COMPARATIVE ANALYSIS OF EVALUATION CRITERIA FOR UNPAVED RURAL ROADS: 
A CASE STUDY

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This study focused on the evaluation of the condition of the unpaved rural road: Sauces Norte - Imbana in the province of Loja, using two main indicators: Unsurfaced Road Condition Index (URCI) and the International Roughness Index (IRI). The IRI was measured using three different devices: MERLIN, Roughometer III, and a mobile application. The collected data were statistically analyzed to determine their distribution and the correlation between the variables. The results revealed a weak correlation between these variables, indicating that each methodology may be assessing different aspects of the road condition or due to the particular conditions of the road. The lack of a strong relationship may be related to the specific characteristics of the studied road, such as its sinuosity and the influence of environmental conditions on roughness measurements. This study underscores the importance of considering a variety of factors when evaluating the condition of unpaved roads and the need to develop and apply suitable evaluation techniques for the specific conditions of each road.

Keywords: International Roughness Index (IRI), Unsurfaced Road Condition Index (URCI), MERLIN, Evaluation of unpaved road pavement.

1 INTRODUCTION

The development of rural regions and their effective integration with urban centers largely depend on the quality and condition of communication routes. In this regard, unpaved roads constitute key infrastructure, especially in developing countries, where they represent approximately 80% of the road network (Ngezahayo et al. 2019). However, these roads often receive less attention and funding for their maintenance and improvement, mainly due to their low traffic volume (Hossain and Tutumluer 2019).

The importance of these roads in socioeconomic progress is indisputable (Saed et al. 2020) despite the considerable challenges they face. The condition of these roads can be severely affected by a series of factors, including adverse weather conditions, heavy vehicle traffic, and deficiencies in road design (Mbabazi 2019, Silva et al. 2021).

In response to this issue, this study addresses the evaluation of the unpaved road Sauces Norte - Imbana in the province of Loja. The International Roughness Index (IRI) and the Unsurfaced Road Condition Index (URCI) will be used as key indicators. However, despite the utility of these indices, they present limitations in terms of their applicability in different contexts and environmental conditions, an aspect that will be analyzed in this article.
The novelty of this work lies in the combined application of these indices and the specific analysis of their validity in the context of the unpaved roads of the study region. The article is structured as follows: the adopted methodology is described, the obtained results are presented and discussed, and finally, relevant conclusions are drawn for the management and maintenance of unpaved roads under similar conditions.

2 METHODOLOGY

This study was carried out on the Sauces Norte – Imbana road with a length of 9.6 kilometers, located in the province of Loja. The road is an unpaved rural road. Two indicators were measured on this road with the aim of quantitatively understanding the condition of the road. On one hand, the URCI (Unsurfaced Road Condition Index) indicator was measured, on the other hand, the International Roughness Index (IRI) was measured.

- **URCI**: Indicates the quality of an unpaved road, ranging on a scale from 0 to 100, with 0 representing a failed road and 100 representing a road in excellent condition. URCI is determined from a visual survey following the methodology of the TM 5-626 manual for Unsurfaced Road Maintenance Management.

- **IRI**: The International Roughness Index (IRI) is a standardized measurement used to quantify the surface roughness of roads and pathways, expressed in meters per kilometer (m/km) or millimeters per meter (mm/m). It represents the accumulated vertical deviation over a span of 1 km and is a key indicator to assess driving comfort and determine maintenance needs for road infrastructure. This index is measured using three methods: the Roughometer III (IRI-Roughometer) (IR.1), the IR-02 - MERLIN machine (IRI-MERLIN) (IR.2), and a mobile phone application named "IRI Regularidad Carreteras APP", hereafter referred to as IRI-App (IR.3).

The aforementioned indicators were chosen due to their common use in the local field of civil engineering and their accessibility. All measurements were attempted to be made within the same time window and under the same weather conditions to ensure data consistency. After data collection, the analysis was performed to determine the correlations between the URCI and the IRI. Additionally, the three methods of measuring IRI were compared with the aim of evaluating their effectiveness on an unpaved road.

3 RESULTS

Data from different indicators were collected on the Sauces Norte-Imbana Road, in the province of Loja, along a 9.6-kilometer stretch, using specific intervals for each indicator and measurement method. To facilitate data comparison, certain adaptations were made, detailed as follows:

- **Calculation of Average IRI Value**: The International Roughness Index (IRI) was obtained for each side of the road (left and right), and an average IRI value was calculated considering both sides. This average measure provides a more complete representation of the road roughness.

- **Interpolation of URCI (Unsurfaced Road Condition Index) Data**: The areas for analyzing the URCI were at 250-meter intervals, differing from the standard which is every 800 meters with the aim of having greater strength in correlations. In addition, the data were adapted using the interpolation technique to obtain values corresponding to 200-meter intervals, with the aim of having all indicators at the same distance.

