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Assessment of Relationship Between Road Roid-Based International Roughness Index and Conventional Surface Distress Index: Two Pavement Evaluation Measures Currently Employed in Nepal

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Abstract

Effective pavement condition evaluation is critical for ensuring the safety, usability, and longevity of road networks, especially in developing countries like Nepal where financial and technical constraints limit access to conventional high-end measurement technologies. Traditional methods such as the International Roughness Index (IRI) and Surface Distress Index (SDI) provide valuable insights but are often costly and resource intensive. This study investigates the potential of the RoadRoid smartphone application as a low-cost alternative for measuring IRI and examines its relationship with the conventionally obtained SDI. Calibration of RoadRoid measurements was conducted against benchmark IRI data collected using a Romdas Z-250 Laser Profiler over a 200-meter reference section. A chi-square goodness-of-fit test validated that there was no statistically significant difference between the RoadRoid-derived measurements and those from the reference profiler at a 95% confidence level. Regression analyses were performed to assess the relationship between RoadRoid-based IRI and SDI, evaluating linear, logarithmic, and third-order polynomial models. The third-order polynomial model exhibited the best fit with a coefficient of determination (R^2) of 0.64, demonstrating a strong correlation between the two indicators. These results confirm that the RoadRoid application, when properly calibrated, can reliably measure pavement roughness and correlate well with surface distress conditions. The findings highlight the potential of smartphone-based technologies to offer affordable, scalable solutions for pavement condition assessment, supporting more efficient maintenance planning and infrastructure management in resource-constrained environments.

Keywords: Pavement Management, RoadRoid, International Roughness Index, Surface Distress Index, Coefficient of Determination, Laser Profiler

1. Introduction

Timely and reliable evaluation of pavement conditions is essential to maintain the safety, usability, and lifespan of road infrastructure, especially in developing countries like Nepal, where financial and technical constraints often make it difficult to construct new pavements every time (Kaiser & Barstow, 2022). Development and urbanization has many drawbacks as well (Shah et al., 2019), especially considering the use of the road and the cost associated with it. According to the Department of Transport Management (DoTM) Nepal (2014), the total number of registered vehicles in the country had been increasing every year according to Shah et,al.(2019) and it has reached 5.54 million in 2024. The number of vehicles being used for ride-sharing services has increased as well in modern days, directly increasing the number of trips and use of the road pavement (Chaudhary et al., 2024). It inversely takes a toll on the pavement, therefore requiring efficient management strategies of the pavement. It is also a significant factor affecting the travel time reliability between two points (S. K. Thapa et al.,

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2024) . Traditionally, in Nepal, pavement performance is assessed using two well-established indicators: the International Roughness Index (IRI) and the Surface Distress Index (SDI). IRI provides a quantitative measure of road smoothness and ride quality, directly influencing user comfort and vehicle operation costs(Hossain et al., 2019). In recent years, IRI has proven to a valuable tool in pavement maintenance planning both in regional as well as national level in Nepal(Sigdel et al., 2024). However, collecting IRI data typically requires sophisticated tools like inertial profilers, bump integrators or laser-based devices, which, although highly precise, are expensive and demand specialized skills to operate (Fares & Zayed, 2023). Some of the tools to obtain IRI include vehicle mounted bump integrators which are only available with Department of Roads in Nepal. In contrast, SDI is based on visual surveys of surface damage such as cracks, potholes, rutting, and bleeding, offering a broader picture of a pavement's overall condition(Utami et al., 2024). While SDI assessments are easier to carry out, they can be subjective and heavily dependent on the experience along with judgement of the surveyor(Hermawati & Putri, 2024). The condition of road is also considered to be one of the major factors associated with crashes in Kathmandu Valley in Nepal (S. Thapa et al., 2023). Better condition of pavement helps in improving the safety of travel, reducing congestion caused due to slow-moving traffic in poor pavement, and enhancing of traffic flow(Kunwar et al., 2025). It can be difficult to manage both pedestrians and vehicles and to regulate the flow of traffic (Thapaliya et al., 2024).

In a country like Nepal, where road networks are expanding rapidly and the demand for effective pavement management is growing, traditional assessment methods face significant challenges due to limited budget, equipment shortages, and a lack of trained personnel (Shrestha, 2023). This situation has created an opportunity for alternative, affordable technologies. One such promising solution is the use of smartphone applications like RoadRoid, which utilize the built-in accelerometers and GPS of a smartphone to estimate IRI. The wide availability of smartphones, combined with the low cost and user-friendly nature of RoadRoid, makes it an attractive option for pavement condition monitoring, particularly in resource-limited settings(Lars Forslöf & Hans Jones, 2015).

