Skid resistance analysis in relation to temperature and surface conditions: a case study of Kaliurang Road KM 8–9

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Abstract
The high number of traffic accidents in Yogyakarta requires a review of road surface conditions, especially in terms of skid resistance which is considered a safety indicator. This study analyzes the effect of surface temperature and road condition on skid resistance value on Kaliurang Road KM 8-9 using British Pendulum Test (BPT) tool. This is based on the viscoelasticity of asphalt, micro and macro texture and the effect of water layers. The results indicate that an increase in temperature decreases skid resistance values, or British Pendulum Number (BPN), in all conditions, with dry values ranging from 90 to 74 and wet conditions ranging from 58 to 43. All test points complied with TRRL standard (>65 BPN) under dry condition while only STA 8+000-8+200 segment complied with minimum limit (>55 BPN) under wet condition. The relationship between surface temperature and skid resistance values was determined using Pearson correlation and simple linear regression analyses. The analysis results indicated a significant negative correlation between temperature and skid resistance values and a decrease in BPN of 0.849 in a dry and 0.950 in a wet condition for each increase of 1 °C in temperature. The results of this study showed that temperature and the presence of water are proven to be significant factors that reduce the skid resistance so that pavement maintenance on Kaliurang Road KM 8-9 is needed to reduce the risk of accidents.

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Introduction

Traffic accidents are one of the main causes of death related to injury, in both developed and developing countries (Syahriza, 2019). This issue is still a serious problem in the Special Region of Yogyakarta, which has broad impacts on public safety, economy, and quality of life. The data from the Regional Development Planning Agency (BAPPEDA DIY) noted 3,281 accident cases from January to September 2025 with 56 deaths, 54 serious injuries and 3,193 minor injuries. The figures indicate that more strategic and effective measures are still required. Traffic accidents can also cause various losses such as damage to public infrastructure and loss of life (Surya et al., 2020). One of the key factors affecting road safety is the behavior and condition of road pavement. Poor quality of pavement may lead to reduced vehicle stability and control especially in an adverse weather condition and hence increase the risk of accident.

Among the various contributing factors, road surface condition plays an important role, particularly in relation to skid resistance. This parameter determines the level of friction between vehicle tires and the pavement, which becomes especially critical during braking or when the road surface is wet (Roshan et al., 2024; Dhuha et al., 2023). This characteristic is influenced by several factors, including surface wear, the presence of water, and temperature (Wu et al., 2020; Fwa, 2021; Fajri, 2025). Asphalt, as a viscoelastic material, tends to soften at higher temperatures, making the surface more slippery, while at lower temperatures it becomes relatively rougher (Hakim et al., 2021). As a result, an increase in temperature generally reduces skid resistance and may lower driving safety, particularly on wet roads.

Kaliurang road located in the northern part of the Special Region of Yogyakarta in Sleman Regency, is a provincial road that connects the provincial capital with regency or city capitals, as well as linking different regencies/cities. The Yogyakarta–Pakem–Kaliurang section has a total length of 20.550 km. This designation is in line with the Decree of the Governor of the Special Region of Yogyakarta Number 41 of 2023 concerning the classification of road segments as provincial roads. Kaliurang road experiences relatively high traffic volumes, which continue to increase from year to year. With such a large number of vehicles, the condition of the road surface becomes crucial in supporting both safety and comfort for road users. Therefore, maintaining the road surface in good condition is essential to ensure optimal service performance.

One of the commonly used indicators to assess the functional condition of a road is the International Roughness Index (IRI). Although Kaliurang road has an IRI value that is considered very good (Suwardo and Utomo, 2020), this does not necessarily indicate a high level of skid resistance, as these two parameters measure different aspects of road performance (Fuentes et al., 2010). At KM 8, the area has been identified as an accident-prone zone, with an Equivalent Accident Number (EAN) of 203 (Hay, 2022). This highlights the importance of evaluating road surface characteristics especially skid resistance in order to reduce accident risk. In this study, the British Pendulum Test (BPT) method is used to measure skid resistance through the British Pendulum Number (BPN). According to Lee et al. (2005), this method is considered effective for assessing the skid resistance of road surfaces. Based on this background, the study aims to analyze skid resistance values along the Kaliurang road KM 8–9 segment to determine whether they meet safety standards, as well as to provide a basis for improving road user safety and comfort.

