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Reviewer paper

# Empowering the Community: Development and Validation of a Participatory Tool for Road Safety Assessment on Colombian Tertiary Roads

# Empoderamiento de la comunidad: desarrollo y validación de una herramienta participativa para la evaluación de la seguridad vial en las carreteras terciarias colombianas

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## Abstract

**Context:** Crash rates on Colombia's tertiary road network exceed the national averages, largely due to the lack of instruments for systematic data collection and the limited involvement of local communities in risk identification. This study aimed to design a road safety diagnostic tool that can be applied by the community, tailored to rural contexts and validated with local stakeholders in the department of Cauca, Colombia.

**Method:** A literature review was conducted to identify the key risk factors affecting road safety on Colombia's tertiary roads. The KABCO scale was incorporated due to its simplicity and suitability for collaborative work. Based on these inputs, a diagnostic tool and a user guide were developed. Finally, a pilot study was implemented through participatory workshops, during which georeferenced points and risk assessments were collected.

**Results:** The pilot's application of the tool enabled the identification and georeferencing of seven critical points along a road segment in the municipality of Popayán. In these locations, speed was identified as one of the most influential factors in the road crashes reported by the community. The tool demonstrated clarity and feasibility of use by participants without prior technical training.

**Conclusions:** The developed tool provides a replicable method that allows rural communities to identify and manage road safety risks, generating valuable data for the formulation of maintenance plans and prevention policies. Its implementation can optimize resource allocation and strengthen collaboration between communities and the responsible authorities.

**Keywords:** Local rural roads, Rural roads, Safety

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**Resumen**

**Contexto**: Las tasas de siniestralidad en la red vial terciaria de Colombia superan los promedios nacionales, en gran parte debido a la falta de instrumentos para la recolección sistemática de datos y a la limitada participación de las comunidades locales en la identificación de riesgos. Este estudio tuvo como objetivo diseñar una herramienta de diagnóstico de seguridad vial que pueda ser aplicada por la comunidad, adaptada a contextos rurales y validada con actores locales en el departamento del Cauca, Colombia.

**Método**: Se realizó una revisión de literatura para identificar los principales factores de riesgo que afectan la seguridad vial en las vías terciarias de Colombia. Se incorporó la escala KABCO por su simplicidad y su idoneidad para el trabajo colaborativo. A partir de estos insumos, se desarrolló una herramienta de diagnóstico y una guía de usuario. Finalmente, se implementó un estudio piloto mediante talleres participativos, durante los cuales se recolectaron puntos georreferenciados y evaluaciones de riesgo.

**Resultados**: La aplicación piloto de la herramienta permitió identificar y georreferenciar siete puntos críticos a lo largo de un tramo vial en el municipio de Popayán. En estos lugares, la velocidad fue identificada como uno de los factores más influyentes en los siniestros viales reportados por la comunidad. La herramienta demostró claridad y viabilidad de uso por parte de participantes sin formación técnica previa.

**Conclusiones**: La herramienta desarrollada ofrece un método replicable que permite a las comunidades rurales identificar y gestionar los riesgos de seguridad vial, generando datos valiosos para la formulación de planes de mantenimiento y políticas de prevención. Su implementación puede optimizar la asignación de recursos y fortalecer la colaboración entre las comunidades y las autoridades responsables.

**Palabras clave**: Vías rurales locales, Vías rurales, Seguridad

## Introduction

Road crashes on rural tertiary roads in Colombia far exceed the national levels, mainly due to the absence of standardized instruments for data collection and the limited involvement of communities in risk identification. Annually, approximately 1.19 million people die in road crashes worldwide [1], and Colombia leads Latin America in mortality rates, with a 26% increase in the number of fatalities between 2021 and 2023, particularly on rural roads [2], [3], [4].

Tertiary roads account for 70% of the national road network and ensure rural connectivity. However, they have experienced significant deterioration due to the lack of maintenance and climatic and geographical challenges [5], [6], [7]. This deterioration restricts access to essential services such as education, healthcare, and food, and it further widens the urban-rural gap, contributing to higher poverty rates in these communities [8], [9].