However, before smartphone-based methods like RoadRoid can be widely adopted in pavement evaluation programs, their accuracy and reliability must be carefully validated (Douangphachanh & Oneyama, 2014). This requires thorough comparisons with standard measurement systems such as high-precision reference profilers. In addition, understanding how well RoadRoid IRI estimates correlate with traditional SDI ratings is equally important as it would create a basis to skip the overall subjective and tedious process of SDI estimation with a modern alternative in the form of RoadRoid. Establishing a strong relationship between these two measures would not only enhance confidence in the use of smartphones for roughness measurement but also open the door for integrated assessment methods that combine both objective data and visual inspections, offering a more complete and practical approach to monitoring pavement conditions. Therefore, the research aims to make a significant contribution to the field of pavement management by demonstrating a scalable and affordable alternative for road condition assessment. This has profound implications for Nepal and other developing nations where budgetary constraints and technical limitations often hinder the implementation of conventional pavement evaluation techniques. Ultimately, the adoption of smartphone-based technologies like RoadRoid could lead to more efficient allocation of maintenance resources, improved road safety, and enhanced user satisfaction, fostering more sustainable road infrastructure development (Khandakar et al., 2025).

2. Literature Review

The roughness evaluation model comparing IRI and visible distresses was developed by Shrestha et. al, (2023) which marks the first time use of RoadRoid-based IRI in Nepal. The instrument which in this case was a smartphone, was calibrated using the Romdas Z-250 reference profiler. In doing so, a certain section was chosen and multiple runs were made to assess the profiler and RoadRoid IRI. The validation process was finalized through a chi-squared test and the sensitivities were proposed for the particular study to assess the relationship between the IRI and the visible pavement distresses in AC pavements(Shrestha et al., 2023).

Roughness measurement for Janderal Sudirman Kalianget road was carried out to assess the road condition. The pavement condition assessment was also conducted in the research, as reported Arianto et.al, (2018). Jenderal Sudirman-Kalianget's pavement was in fair condition (20.35%) and in good condition (37.17%) over 4.2 kilometers. Both areas need routine repair. On the other hand, 2.7 kilometers (23.89%) and 2.1 kilometers

(18.58%) were subpar and required regular repair and maintenance. For the computation of the IRI data, RoadRoid, an Android-based application, was used. The device used accelerometer and vibration sensors that were present in the smartphone for the collection of the roughness data. Table 1 and Table 2 show the pavement condition criteria based on IRI and SDI, respectively.

Table 1. Pavement Condition Criteria based on IRI (Arianto et al., 2018)

IRI value	Pavement Condition
IRI<4	Good
4<IRI<8	Fair
8<IRI<12	Bad
IRI>12	Poor

Table 2. Pavement Condition Criteria based on SDI (Arianto et al., 2018)

SDI value	Pavement Condition
SDI<50	Good
50<SDI<100	Fair
100<SDI<150	Bad
SDI>150	Poor

The assessment of the relationship between the pavement performance indicators with pavement condition index and IRI, which was also RoadRoid based indicated a strong negative correlation between the two parameters with the highest correlation between the two being 0.7858. The PCI was assessed according to the instructions from ASTM 6433 in roads in Kathmandu and for the same sections IRI was evaluated using RoadRoid application. The relationship between the two also indicated a need of another pavement evaluation along with IRI for highest degree of effectiveness(Shrestha et al., 2024).

Setiadji emphasized that road functional classification is typically evaluated using the International Roughness Index (IRI) and the Surface Distress Index (SDI) due to their straightforward procedures and ease of use. However, SDI results often fall short when it comes to accurately reflecting the true condition of the road. To address this, the project aimed to improve the evaluation of SDI by analyzing the extent and severity of surface cracks. For a more reliable assessment, the study referenced the Pavement Condition Index (PCI), recognized as a comprehensive and dependable measure of road quality. However, one of the main challenges in field evaluations of PCI is the reliance on untrained or inexperienced personnel, which can affect the accuracy of the results (Setiadji et al., 2019).

Recent research shows that Unmanned Aerial Vehicles (UAVs) are becoming a reliable alternative to traditional pavement surveys. UAVs capture high-resolution images that are turned into 2D and 3D models, which can be used to assess road conditions using methods like the Pavement Condition Index (PCI) and Surface Distress Index (SDI). Astor et.al, (2023) reports an accuracy rate between 75% and 98% when compared to manual field measurements.