Methods

Skid resistance

Skid resistance describes the frictional force between the tires of a vehicle and the surface of the road. It determines whether a vehicle can stop or turn without skidding. The property is affected by the surface texture of the property, the rougher the texture the more friction it generates (Pandia et al., 2016). Adequate skid resistance is required to keep vehicles stable, especially when braking, and this is even more important on wet surfaces.

Skid resistance is usually expressed as a number known as Skid Resistance Value (SRV). This is a numerical representation of the amount of friction as determined from the testing. SRV is a quantifiable measure of whether a road surface has sufficient friction to allow safe braking. The value may be affected by a number of factors including surface wear, temperature, pavement materials and other conditions.

To determine whether a pavement surface is considered safe, a minimum skid resistance standard is required. This minimum value is important to ensure driving safety, especially on wet roads where the risk of skidding is higher. The recommended minimum skid resistance values generally refer to the standard proposed by Bullas (1969) from the Transport and Road Research Laboratory (TRRL), which classifies minimum skid resistance into three categories. A clearer explanation is presented in Table 1. If skid resistance values fall below the minimum standard, the risk of skidding increases. Therefore, the minimum threshold serves as an important reference in determining whether a road surface is sufficiently safe in terms of the friction it provides.

Table 1. Recommended Minimum Skid Resistance Values (Bullas, 1969)

Category	Type of Location	SRV
A	Difficult locations such as: 1. Roundabouts 2. Curves with a radius < 150 m on highways 3. Gradients of 1:20 or steeper, with a length > 100 m 4. Signalized intersection approaches on highway	≥ 65 BPN
B	Major/arterial roads, continuous high-speed roads, and Class I roads with heavy urban traffic (>2,000 vehicles per day)	≥ 55 BPN
C	Other locations	≥ 45 BPN

Friction Coefficient

The friction coefficient refers to the frictional force generated as a result of the ratio between the normal load acting on the road surface and the resulting tire grip. In pavement systems, friction ensures that vehicles remain stable and controllable, as illustrated in Figures 1 and 2 (Hall et al., 2009).

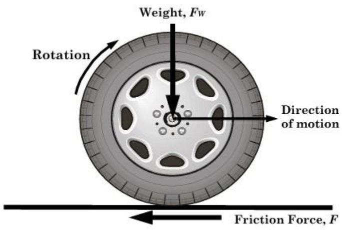

Figure 1. Frictional Force Between Vehicle Tires and Pavement Surface

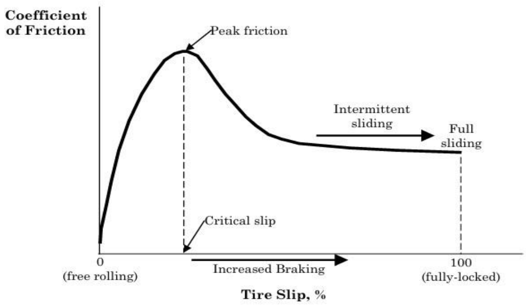

Figure 2. Pavement Friction and Tire Slip

The friction coefficient varies with the level of slip. It generally increases and reaches its peak at around 10–20% slip, then decreases toward the sliding friction value at 100% slip. The difference between the peak and sliding values can be as much as 50%, and may be even greater under wet conditions. This means that friction force is reduced above a critical limit of slip, which reduces the grip of the tire, particularly in the case of wet pavements, where the risk of skidding is higher. The friction coefficient is calculated using equation 1.

$$f = F/L \tag{1}$$

where f is the friction coefficient, F is the frictional force between the tire and the road surface, and L is the normal load.

The Friction Number (FN) is a measure of the ability of a road surface to resist skidding. It is the product of the coefficient of friction and 100 . It depends on the ratio of the frictional force to the normal load . This value is then represented in equation 2.

$$FN = 100 \text{ x } F/L \tag{2}$$

where FN is the friction number, F is the frictional force, and and L is the normal load.

Effect of Temperature on Skid Resistance Values

Daily temperature variations may produce changes in surface conditions which influence BPN values from BPT testing. Skid resistance tends to decrease during the day during the increased surface temperatures (Novamaulina et al., 2019). Therefore, it is necessary to do the temperature correction to the reference temperature of 27 o C, referring to SNI 4427:2008 by using the correction factors as shown in Table 2.