One major challenge is the lack of crash records on the tertiary road network by the competent authorities, which prevents proper diagnostics. The National Road Safety Observatory (ONSV) does not provide a complete municipal breakdown for tertiary roads. Moreover, in the case of the Department of Cauca, only five of the 42 existing municipalities have reported official data on tertiary infrastructure, leaving 88% of the territory without information. The absence of this data generates bias in intervention efforts, as investments are allocated to areas that do report information, while vulnerable areas are neglected.

In this context, our study proposes the development of a community-based road safety diagnostic tool for rural tertiary roads. Designed to actively engage local communities in the Department of Cauca, the tool integrates technical criteria (the KABCO scale) with participatory protocols for the collection of georeferenced data. Thus, this study seeks to close the information gap and strengthen collaboration between users and institutions, improving the accuracy of the diagnosis and enhancing the effectiveness of interventions both in Colombia and other rural contexts across Latin America.

**Methodology**

This study employed a sequential mixed-methods design, which was carried out through four interconnected phases to develop and validate a community-based road safety assessment tool for tertiary roads (Fig. 1).

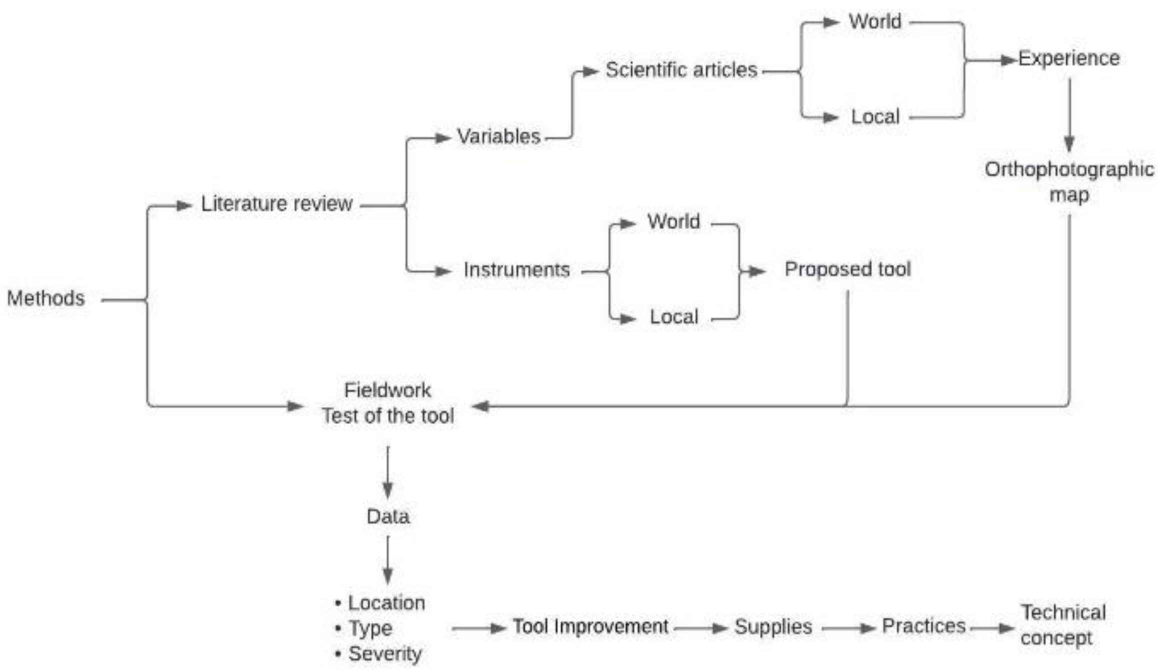


**Figure 1.** Methodology

**Phase 1: systematic literature review**

The literature review was conducted in two complementary stages, following the principles of the PRISMA guidelines (preferred reporting items for systematic reviews and meta-analyses).

*Stage 1: identification of factors through a systematic review*

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An initial systematic search was carried out to identify risk factors affecting road safety on rural roads. The search was conducted in the Scopus, Web of Science, SciELO, and Google Scholar databases, using search strings that combined keywords such as “road traffic crashes,” “rural roads,” “road safety,” “crash rate,” and “human factors,” together with Boolean operators to refine the results. The search period was limited to publications between 2019 and 2025, in order to ensure up-to-date and relevant information.

