DQI) scoring was adjusted to emphasize actual drainage performance, including runoff clearance and water retention, rather than penalizing solely for structural absence. This performance-based approach ensures a balanced and realistic evaluation of drainage conditions under local design and maintenance practices. In accordance with the methodology proposed by Khan and Rahman (2021), the Drainage Quality Index (DQI) is defined by the formula presented in Equation 5.

$$DQI = \frac{\text{Sum of all element scores}}{\text{Number of all elements}} \quad (5)$$

In accordance with the AASHTO Pavement Condition Index (PCI) manual, the Drainage Quality Index (DQI) scoring was performed based on the criteria summarized in Table 2.

Table 2. DQI Condition Classification According to PCI Manual

DQI (%)	Condition	Description	Maintenance Priority
85-100	Excellent	Efficient drainage, no ponding, clean ditches	No significant drainage problem, routine maintenance recommended
70-85	Good	Minor silt or vegetation, water drains quickly	Minor issues, minor maintenance recommended
55-70	Fair	Some clogging, minor Ponding after rainfall	Moderate issues, repair needed soon
40-55	Poor	Frequent standing water, sediment in drains	Severe issues, urgent maintenance recommended
25-40	Very Poor	Blocked ditches, erosion or severe ponding	Drainage system non-functional, immediate repair required

2.4 Traffic and Pavement Characteristics

In this study, axle load, traffic volume, subgrade condition, and pavement age were considered as important factors affecting surface distress in flexible pavements. Axle load and traffic volume were used to represent the intensity and repetition of traffic loading on the pavement structure. Subgrade condition was evaluated to reflect the supporting strength of the pavement foundation. Pavement age was included to account for material aging and the accumulation of traffic-related damage over time.

These factors were incorporated into the methodology to examine their influence on the observed surface distresses.

For all road classes considered (National, Regional, and Zilla roads) a standard axle load of 8.16 ton was adopted following RHD guidelines. The same ESAL conversion procedure was applied across all road types to quantify cumulative traffic loading on the pavements.

According to RHD traffic volume ranges, national highways carry the largest traffic volumes with AADT frequently above 1000 vehicles/day, regional highways have moderate volumes often between 500–2000 vehicles/day, while zilla roads generally experience lower traffic intensities, mostly under 1000 vehicles/day.

2.5 Integration of Visual Inspection & DQI

The study integrates visual inspection and the Drainage Quality Index (DQI) to comprehensively assess pavement condition. Visual inspection identifies surface distresses, while DQI evaluates drainage efficiency. This combined approach highlights sections where inadequate drainage accelerates pavement deterioration, supporting data-driven maintenance planning.

3 RESULT & DISCUSSION

3.1 Visual Inspection Result

The national highway shows minor cracking, rutting and pothole density, indicating good to excellent condition. The regional highway exhibits moderate cracking, rutting and pothole density, indicating fair to good condition. The zilla road shows extensive cracking, deep rutting and high pothole density, indicating poor to fair condition. The collected data on Visual Inspection for different types of roads are tabulated as Table 3.

Table 3. Visual Inspection Result

Roads	Chainage(km)	Cracking (%)	Rutting Depth(mm)	Potholes Density(no./km)	Visual Rating (0-100)	Condition
N603	0-5	4.43	4.0	5	84.5	Good-Excellent
	5-10	6.00	1.3	3	83.0	Good-Excellent
	10-15	3.74	3.2	7	82.0	Good-Excellent
R681	0-5	12.67	11.5	13	65.0	Fair-Good
	5-10	13.14	10.3	19	62.0	Fair-Good
	10-15	11.32	11.0	17	69.5	Fair-Good
Z6020	0-5	21.75	17.2	25	46.0	Poor-Fair
	5-10	21.40	15.5	22	41.5	Poor-Fair
	10-15	19.76	15.6	21	40.0	Poor-Fair

3.2 Drainage Quality Index Result

Drainage assessment indicates that the N603 section is in good to excellent condition, the R681 section is in fair to good condition, and the Z6020 section is in poor to fair condition. The N603 benefits from effective cross slope, camber, and well-maintained culverts, while the R681 experiences moderate runoff efficiency and localized erosion. The Z6020 suffers from inadequate slope, silted culverts and also severe erosion. Field measured DQI data for different types of roads are given in Table 4.

Table 4. Drainage Quality Index (DQI) Result

Roads	Chainage (km)	Surface Water Ponding	Side Drain	Cross Slope	Culverts	Erosion	DQI	Condition
N603	0-5	95	N/A	98	92	90	93.75	Excellent
	5-10	92	N/A	95	84	82	88.25	Excellent
	10-15	90	N/A	90	82	80	85.50	Good
R681	0-5	69	N/A	70	73	68	70.00	Fair
	5-10	83	N/A	84	80	79	81.50	Good
	10-15	86	N/A	85	82	80	83.25	Good
Z6020	0-5	67	N/A	66	64	62	64.75	Fair
	5-10	55	N/A	60	54	50	54.75	Poor
	10-15	50	N/A	58	50	44	50.50	Poor

3.3 Assessment of Traffic and Pavement Characteristics

According to Roads & Highway Department (RHD) road design guide and Bangladesh road studies criteria the axel load, traffic volume, subgrade condition and pavement age are given in Table 5.