- **Average of IRI-Roughometer (IR.01) and IRI-App Values (IR.03)**: The IRI values obtained through the Roughometer III and the "IRI Regularidad Carreteras APP"
application, which provide measurements every 100 meters, were averaged to obtain values corresponding to 200-meter intervals.

- Interpolation of IRI-Merlin Data (IR.02): The IRI data obtained through the Merlin machine were at 400-meter intervals. The data were adapted to obtain values every 200 meters.

The resulting adapted data are presented in Figure 1 for ease of interpretation. Figure 1 shows the obtained and adapted values for each indicator and measurement method along the 9.6 km stretch every 200 meters.

These results provide a basis for the detailed discussion and interpretation of the findings, which will be developed in the next section of the document.

Figure 1. IRI values measured on the Sauces Norte - Imbana road - 9.6 km.

Variability was observed in the "IRI-Roughometer" (IR.01) data, prompting the data to be smoothed using a moving average method with a 5-point window. This technique averages the values of five consecutive points to minimize variability and emphasize overarching trends. As a result, a smoothed data series was produced, offering clearer trend visualization. The smoothed data are labeled "IRI-Roughometer (smoothing)" and can be seen in Figure 1.

4 DISCUSSION

In this section, inferential statistics are used to analyze and correlate the results exposed every 200 meters, obtained by the four methods of road condition evaluation.

Table 1 shows the correlation between the IRI-Roughometer (IR.01), IRI-Roughometer (smoothing), IRI-MERLIN (IR.02), IRI-App (IR.03), and URCI variables. Correlation values vary between -1 and 1. A value close to 1 indicates a strong positive correlation, a value close to -1 indicates a strong negative correlation, and a value close to 0 indicates a weak or non-existent correlation. In this case, it appears that there is no strong correlation between the variables. The strongest correlation (although it is still quite weak) is between IRI-MERLIN (IR.02) and IRI-App (IR.03), and it is a negative correlation (-0.272104). This means that as IRI-MERLIN (IR.02) values increase, IRI-App (IR.03) values tend to decrease. Later on, the assumptions for these low correlations are discussed.
Table 1. Correlation analysis results.

<table>
<thead>
<tr>
<th>Variable</th>
<th>IRI-MERLIN</th>
<th>IRI-Roughometer</th>
<th>IRI-App</th>
<th>IRI-Roughometer (smoothing)</th>
<th>URCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. IRI-MERLIN</td>
<td>Pearson's r</td>
<td>—</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>—</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>2. IRI-Roughometer</td>
<td>Pearson's r</td>
<td>0.05</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.74</td>
<td>—</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>3. IRI-App</td>
<td>Pearson's r</td>
<td>-0.27</td>
<td>-2.37×10⁻³</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.06</td>
<td>0.99</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>4. IRI-Roughometer (smoothing)</td>
<td>Pearson's r</td>
<td>0.24</td>
<td>0.59</td>
<td>*** 0.19</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.11</td>
<td>2.74×10⁻⁵</td>
<td>0.22</td>
<td>—</td>
</tr>
<tr>
<td>5. URCI</td>
<td>Pearson's r</td>
<td>-0.22</td>
<td>0.06</td>
<td>0.08</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.13</td>
<td>0.70</td>
<td>0.59</td>
<td>0.23</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01, *** p < .001

The analysis was then continued, and a normality test was applied to all variables, the results of which are presented in Table 2.

Table 2. Normality analysis results.

<table>
<thead>
<tr>
<th></th>
<th>IRI-MERLIN</th>
<th>IRI-Roughometer</th>
<th>IRI-App</th>
<th>URCI</th>
<th>IRI-Roughometer (smoothing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-value of Shapiro-Wilk</td>
<td>0.694</td>
<td>4.724×10⁻⁴</td>
<td>0.901</td>
<td>0.215</td>
<td>0.051</td>
</tr>
</tbody>
</table>

The Shapiro-Wilk test is used to determine if a data sample fits a normal distribution. The null hypothesis of the test is that the data is normally distributed. In this case, only the IRI-Roughometer variable has a p-value less than 0.05, indicating that its data is not normally distributed, thus this variable is not considered for this correlation analysis. The other variables (IRI-MERLIN (IR.02), IRI-App (IR.03), IRI-Roughometer (smoothing) and URCI) have p-values greater than 0.05, indicating that we cannot reject the null hypothesis that their data is normally distributed. This is in line with the findings of Yang et al. (2022), where he explains that the IRI-App (IR.03) values are normally distributed, regardless of the type of phone used and the type of road evaluated.

A regression analysis was then performed with the aim of identifying some relationship. In this case, the URCI was considered as the dependent variable and the values of IRI-MERLIN (IR.02), IRI-Roughometer (smoothing), and IRI-App (IR.03) were considered as independent variables. Several regression analyses were carried out to model the dependency and make predictions, resulting in the following values as indicated in Table 3.