Metrics such as mean squared error and R^2 also show that UAV-based evaluations closely match traditional methods, making UAVs a practical and efficient tool for pavement assessment.

Suryoto and Siswoyo (2017) developed a linear model to describe the relationship between the Surface Distress Index (SDI) and the International Roughness Index (IRI). They measured SDI by manually assessing both major and minor surface distresses through visual inspection surveys. In contrast, IRI values for the same road sections were obtained using a vehicle-mounted bump integrator. The relationship between SDI and IRI was expressed with the equation: $SDI = 32.684 + 3.3455 \times IRI$. To assess the strength of this relationship, they used Pearson correlation analysis, which resulted in a correlation coefficient of 0.203, a value indicating a rather weak association between the two measures (Suryoto et al., 2017).

A study comparing the International Roughness Index (IRI), Pavement Condition Index (PCI), and the Bina Marga method was conducted to evaluate flexible pavement conditions and guide maintenance decisions. The IRI, which focuses on surface smoothness, classified most road segments as having a "Moderate" roughness level with an average value of 7.2. The PCI, which evaluates visible surface distresses, rated the roads as being in "Fair" condition with a score of 41.2. In contrast, the Bina Marga method, which assesses maintenance needs, recommended "Routine Maintenance" with a value of 6.8. These differences highlight how each method emphasizes different aspects of pavement condition. While IRI reflects ride quality, PCI provides a more comprehensive view of surface defects, and Bina Marga focuses on maintenance actions. Overall, the findings suggest that minor issues like cracks and surface unevenness are present and should be addressed promptly to maintain user comfort and prevent further deterioration (H et al., 2023).

Roughness, measured by the International Roughness Index (IRI), is a key indicator of pavement condition, reflecting surface smoothness and safety. This study examined the relationship between IRI and surface distresses on eight PMGSY roads in Rajasthan, India. Distress data was collected every 50 meters, and roughness was measured using a calibrated Bump Integrator. To isolate distress effects, unevenness from a new pavement stretch was subtracted from the test data. A regression model was then developed to relate IRI to visible surface distresses based on field measurements (Bhanegaonkar, 2013).

3. Study Area

The study mainly focuses on National Highways and Feeder Roads within the Kathmandu Valley for data collection. The locations were carefully chosen to ensure that all types of roads are represented. This approach helps in capturing a wide range of pavement distresses, allowing the model to be developed with a diverse and comprehensive dataset, and a wide range of IRI and SDI values are covered. A total of 52.4 Km data was taken which consisted of 524 sections with each section being 100 m. The average length of each section was also noted to calculate the distress density in later part of this study for SDI computation.