Table 2. The Correction BPN Value

Temperature (°C)	Correction
<27	0
27-32	+1
32-37	+2
>37	+3

The road surface conditions also play a very important role for the skid resistance, as they affect the efficiency of the tire-pavement contact. When it's wet, a layer of water builds up on the surface and this cuts down the interaction between the tyre and the road. The study used a uniform application of water to the pavement surface before measuring skid resistance to simulate wet surface conditions. This translates to less friction, and a greater chance of skidding. This results in lower SRV values, as water presence and thickness significantly reduce the friction coefficient, especially at lower speeds. On the other hand, dry surfaces give the best contact between tire and pavement and therefore a higher and more stable friction. On the wet surface, vehicles with smoother tires are more dangerous than on the dry surface (Hakim et al., 2021). That's why surface texture works best in dry conditions and they're the safest ones to drive on.

British Pendulum Test (BPT)

This study used BPT device to obtain SRV based on SNI 4427:2008. This instrument measures the energy of friction between a rubber slider attached to the arm of the pendulum and the surface of the pavement and produces the BPN which indicates the skid resistance. The use of BPT is important because it has been shown to be effective, relatively simple to operate in the field and able to provide consistent results when evaluating road surface safety. The BPT testing device used in this study is presented in Figure 3.

Figure 3. British Pendulum Test (BPT)

Before the test, the preparation steps are needed to be conducted to ensure the accurate results in line with the standard procedures. Dust, sand, oil and other debris must not affect the friction measurement which means that the road surface must be cleaned beforehand. Then check the condition of the slider, the rubber should be clean, not worn and without cracks. Any slider which has been used more than 500 times should be replaced. The device is then placed on a flat surface and the pendulum height is adjusted until the slider contacts the surface at the midpoint of the swing path with a contact angle of 0°$±$5°. Testing can be done in dry or wet conditions, the surface being water-sprayed before releasing the pendulum in wet testing. Finally, an initial calibration is performed by swinging the pendulum without touching the test surface to ensure that the pointer returns to zero.

Study Location

The study was conducted on Kaliurang road KM 8-9, which is a 1 km segment of two-way flexible pavement road with 3 meters width for each lane. In total, 10 test points were established at 100m intervals (STA 8+000–8+900). Min. 5 swings of pendulum were carried out at each point based on SNI 4427:2008. The testing points were arranged so as to follow a zig-zag pattern to give a more even distribution of data. The measurements were carried out along the wheel path, about 1.5 m from the edge of the road, which is the area subject to the highest traffic loads and more prone to wear and reduction of skid resistance. Detail as shown in Figures 4 and 5.

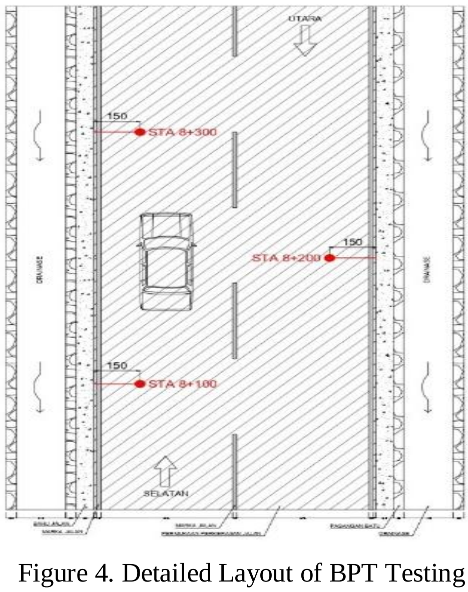

Figure 4. Detailed Layout of BPT Testing Stations

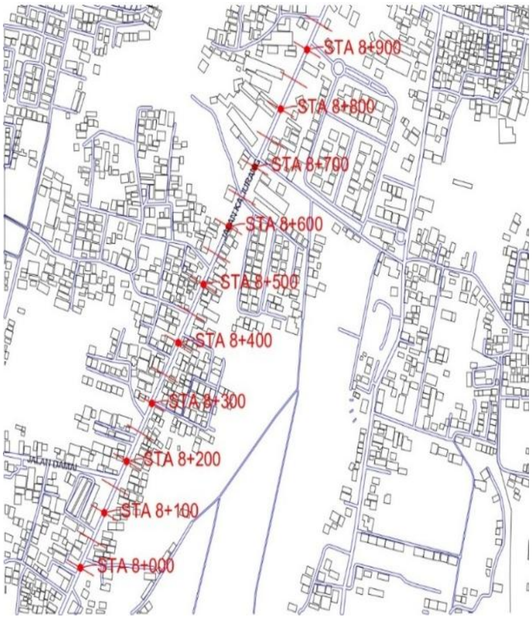

Figure 5. BPT Testing Station Locations

Study Period

The study was carried out on Monday (morning) and Tuesday (afternoon), with data collection conducted at one-hour intervals for each lane. The road consists of two lanes, namely the southbound and northbound lanes, each with two sides. Each side includes five testing points located on the west and east sides, resulting in a total of 10 testing points. The field data collection schedule is presented in Table 3.