Table 3. Results of the regression analysis of different models.

<table>
<thead>
<tr>
<th>Model Comparisons</th>
<th>URCI vs IRI-MERLIN (IR.02)</th>
<th>URCI vs IR-App (IR.03)</th>
<th>URCI vs IR-App (IR.03)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>R-Square</td>
<td>Model</td>
<td>R-Square</td>
</tr>
<tr>
<td>URCI = 1/(0.012262 + 0.0000375402*IRI-MERLIN/2)</td>
<td>5.58%</td>
<td>URCI = 1/(0.0150326 - 0.0000354811*IRI-App/2)</td>
<td>1.73%</td>
</tr>
<tr>
<td>Inverse of Y</td>
<td>5.40%</td>
<td>Log-Y Square-X</td>
<td>1.64%</td>
</tr>
<tr>
<td>Log-Y Square-X</td>
<td>5.35%</td>
<td>Square Root-X Square-X</td>
<td>1.58%</td>
</tr>
</tbody>
</table>
Upon analyzing the correlation models, we observed that there is no relationship whatsoever between the variables. If each of these variables serves to evaluate the pavement, there should presumably be a relationship between them. However, in our research, no connection was found between the variables. The null correlations found in our research contradict the investigation by Namur and Solminihac (2009), where the authors found a moderate correlation between indexes: Chilean DNV and IRI. They estimated that for gravel roads, there is a correlation of an R^2 of 69%, and on earth roads, a correlation of R^2 equal to 58%. Furthermore, in the same investigation, the authors refer to the error of repeatability and reproducibility in the measurements that can affect the typical error of correlation equations. The authors explain that they have a 30% error due to repeatability and reproducibility, which would be equivalent to a 0.6 m/km of IRI. In our research, we did not pass the Roughometer III (IR.01) multiple times, this is an important finding, therefore, for future research, the IRI measurement equipment should be passed several times with the aim of obtaining a robust IRI measurement and being able to correlate it with other variables on unpaved roads.

Analyzing the results found in our research, where there is no correlation between the variables IRI-MERLIN (IR.02), IRI-Roughometer (smoothing), IRI-App (IR.03), and URCI, we can infer that this may be due to the sinuosity of the road (both the road's horizontal and vertical curves), as the study section Sauces Norte - Imbana has small turning radii. Therefore, the operating speed is affected, as is the engine power. The aforementioned coincides with what was written by Namur and Solminihac (2009), who specifies that when this type of road configuration is present, IRI correlations are not valid. On the other hand, Sayers et al. (1986) indicates that for an unpaved road, the roughness is sensitive to so many environmental conditions that the IRI changes in a much shorter time. If there is rain, significant changes in humidity or temperature, or traffic on the site, the roughness can change in a matter of weeks, days, or even hours. Therefore, calibrations involving unpaved roads must be planned so that the devices that measure IRI take measurements at the same time. Sayers et al. (1986) also mentions that when calibration sites are exposed to maintenance, the IRI values are affected, and previous measurements are lost. This renders them invalid for future calibrations.

5 CONCLUSIONS

This study was conducted with the aim of evaluating the effectiveness and correlation between the indicators of road condition: URCI and IRI, using three different methods to measure the latter: IRI-Roughometer (IR.01), IRI-MERLIN (IR.02), and IRI-App (IR.03). The study was carried out on the Sauces Norte – Imbana road in the province of Loja. However, the results indicate a weak correlation between these indicators, suggesting that each of them might be evaluating different aspects of the road condition.

Through statistical analysis, it was determined that the IRI-Roughometer (IR.01) data does not distribute normally and was therefore excluded from the correlation analysis. The IRI-MERLIN (IR.02), IRI-App (IR.02), IRI-Roughometer (smoothing), and URCI data, on the other hand, distributed normally. Nonetheless, no significant relationship between these variables was found.

These results could be attributed to the specific characteristics of the studied road, as factors such as the sinuosity of the road and the influence of environmental conditions can affect roughness measurements and their relationship with the overall state of the road.

Despite not having found a strong correlation between the indices, this study highlights the importance of considering various factors when evaluating road conditions, particularly unpaved roads.
roads. Additionally, it underscores the need to develop and apply measurement and evaluation techniques that are suitable for the specific conditions of each road.

Therefore, it is recommended to carry out future research on a wider variety of roads and conditions, in order to gain a better understanding of how these indicators can be effectively applied. In addition, alternatives should be sought to improve the precision of roughness measurement and more accurately assess the quality of unpaved roads.

Finally, this study provides valuable insight into the application and effectiveness of these indicators and measurement methods on the roads of the province of Loja, and provides a solid foundation for future research in this field.

References