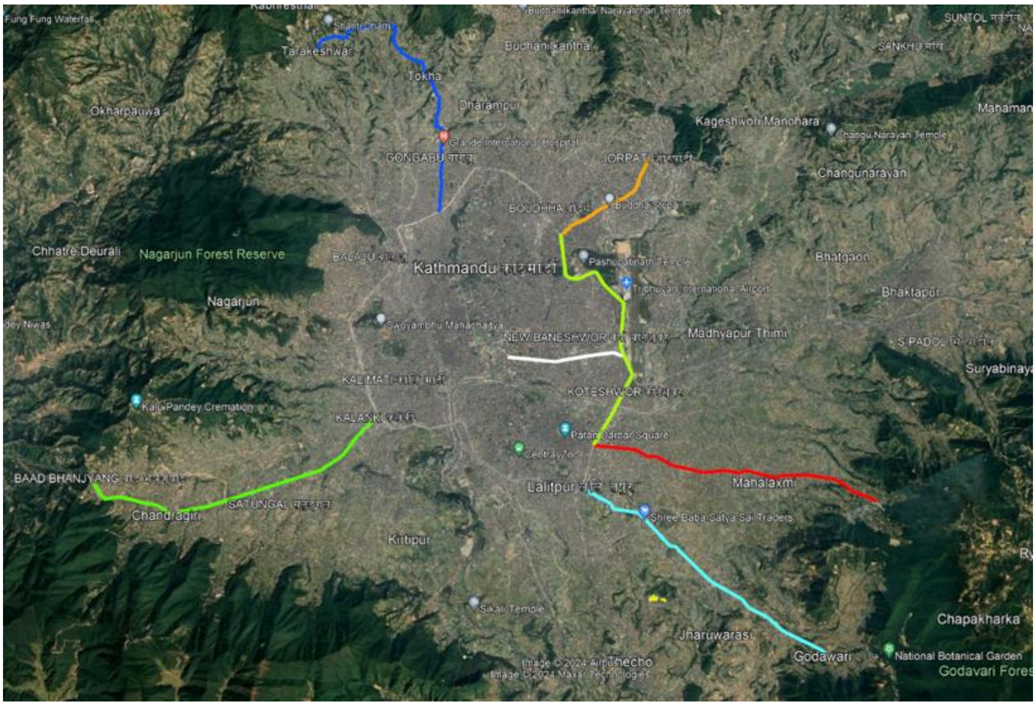

Figure 1. Proposed Study Area

Table 3. Description of Study Area

S. N	Road Section	Length of Link surveyed for study	Designation
1	Satdobato-Harisiddhi-Godawari	8.2 km	F024
2	Gwarko-Sanagau-Lamatar	8.0 km	F072
3	Kalanki-Chandragiri	9.1 km	H02
4	Maitighar-Baneswor-Tinkune	4.2 km	H03
5	Gwarko-Koteshwor-Tinkune-Sinamangal-Chabail	8.2 km	NH39

S. N	Road Section	Length of Link surveyed for study	Designation
6	Chabail-Jorpati	3.7 km	F027
7	Samakhusi-Tokha-Tarakeshwor	11 km	F082
	Total		52.4 km

4. Methodology

This study investigates the relationship between the International Roughness Index (IRI) derived from RoadRoid, a smartphone-based application, and the traditional Surface Distress Index (SDI), both of which are commonly employed for pavement evaluation in Nepal. The detailed methodology is as presented below.