Table 3. Field Data Collection Schedule

Date	Session	Time (WIB)	Test Points
Mon, 3 Nov 2025	Morning	07.00-08.00 08.00-09.00	5 points (east side) 5 points (west side)
Tues, 4 Nov 2025	Afternoon	12.00-13.00 13.00-14.00	5 points (east side) 5 points (west side)

Result

Skid Resistance Results

The results of skid resistance and surface temperature measurements at each testing point (STA 8+000, STA 8+100, STA 8+200, STA 8+300, STA 8+400, STA 8+500, STA 8+600, STA 8+700, STA 8+800, and STA 8+900) produced BPN values, which are presented in graphical form in Figures 6 and 7. These graphs illustrate the distribution of BPN values along the test segment, making it easier to identify variations in road surface skid resistance at each measurement point.

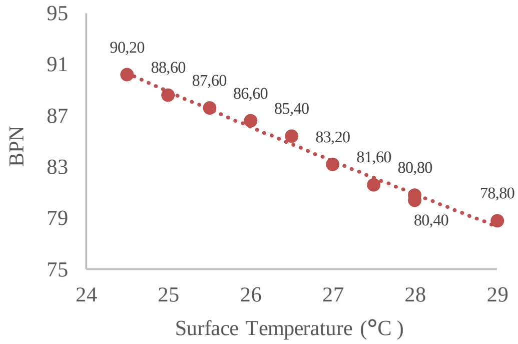

Figure 6. BPN Values Graph in Morning and Dry Conditions

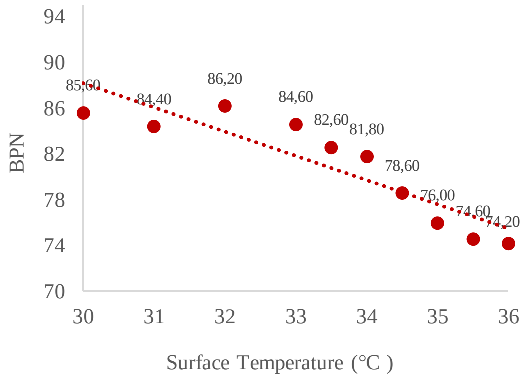

Figure 7. BPN Values Graph in Afternoon and Dry Conditions

The graph shows the relationship between surface temperature and BPN values under dry conditions, both in the morning and afternoon. In the morning, an increase in temperature from 24.5°C to 29°C is accompanied by a decrease in BPN from 90.20 to 78.80. A similar trend is observed in the afternoon, where the temperature rises from 30°C to 36°C and the BPN drops from 85.60 to 74.20. These findings indicate a negative relationship between temperature and skid resistance under dry conditions. As the temperature increases, the BPN value decreases. This occurs because higher temperatures soften the asphalt surface and reduce its microtexture, leading to lower friction. These results are consistent with Novamaulina et al. (2019), who reported that higher daytime temperatures accelerate the reduction of skid resistance.

For wet conditions, the graphs presented in Figures 8 and 9 are used to evaluate the ability of the road surface to provide friction in the presence of water or surface wetness.