Table 5. Pavement Characteristics

Road	Vehicle Type	Average Axle Load(t)	AADT	Subgrade Condition	Pavement Age
N603	Heavy Truck	10	8500	Fair	11
R681	Medium Truck	9	4200	Moderate	15
Z6020	Light Truck	7	3500	Low	18

Axle load, AADT, subgrade condition, and pavement age are interrelated factors that collectively influence pavement deterioration and often produce similar trends in pavement distress.

3.4 Integration of Visual Inspection & DQI

Roads with low DQI scores consistently show higher pavement distress, highlighting the critical influence of drainage on pavement performance. The graphical data is given in Figure 1.

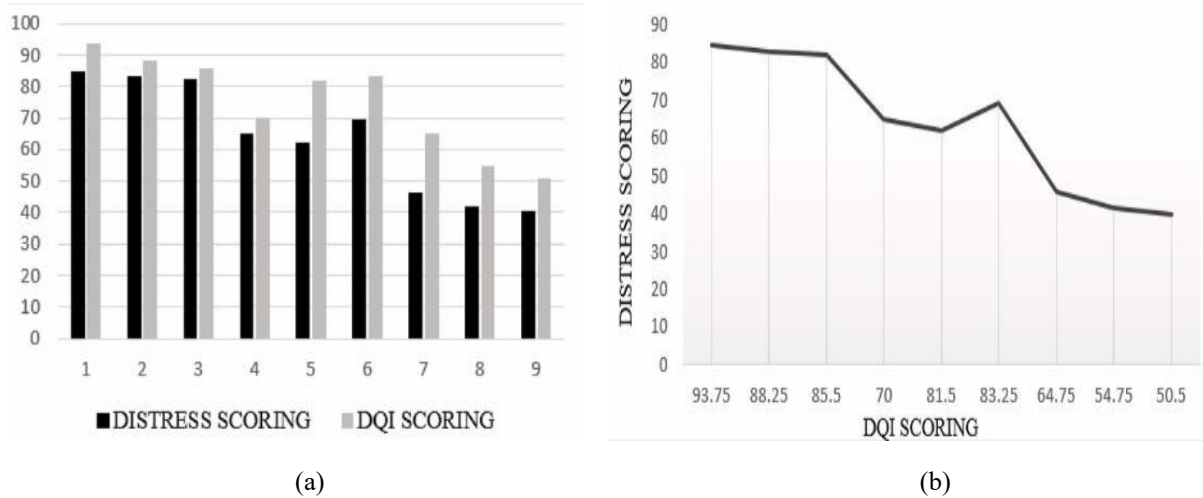


Figure 1. (a)Flow chart on Distress & DQI Scoring and (b) Distress Scoring vs DQI Scoring

Lower DQI Value=Higher Surface Distress; Higher DQI Value=Lower Surface Distress

N603, with high DQI, maintains good pavement condition despite moderate traffic, whereas Z6020 suffers extensive distress due to poor drainage. R681 shows intermediate behavior, where moderate drainage deficiencies align with moderate distress levels.

3.5 Statistical Analysis

A comprehensive statistical analysis was performed to examine the relationships among the pavement condition indicators considered in this study. The degree and direction of association between the variables were first evaluated using the Correlation coefficient. Subsequently, regression analysis was conducted to establish the quantitative relationship between the dependent and independent variables. The statistical significance of the estimated regression coefficients was examined at a 95% confidence level. Additionally, confidence intervals were determined to assess the precision and reliability of the estimated parameters. Together, these statistical analyses provided a well-established analytical approach for evaluating the strength, significance, and reliability of the observed relationships.

The Correlation analysis revealed a strong positive association between DQI and visual inspection scores, with a correlation coefficient (R) of 0.95. This exceptionally high value indicates a close correspondence between the two variables, suggesting that DQI reliably reflects the outcomes of visual inspection measurements.

To further examine the relationship between DQI and visual inspection scores, a linear regression analysis was performed, and the results are presented graphically in Figure 2.