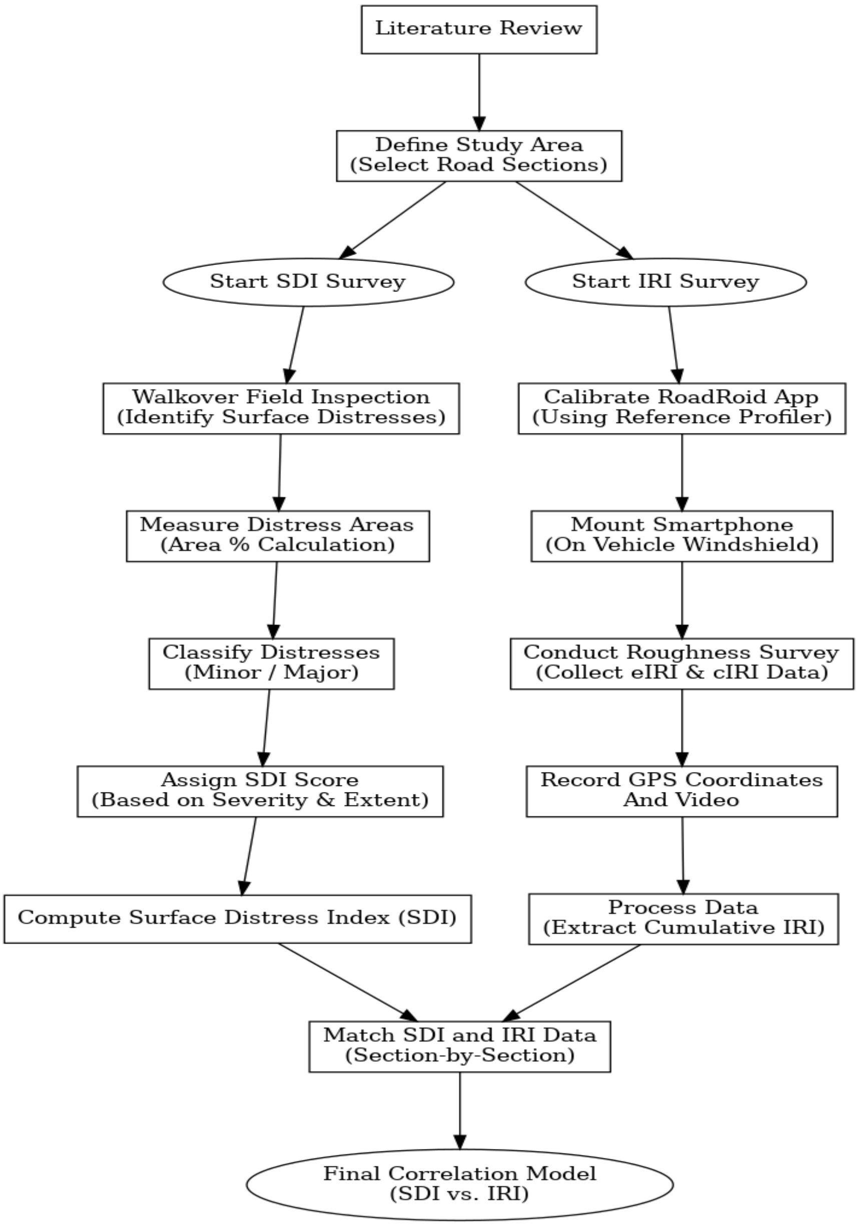

Figure 2. Methodology followed

After carrying out relevant literature and the selection of study area, the process of roughness data collection and distress data collection for SDI was initiated. Before the roughness data collection, a detailed calibration process was performed for the IRI. A license for the RoadRoid application was acquired, and calibration procedures recommended in the official RoadRoid User Guide were rigorously followed. Calibration involved setting up two devices in the same vehicle that was designated for data collection, with smartphones mounted on the windshield in accordance with best practices outlined in the guide. The validation of IRI measurements obtained through the RoadRoid application was carried out using secondary data sourced from a prior study conducted by Shrestha and Pradhananga (2023). In this process, the IRI values recorded by RoadRoid were compared against benchmark measurements collected using a Romdas Z-250 Laser Profiler over a designated 200-meter reference section within Pulchowk Campus. In the same section, multiple trial runs were performed with different sensitivity settings on the smartphone accelerometer to identify the configuration that closely matched the profiler readings. The sensitivity that yielded the most accurate match was adopted for subsequent data collection across all road sections. To find out if there were any major differences between the IRI values recorded by the RoadRoid app and the expected values from the standard reference profiler, a chi-square goodness-of-fit test was used. Since the original IRI data was collected with a 2.5-meter reference profiler, it was adjusted to match the 5-meter reference standard for a fair comparison.

For this test, two hypotheses were set up. The null hypothesis (H_0) assumed there would be no significant difference between the IRI values from RoadRoid and the reference profiler. On the other hand, the alternative hypothesis (H_1) suggested there would be a noticeable difference between the two. The chi-square test was carried out at a 95% confidence level, meaning the results were evaluated against a significance threshold of 0.05. Multiple trials were conducted with different sensitivities. The figure given below represents the plot of comparison of IRI using reference profiler and third trial of RoadRoid IRI estimation.

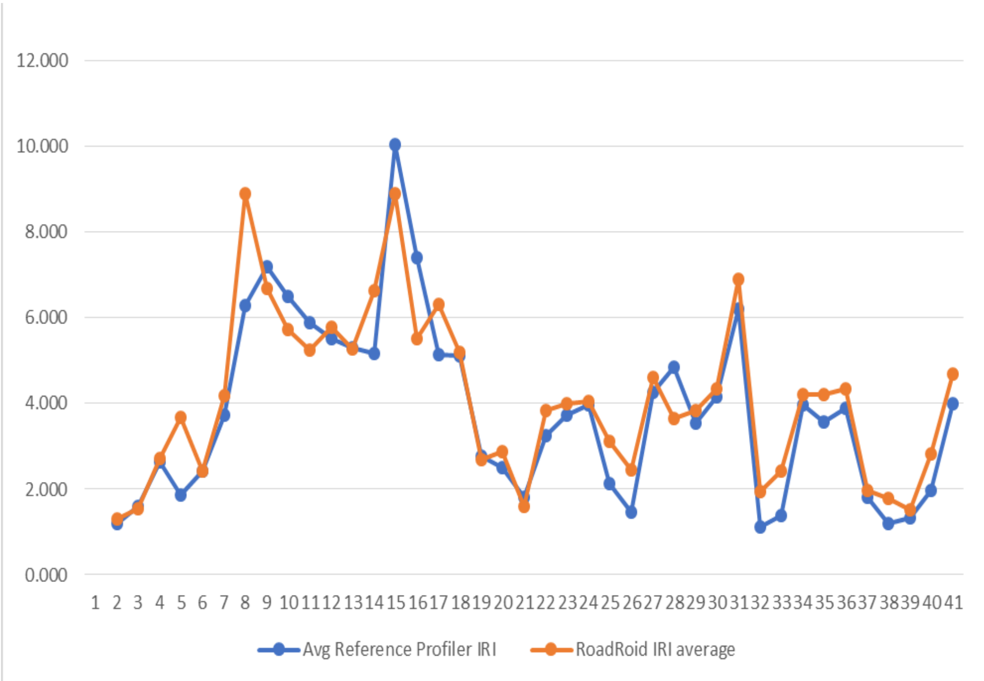

Figure 3.Reference Profiler vs RoadRoid IRI

The results of the chi-squared test are presented in table below.