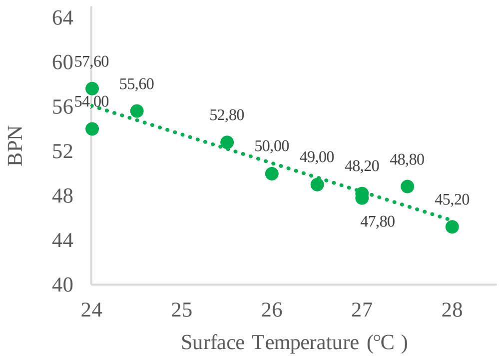

Figure 8. BPN Values Graph in Morning and Wet Conditions

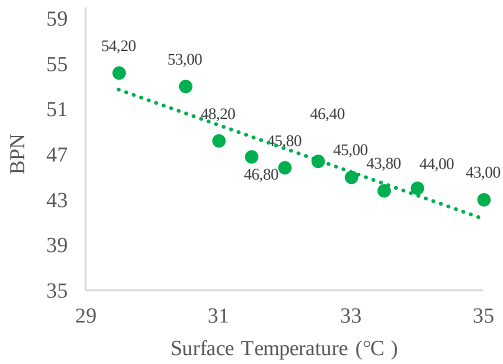

Figure 9. BPN Values Graph in Afternoon and Wet Conditions

The graph indicates that under wet conditions, BPN values are generally lower than those observed under dry conditions, even though the surface temperature decreases by about 0.5–1°C due to the cooling effect of water. In the morning, a temperature of 24°C corresponds to a BPN of 57.60, which drops to 45.20 at 28°C. In the afternoon, BPN decreases from 54.20 at 29.5°C to 43.00 at 35°C. The effect is to reduce the temperature of the surface as the water absorbs heat by evaporation . It also forms a thin layer that reduces effective contact between tire and pavement.

Consequently, friction is greatly reduced.

The lowest skid resistance values are those of wet afternoons due to the combined effects of high temperature and asphalt softening and friction reduction due to water. This result is in agreement with Hakim et al. (2021) who reported that wet surfaces increase the risk of skidding, especially for vehicles with smoother tires.

Figure 10 shows a comparison of BPN values in the morning under dry and wet conditions. This graph emphasizes the difference in surface skid resistance values between the two conditions, thereby allowing the effect of surface moisture on the skid resistance values at each STA to be observed during the morning period.

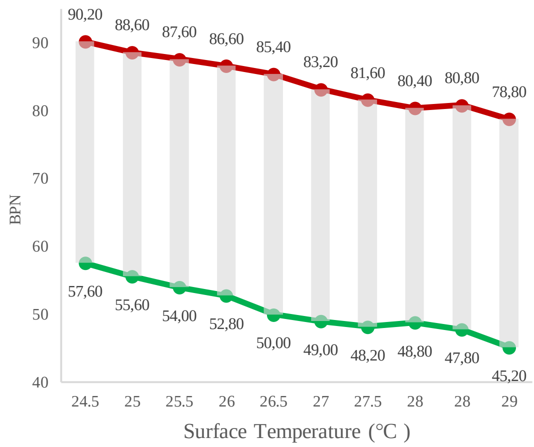

Figure 10. BPN Values Graph in Morning, Dry Conditions (Red) and Wet Conditions (Green)

As shown in graph BPN values decrease as the temperature increases under dry and wet conditions but the decrease under wet conditions is much greater. The BPN under dry condition at about 24°C is 90.20 and under wet condition is only 57.60. As the temperature increases to 29°C, the dry BPN decreases to 78.80, and the wet BPN decreases more sharply to 45.20. This difference of about 32-34 points shows the importance of water in reducing the friction. Water forms a separating layer that weakens the friction mechanism, while higher temperatures soften the asphalt and reduce its microtexture. As a result, wet conditions lead to a more pronounced decrease in BPN compared to dry conditions. Furthermore, a comparison of BPN values under dry and wet conditions in the afternoon is presented in Figure 11.

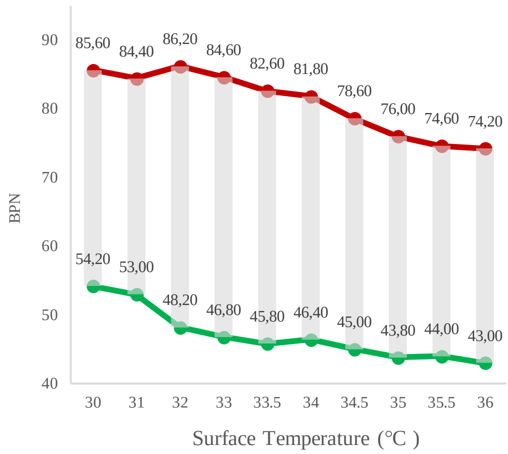

Figure 11. BPN Values Graph in Afternoon, Dry Conditions (Red) and Wet Conditions (Green)

The graph in Figure 11 shows that an increase in surface temperature from 30°C to 36°C leads to a decrease in BPN values under both conditions. Under dry conditions, BPN decreases from 85.60 to 74.20, while under wet conditions it drops from 54.20 to 43.00. This pattern confirms a negative relationship between temperature and skid resistance, where higher temperatures reduce the road surface’s ability to resist skidding. Under dry conditions, the decrease is mainly due to asphalt softening at higher temperatures. In contrast, under wet conditions, the combined effect of temperature and water accelerates the formation of a separating layer between the tire and the road surface, resulting in a greater reduction in BPN. These findings are consistent with Wu et al. (2020), who reported that increasing temperature significantly reduces skid resistance, particularly on wet surfaces.