The inclusion criteria covered studies focused on road safety on rural tertiary roads. We excluded studies addressing only urban roads or highways, as well as documents without full access or with information not applicable to the Latin American context.

From the selected literature, information on factors affecting road safety was systematically extracted and classified into five main categories based on the Highway Safety Manual [10] and expanded to the Colombian rural context. The factors were originally grouped into human, roadway, and vehicle factors according to the HSM (2009), with the addition of the environmental factor—which varies by road section and may influence road safety—and the institutional factor—state actions that, in theory, should be implemented to ensure an adequate level of road safety but are often absent.

To assess and prioritize these factors during the community-based application of the tool, the KABCO scale was integrated. This scale is a standardized classification system that categorizes the severity of risks according to their observed potential for harm in a crash and includes the following levels:

- K: killed (fatality)
- A: incapacitating injury
- B: non-incapacitating injury
- C: possible injury
- O: no injury

This scale was selected due to its conceptual simplicity and its compatibility with the empirical knowledge of rural communities, allowing users without specialized technical training to assess and classify the risks identified in their territories. Furthermore, it was validated through pilot testing.

*Stage 2: factor-specific literature review*

Once the risk factors had been identified in Stage 1, a targeted literature search was conducted to document the specific scientific evidence supporting the influence of each factor on rural road safety. This stage aimed to consolidate a robust evidence base for each individual factor.

For each factor identified, targeted searches were carried out, using the factor name as the main term, combined with road safety-related keywords and rural context terms.

The bibliographic information for each factor was managed in a structured matrix, linking each factor to its specific references. This approach made it possible to trace the available evidence for each identified factor and to assess the robustness of the existing knowledge base.

Note that a PRISMA diagram is not presented for Stage 2, as it consisted of multiple targeted searches rather than a single systematic review. The PRISMA diagram in Fig. 2 exclusively documents Stage 1.

The factors identified in Stage 1 and validated with specific evidence in Stage 2 were subsequently submitted to evaluation by the expert panel (described in Phase 2) to determine their relevance and specific applicability to the context of tertiary roads in the Department of Cauca.

*Phase 2: validation by an expert panel*

A panel of four road safety experts was established to validate and refine the identification of critical factors according to the original article. The experts included in the study each have more than 15 years of experience in projects related to the subject matter and teach road safety courses in postgraduate programs at Colombian universities. This ensures the reliability of the opinions provided, as well as their relevance and equal weighting.

The assessment was conducted through structured and independent interviews. Each participant was first contextualized regarding the findings from the literature in relation to the specific conditions of the region. Based on this information, by assigning scores, each expert evaluated the relevance and applicability of the identified variables in the context of tertiary roads.

Using the collected information, a final consensus was reached through validations based on convergent expert knowledge. This ensured the identification of critical factors via the integration of individual perspectives and their collective and systematic validation.

*Phase 3: tool development*

Based on the factors validated by the experts, a tool was designed as a practical instrument to assess road safety on tertiary roads through the identification of risk factors, the recording of structured data, and the prioritization of interventions. Its application is participatory, incorporating local community knowledge of road incidents in contexts where official data are unavailable.

The tool was designed while considering the sociodemographic characteristics of rural communities and their educational standards [9], employing an approach that offers an informed understanding of the problem and facilitates the selection of the most influential factors for road safety on tertiary roads in Cauca.

The tool differs from traditional methodologies in its adaptability to the sociodemographic context surrounding tertiary roads in Cauca, its participatory approach, and the use of accessible technological resources such as georeferencing and orthophotography via smartphones. The application was developed in three interconnected stages: (i) the identification of the study section through detailed inspection, in order to recognize existing risk factors; (ii) the recording of information in a standard format that allowed for the systematic structuring of findings and the georeferencing of critical points; and (iii) the prioritization of risks, classifying them according to the KABCO scale based on their impact on road safety.