Table 4. Chi square test computation table

IRI interval	Observed frequency	Expected frequency	O-E	(O-E)^2/E
0-2	14	18	-4	0.89
2-4	26	28	-2	0.14
4-6	32	24	8	2.67
6-10	8	10	-2	0.40
Sum	80	80	Chi sq value	4.10

Degree of Freedom=d-1=4-1 =3

Value of Chi square= 4.10

P value (from chi-square test table) = 0.251 >>> 0.05 (so ok)

Since the p-value was found to be greater than the established level of significance, the null hypothesis was accepted. This indicates that there is no statistically significant difference between the expected IRI values obtained from the reference profiler and the observed IRI values recorded using the RoadRoid application under the specified sensitivity presets. Consequently, the same sensitivity settings, vehicle, and survey parameters were consistently applied for RoadRoid-based evaluations throughout the model development process in this research.

Additionally, the accelerometer sensitivities corresponding to the third and ultimately successful trial are presented in table below.

Table 5. Accelerometer table

Vehicle Speed	Accelerometer Sensitivity	Default value
20 Km/hr	0.38	0.36
40 Km/hr	0.6	0.53
60 Km/hr	0.65	0.59
80 Km/hr	0.56	0.56
100 Km/hr	0.57	0.57
120 Km/hr	0.52	0.52

Roughness data were gathered by securely mounting the smartphone horizontally on the windshield and calibrating the device to ensure vertical acceleration (Y-axis) measurements were isolated. It utilizes the tri-axis accelerometer sensor presented in the smartphone for the estimation of vertical deflection and processes it in form of IRI. The RoadRoid application was initialized, and the sensor axes were zeroed prior to starting each survey. Video recordings of the entire survey route were captured using the application to aid in subsequent correlation with distress locations. During the survey, data on estimated IRI, cumulative IRI, GPS coordinates, distance traveled, and other relevant parameters were collected. To prevent smartphone overheating and ensure smooth functioning of the application, the data collection was limited to around 650 MB per continuous session.

Surface distress data were collected through visual inspections conducted by a team of surveyors. Separate data was taken for each of 524 sections, and the corresponding length and width of the section are also noted for area calculation for SDI computation. Each visible surface defect, such as potholes, cracking, rutting, and patches, was recorded with precise location references. These visual observations were synchronized with the video data from the roughness survey to ensure accurate spatial matching. For each section, the area covered by distress was quantified and expressed as a percentage of the total section area, resulting in a measure of distress density.

5. Results

After collection, the roughness and distress data were preprocessed to ensure alignment between the two datasets. Distress observations were matched with their corresponding cumulative IRI values using the recorded videos and GPS coordinates. The raw distress data were converted into distress density percentages by dividing the defective area by the total surveyed section area. Sections containing non-flexible pavement materials were excluded during this stage to preserve dataset integrity. For the analysis, the Surface Distress Index (SDI) was calculated based on the standard methodology employed by the Department of Roads (DoR) in Nepal. SDI values were computed by combining distress densities, giving greater weight to critical distresses such as potholes and exposed base areas. Regression analysis was then performed to explore the relationship between cumulative IRI and SDI values. Three types of regression models: linear, logarithmic, and polynomial (up to the third degree), were developed using Microsoft Excel (2019) with statistical analysis add-ins. Scatter plots were generated for each model, and the coefficient of determination (R^2) was used to assess model performance. interpretability. The outputs of regression models are presented with the help of table 6 and 7 below.

Table 6. Regression statistics of SDI vs IRI

Regression Statistics	
Multiple R	0.788665
R Square	0.621992
Adjusted R Square	0.621268
Standard Error	0.524041
Observations	524

Table 7. Summary of Outputs

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	235.8762	235.8762	858.9232	2.4E-112
Residual	522	143.3509	0.274619		
Total	523	379.2271			

The linear, logarithmic and polynomial relationship between the IRI and SDI is presented with the help of Equation 1,2 and 3 respectively and is represented in Figure 4,5,6 as shown below. The corresponding coefficient of determination of 0.62, 0.63 and 0.64 was obtained for linear, log and cubic relationship between the variables.