Based on field measurements, where SRV values have been corrected for temperature and expressed as BPN, several values fall below the minimum threshold according to the Bullas (1969) standard from the Transport and Road Research Laboratory (TRRL), as presented in Table 1. The classification of BPN values under dry and wet conditions is shown in Tables 4 and 5.This graph illustrates the difference in road surface skid resistance between the two conditions during the afternoon, when surface temperatures are higher than in the morning.Physical property testing was conducted on the asphalt, aggregate, and filler materials, with the results presented in Tables 4 to 5.

Table 4. Summary of BPN Classification in Dry Conditions

Session Time	STA Point	Surface Temperature (°C)	Mean	Meets Spesification (≥ 65 BPN)
Moring	8+000	24,5	90,20	Yes
	8+200	25	88,60	Yes
	8+400	25,5	87,60	Yes
	8+600	26	86,60	Yes
	8+800	26,5	85,40	Yes
	8+100	27	83,20	Yes
	8+300	27,5	81,60	Yes
	8+500	28	80,40	Yes
	8+700	28	80,80	Yes
	8+900	29	78,80	Yes
Afternoon	8+000	30	85,60	Yes
	8+200	31	84,40	Yes
	8+400	32	86,20	Yes
	8+600	33	84,60	Yes
	8+800	33,5	82,60	Yes
	8+100	34	81,80	Yes
	8+300	34,5	78,60	Yes
	8+500	35	76,00	Yes
	8+700	35,5	74,60	Yes
	8+900	36	74,20	Yes

Under dry conditions, all BPN values from STA 8+000 to STA 8+900, both in the morning and afternoon, are above 65 BPN. This means that all points meet the TRRL standard and can be considered safe in terms of skid resistance. These relatively high values indicate that the pavement’s micro- and macro-texture are still in good condition, with no signs of bleeding and no significant polishing. Therefore, all testing points under dry conditions can be classified as having very good skid resistance. The distribution of testing points (STA) along with the corresponding results is shown in Figure 12, where the data are presented more clearly using color-based classification of BPN values.

Tabel 5. Summary of BPN Classification in Wet

Session Time	STA Point	Surface Temperature (°C)	Mean	Meets Spesification (≥ 65 BPN)
Moring	8+000	24	57,60	Yes
	8+200	24,5	55,60	Yes
	8+400	24	54,00	No
	8+600	25,5	52,80	No
	8+800	26	50,00	No
	8+100	26,5	49,00	No
	8+300	27	48,20	No
	8+500	27,5	48,80	No
	8+700	27	47,80	No
	8+900	28	45,20	No
Afternoon	8+000	29,5	54,20	No
	8+200	30,5	53,00	No
	8+400	31	48,20	No
	8+600	31,5	46,80	No
	8+800	32	45,80	No
	8+100	32,5	46,40	No
	8+300	33	45,00	No
	8+500	33,5	43,80	No
	8+700	34	44,00	No
	8+900	35	43,00	No

Under wet conditions in the morning, STA 8+000–8+200 meet the specification (>55 BPN), while STA 8+400–8+900 do not. In the afternoon, all points from STA 8+000 to STA 8+900 fall below the minimum threshold. These substandard values indicate that, at those locations, the frictional capability of the road surface is reduced, which may increase the risk of skidding under wet conditions. The distribution of testing points (STA) along with the results is presented in Figure 13, using color-coded BPN classification to make the interpretation clearer.

Figure 12. Distribution of BPN Classification at Each STA in Morning and Afternoon (Dry)

Figure 13. Distribution of BPN Classification at Each STA in Morning and Afternoon (Wet)

After collecting the field data, it was analyzed to determine the direction and strength of the relationship between surface temperature and skid resistance using Pearson correlation and simple linear regression, as presented in Tables 6 and 7.