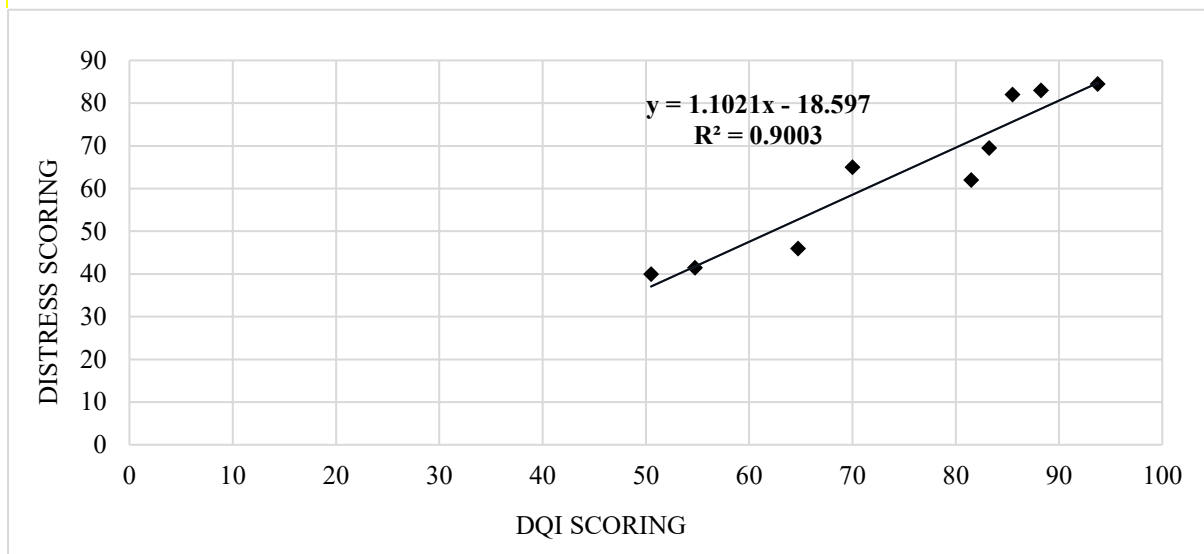


Figure 2. Regression Line for Distress Scoring vs Drainage Quality Index (DQI) Scoring

The graph of surface distress versus DQI, shown in Figure 2, illustrates a clear negative trend between the two variables. The regression line fitted to the data yielded a coefficient of determination (R^2) of 0.9003, indicating that approximately 90% of the variation in surface distress can be explained by DQI. This high R^2 value demonstrates the strong predictive capability of DQI and confirms its reliability as an indicator of pavement condition.

The regression analysis indicates a clear and positive agreement between the Drainage Quality Index (DQI) and visual inspection results, highlighting the consistency of the two approaches in assessing pavement condition. This positive relationship demonstrates that visual inspection effectively represents pavement performance trends that are also captured through DQI-based evaluation. The observed agreement supports the reliability of visual inspection as a practical and cost-effective assessment tool, especially for large-scale or preliminary pavement condition surveys.

The samples were collected from a variety of roads across the city, including urban and semi-urban areas, with differing traffic volumes ranging from high to low. This diverse selection provides a clear representation of the overall pavement condition in the city. The high and low sample values correspond to well-maintained and deteriorated road sections respectively. Moreover, the mean VDR ≈ 61.94 and DQI ≈ 74.17 indicate moderate pavement and drainage conditions, which reasonably reflect the average city-level road quality. As the selected road segments are located in different parts of Rajshahi city, rather than being concentrated in a single area, this distribution ensures graphical variation indicating that the sample is not biased toward any specific locality.

Figure 3 and 4 Figure represents the field observations of pavement distresses and the corresponding Drainage Quality Index (DQI) evaluation.



Figure 3. Distress Scoring



Figure 4. Drainage Quality Index (DQI) Scoring

4 CONCLUSION

This study evaluated the pavement condition of three roads categories within Rajshahi city as such: National (N603), Regional (R681) and Zilla (Z6020) roads by integrating Visual Inspection (cracking, rutting, potholes), Drainage Quality Index (DQI) and pavement characteristics. The following conclusions were obtained:

- National Highway exhibited approximately 85–95% drainage efficiency and 90% pavement condition, indicating that effective drainage contributes significantly to pavement durability.
- Regional Highway showed about 65–75% drainage efficiency and 70% pavement condition, showing that partial drainage deficiencies accelerate surface deterioration.
- Zilla Road recorded only 40–55% drainage efficiency and 45% pavement condition, emphasizing the critical influence of drainage on pavement performance.
- A clear correlation was observed between low DQI values and high pavement distress, demonstrating that integrating visual inspection with DQI provides a reliable method for prioritizing maintenance and repair.
- Pavement deterioration is influenced by factors such as axle load, traffic volume, pavement age, and subgrade condition, which generally exert a consistent effect on pavement performance. However, drainage condition plays a more critical role in causing pavement distress, highlighting its dominant impact in the deterioration process. Considering all these factors together provides a reliable basis for pavement condition assessment and maintenance planning.
- Regular monitoring and timely maintenance, particularly of drainage facilities and also traffic quality control are essential to prolong pavement life, especially for regional and zilla roads in limited-resource areas.

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DECLARATION OF USE OF AI

The authors declare that this study on pavement condition assessment of selected road segments in Rajshahi city is entirely derived from original field data and independent analysis conducted by the authors. Artificial intelligence (AI) tools were used exclusively for language editing, grammatical improvement, and assistance in locating relevant literature and reference papers to enhance the clarity and completeness of the manuscript. No AI tools were used for data collection, data processing, statistical analysis, result interpretation, figure preparation, or formulation of conclusions. The authors take full responsibility for the originality, accuracy, and integrity of the work.

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