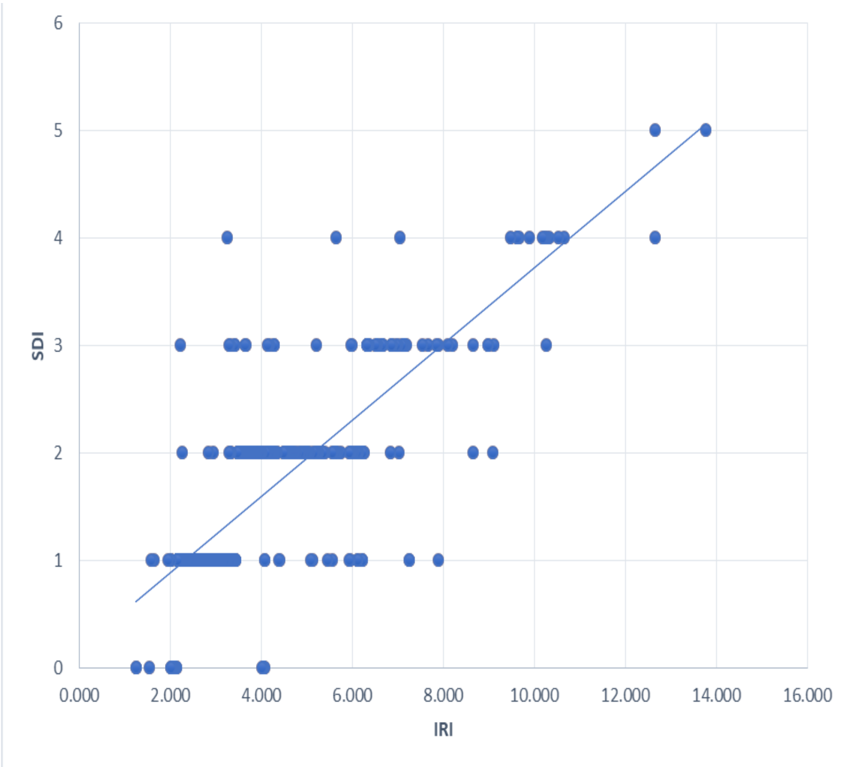

Figure 4. SDI vs IRI linear

$$SDI = \begin{cases} 0.3554 \times IRI + 0.1693, & \forall \quad IRI < 13.592 \ m/km \\ 5, & \text{Otherwise} \end{cases} \quad R^2=0.62 \qquad (1)$$

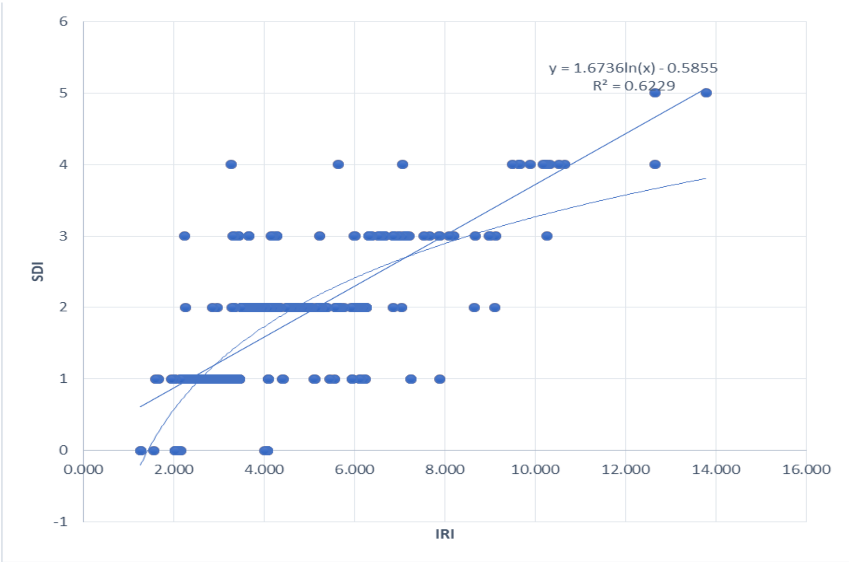

Figure 5. SDI vs IRI log

$$SDI = \begin{cases} 1.674 \times \ln(IRI) - 0.5855, & \forall \quad IRI < 27.33 \ m/km \\ 5, & Otherwise \end{cases} \qquad (2)$$