*Phase 4: pilot testing and community validation*

For the pilot implementation, we selected a 1 km segment of the road between La Tetilla and Puente Zaté in the municipality of Popayán, Department of Cauca. The reasons for our choice included compliance with geometric design standards and the verification of road safety, traffic conditions, and environmental considerations. The characteristics of the segment include an average width of 4.5 m, an average longitudinal slope of 5%, the absence of basic drainage infrastructure and sewer networks, and alternative routes that allow for traffic continuity without full closures.

From a geological and geomorphological perspective, the section is located on the Cauca-Patía inter-Andean plateau, characterized by volcanic deposits and erosion processes differentiated by their temporality. The area exhibits tectonic activity, with geological faults that influence ground stability, generating mass movements and erosion. The predominant soils are of alluvial origin and highly susceptible to erosion, affecting maintenance activities and road safety.

Community participation was sought by assessing 21% of the households adjacent to the road and within a 2 km radius of the segment. These households were selected through convenience sampling in order to evaluate the effectiveness and applicability of the initial tool. The participants received a two-hour training session on basic road safety concepts and the evaluation methodology prior to the process. In addition, three complementary site visits were scheduled over a six-week period to collect and verify relevant information.

These activities included a systematic environmental analysis using standardized technical forms to document geographical and climatic characteristics; structured road inspections using checklists to identify deficiencies related to geometric design, visibility, and surface conditions; and community input collected through three-hour participatory workshops employing social cartography techniques and semi-structured interviews to understand perceived problems and critical points. Data was recorded in digital formats and validated through triangulation between technical observations and community perceptions.

The tools employed included drones to capture high-resolution orthophotographs, which were processed with Agisoft Metashape; georeferencing of critical points using Google Earth; and heat maps to represent the spatial distribution of road safety issues.

After applying the tool and analyzing the collected data, adjustments were made to improve the accuracy and relevance of the information gathered. The pilot test and subsequent refinements enhanced the tool's structure, sequence, and clarity, allowing users to collect reliable data to support the technical understanding of the specific risks associated with the analyzed roadway.

## Results

### Systematic review and characterization of influential factors

*Stage 1: identification of factors through a systematic review*

The information search was conducted using a structured strategy that included recognized scientific databases and complementary sources, in order to ensure a broad and relevant

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coverage of the study topic. First, the Scopus, Web of Science, and SciELO databases were consulted due to their relevance in indexing high-quality scientific literature and their coverage of studies related to road safety, infrastructure, and risk factor analysis. As a result of this search, 76 database records were identified: 47 documents from Scopus, 16 from Web of Science, and 13 from SciELO.

Additional information sources were included to complement the scientific evidence, including manual searches in specialized journals and gray literature, which comprised theses, technical reports, and relevant institutional documents. Together, these strategies made it possible to identify a total of 83 documents that were potentially relevant to this study.