Table 6. Summary of Pearson Correlation Analysis Results

Condition			Correlations: Surface Temp.	Correlations: BPN Value
Dry	Surface Temp.	Pearson correlation	1	-0,727
		Sig. (2-tailed)		0,000
		N	20	20
	BPN Value	Pearson correlation	-0,727	1
		Sig. (2-tailed)	0,000	
		N	20	20
Wet	Surface Temp.	Pearson correlation	1	-0,552
		Sig. (2-tailed)		0,012
		N	20	20
	BPN Value	Pearson correlation	-0,552	1
		Sig. (2-tailed)	0,012	
		N	20	20

Table 7. Summary of Pearson Correlation Analysis Results

Condition	Output	Description	Analysis Results
Dry	Variables Entered/Removed	Method	
	Model Summary	R	0,727
		R^2	0,529
		Adjusted R Square	0,503
		Std. Error of the Estimate	3,196
	ANOVA	Sig.	0,000
	Coefficients Table	Constant (a)	108,345
		Regression Coefficient (b)	-0,856
		Sig.	0,000
		t Value	4,496
		t Table	1,734
Wet	Variables Entered/Removed	Method	
	Model Summary	R	0,552
		R^2	0,305
		Adjusted R Square	0,267
		Std. Error of the Estimate	6,077
	ANOVA	Sig.	0,012
	Coefficients Table	Constant (a)	79,585
		Regression Coefficient (b)	-1,103
		Sig.	0,012
		t Value	6,916
		t Table	1,734

The results of the Pearson correlation analysis show an r value of –0.727 under dry conditions and –0.552 under wet conditions, with significance values of 0.000 and 0.012, respectively. These results indicate a strong and statistically significant negative relationship between surface temperature and skid resistance. In other words, as temperature increases, the BPN value decreases.

The results are further supported by simple linear regression analysis. Under dry conditions, the equation obtained is BPN = 108.345 – 0.856 (Temperature) with an R^2 value of 0.529, while under wet conditions the equation is BPN = 79.585 – 1.103 (Temperature) with an R^2 of 0.305. In both conditions the calculated t-values are also larger than the critical t-values, which indicates that the effect of temperature is statistically significant. Practically, the BPN decreases by 0.856 for every 1°C increase in temperature for dry conditions and 1.103 for wet conditions. This demonstrates the strong and consistent influence of surface temperature on the reduction of road skid resistance.

Conclusion

Several important findings can be summarized from the results obtained with the BPT device. BPN decreases at all conditions with increase of temperature from 24-36°C. The BPN under dry conditions decreases from 90.20 to 78.80 in the morning and from 85.60 to 74.20 in the afternoon. Under wet conditions the decrease is more pronounced from 57.60 to 45.20 in the morning and from 54.20 to 43.00 in the afternoon. The approximately 32–34 point difference between dry and wet conditions indicates that the risk of skidding increases significantly at higher temperatures when the surface is wet. All the dry condition measurements are above the standard threshold of >65 BPN indicating generally good pavement conditions. However, for wet conditions only a small portion of the measurements are above the >55 BPN standard while the majority of the points are below the safe limit. This indicates that some segments become more dangerous and require maintenance attention. The strong negative relationship between temperature and BPN is observed with correlation values of -0.727 (dry) and -0.552 (wet) with significance level of 0.000. This shows that increase in temperature will invariably lead to reduction in skid resistance especially under wet conditions. The regression analysis also confirms the significant effect of temperature on BPN with R2 values of 52.9% (dry) and 30.5% (wet). It was found that an increase of 1°C in temperature causes a reduction of 0.856 in BPN when tested under dry condition and 1.103 when tested under wet condition which indicates that the temperature is an important factor in reduction of road skid resistance especially when the surface is wet.

Future research should look at the combined effects of temperature, rainfall intensity, pavement texture, and traffic characteristics on skid resistance performance. Additionally, long-term monitoring in various road types and environmental conditions is suggested to enhance road safety assessments' accuracy.

Declaration Statement

The authors declare that ChatGPT (OpenAI) was used solely for language proofreading, grammar correction, and improvement of writing clarity during the preparation of this manuscript. All scientific content, including the study design, methodology, data analysis, interpretation of findings, and conclusions, were developed and verified exclusively by the authors. The authors take full responsibility for the accuracy, originality, integrity, and validity of the manuscript's content.

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