R^2=0.63

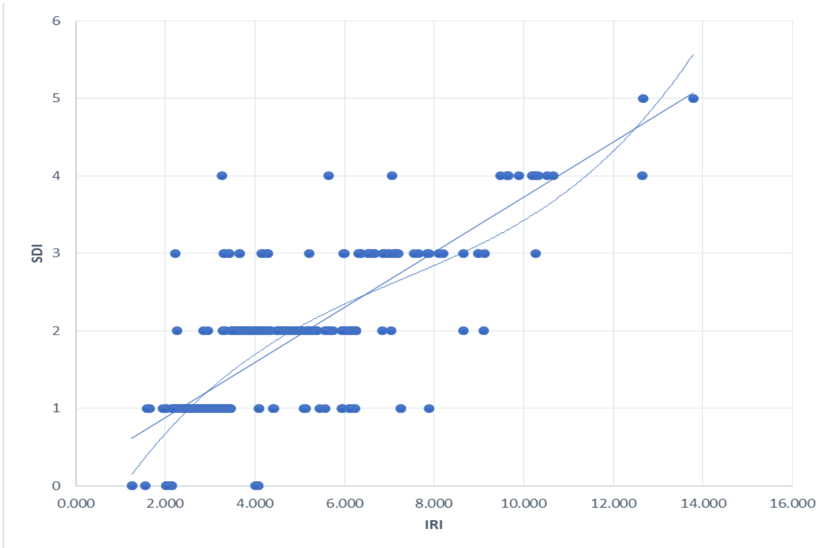

Figure 6. SDI vs IRI cubic

$$SDI = \begin{cases} 0.0048 \times IRI^3 - 0.105 \times IRI^2 + 1.0083 x\, IRI - 0.9613, & \forall \quad IRI < 14.208 \ m/km \\ 5, & Otherwise \end{cases} \qquad (3)$$

R^2=0.64

The best fit relationship between IRI and SDI is found to be of polynomial relationship of order 3 between the two, with the coefficient of determination of 0.64. Although the polynomial regression demonstrated the highest R^2 value, linear and logarithmic models were also considered to avoid model overfitting and ensure On comparing similar literature, based on the study carried out by Shrestha and Khadka (2021), the best fit relationship between SDI and IRI was found to be of a Polynomial in nature with a coefficient of determination of 0.5831. The study, therefore, aligns with the relevant literature(Ghaith et al., 2015; Mansourian & Zoej, 2008; Rahardjo & Suparman, 2017; Shrestha & Khadka, 2021). The relationship between the SDI and IRI was successfully evaluated based on the collected data presented with a positive correlation.

6.. Conclusion and Future Scope

This study aimed to assess the viability of using the RoadRoid smartphone application as a cost-effective alternative for measuring the International Roughness Index (IRI) and to explore its relationship with the conventionally obtained Surface Distress Index (SDI) for pavement condition evaluation. By calibrating RoadRoid measurements against benchmark IRI data from a Romdas Z-250 Laser Profiler and conducting a systematic surface distress survey, the research provided a dual perspective on pavement performance through both objective and visual assessments.

The validation process confirmed that the IRI measurements derived from RoadRoid, when properly calibrated, closely align with those obtained from the reference profiler, demonstrating sufficient accuracy for practical applications in the context of Nepal's road infrastructure. Statistical analysis further revealed a significant correlation between RoadRoid-based IRI values and the visually assessed SDI. Among the regression models evaluated, the third-order polynomial model exhibited the best fit, with a coefficient of determination (R^2) of 0.64, indicating a strong relationship between roughness and surface distress conditions.

These findings highlight the potential of integrating smartphone-based technologies into pavement management systems, particularly in developing countries where resource limitations often preclude the widespread use of high-end profiling equipment. The adoption of RoadRoid offers a scalable, affordable, and accessible tool for road condition monitoring, capable of supporting informed decision-making for maintenance prioritization and budget allocation and can therefore serve as an alternative of the conventionally used Surface Distress Index commonly employed in Nepal.

The study further demonstrates that RoadRoid, coupled with traditional visual surveys, can provide a comprehensive and reliable framework for pavement evaluation. Future research should focus on expanding the dataset across different road classifications and environmental conditions, as well as exploring real-time data collection and integration capabilities to enhance the efficiency and accuracy of pavement management systems in resource-constrained settings (Khatoon et al., 2024).

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