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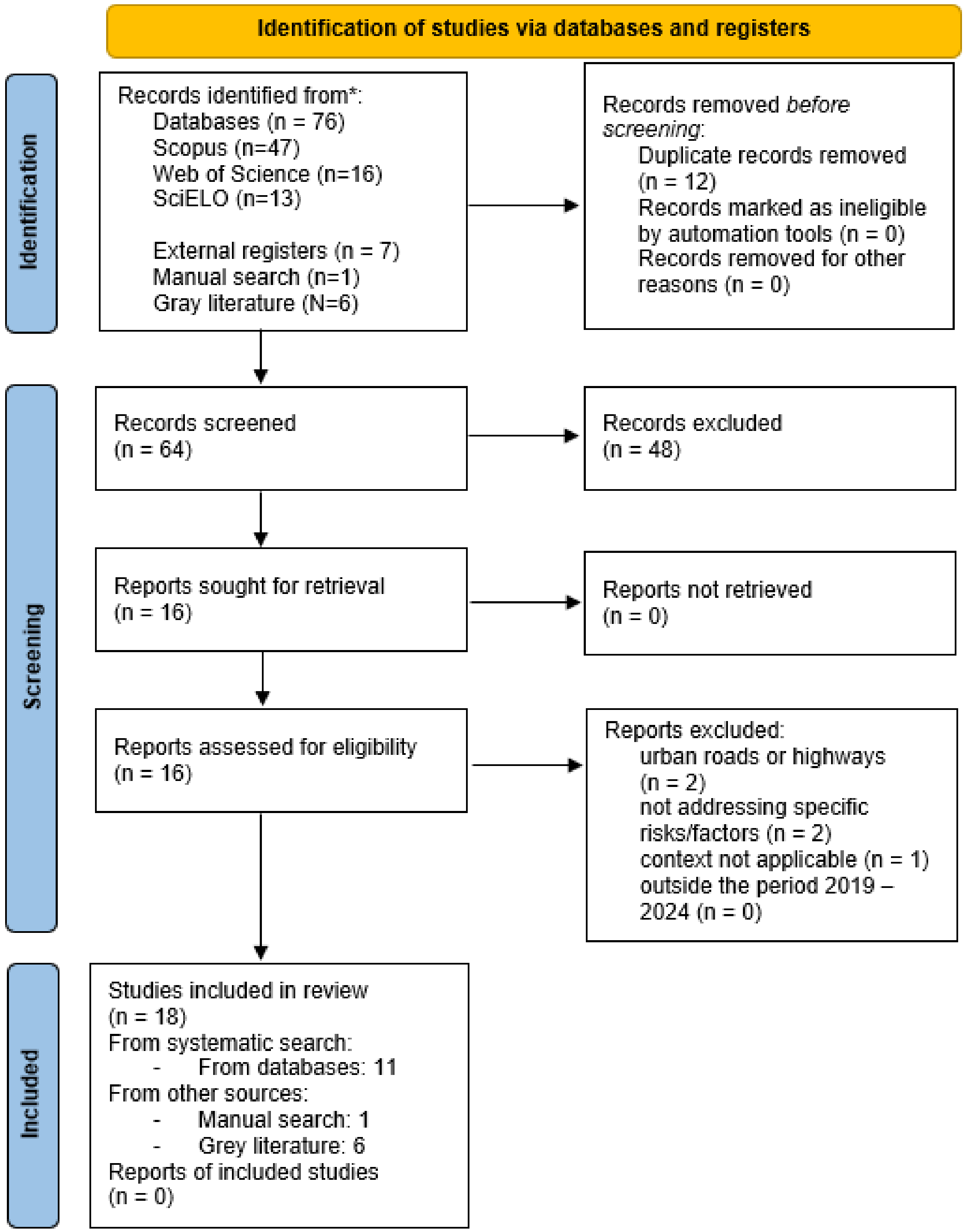


**Figure 2.** PRISMA flow diagram

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The systematic literature review made it possible to identify a total of 47 risk factors associated with road crashes on rural roads, prioritizing information from studies conducted in rural areas and low-traffic local roads. The distribution of these factors by category is presented in Fig. 3, showing a significant concentration in human and roadway factors, which, together, account for 85% of the identified factors.

The five main risk factor categories, based on international literature and adapted to the Colombian context, were distributed as follows:

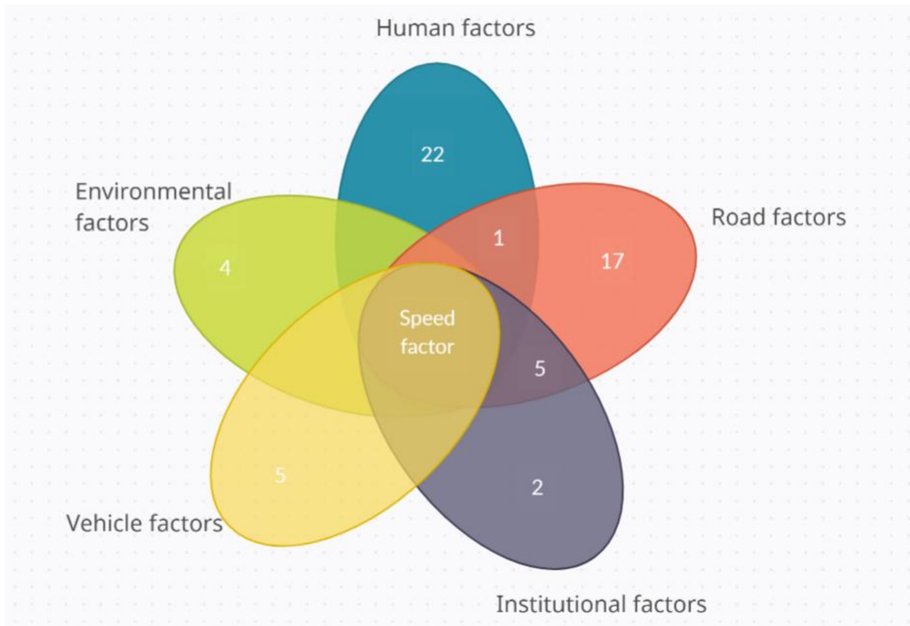


**Figure 3.** Interaction of concurrent factors in road crashes

**Human factors (23 factors, 49%).** This category comprises the largest number of identified variables, including driver behaviors that generate unsafe conditions such as speeding, alcohol and psychoactive substance consumption, non-compliance with safety protocols, distracted driving, inadequate reaction time, physical and mental conditions, experience, andage, among others.

**Road factors (23 factors, 49%).** These are related to deficiencies in road infrastructure safety, including the absence of signage, deterioration of the running surface, inadequate road geometry, pavement conditions, curve density, sight distance, geometric alignment, vertical grade, lighting, intersections, the International Roughness Index (IRI), access points, and cross-section characteristics.

**Institutional factors (five factors, 11%).** These include the lack of traffic regulation and enforcement, the absence of preventive maintenance plans, non-compliance with regulations, deficiencies in safety barriers, and the inadequate management of surface friction.

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**Vehicle factors (five factors, 11%).** These are related to the mechanical conditions and proper functioning of vehicles, including the use of poorly maintained vehicles, brake failures, worn tires, maintenance deficiencies, and inadequate technical-mechanical conditions.

**Environmental factors (four factors, 9%).** These consider the influence of climate on terrain conditions and their direct relationship with road crashes, including erosion or slippery surfaces due to rainfall, surrounding terrain types, land use, and adverse weather conditions.

*Stage 2: factor-specific literature review*

For each of the factors identified in Stage 1, a targeted literature search was conducted with the aim of consolidating the evidence base to support their influence on road safety on rural roads.

The factor-specific review resulted in the identification of more than 40 additional bibliographic references, each providing evidence on the relationship between specific factors and road safety in rural contexts. The complete account of factors with and their corresponding references is presented in Table I.

The targeted search revealed different levels of bibliographic availability depending on the factor category.

- **Human factors.** Multiple references were identified for each factor. Factors such as speed, alcohol consumption, and distraction are supported by extensive international documentation.
- **Roadway factors.** The documentation was consistent for factors related to road geometry and surface conditions, with more limited availability for factors specific to tertiary or rural roads.
- **Vehicle factors.** The identified literature focused mainly on general mechanical conditions rather than on specific characteristics of vehicles used in rural contexts.
- **Environmental factors.** A smaller body of literature specific to rural contexts was identified, highlighting this category as an area requiring further research.
- **Institutional factors.** The available documentation was comparatively limited, particularly for developing countries, reflecting the emerging nature of this approach in rural road safety.

**Table I**

**List of identified risk factors with supporting bibliographic evidence**

| List of factors | Category | Author |
|---|---|---|
| Evasive actions | Human factor | [11] |
| Acceleration/deceleration | Human factor | [12] |
| Attention | Human factor | [13], [12] |
| Information processing capacity | Human factor | [10] |
| Driver’s ability to adapt to the geometry of the track/trajectory used | Human factor | [14] |
| Unsafe behaviors | Human factor | [15] |

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| **List of factors** | **Category** | **Author** |
|---|---|---|
| Precondition for unsafe behavior | Human factor | [15] |
| Physical conditions of the driver | Human factor | [11] |
| Mental conditions | Human factor | [11] |
| Use of psychoactive substances | Human factor | [16], [17] |
| Distractions | Human factor | [18] |
| Age | Human factor | [10], [19], [20] |
| Experience | Human factor | [10], [18] |
| Driver skill | Human factor | [11], [13] |
| Driving time | Human factor | [21] |
| Inappropriate lateral position | Human factor | [13] |
| Drowsiness | Human factor | [22] |
| Insecure monitoring | Human factor | [23] |
| Perception-response time | Human factor | [24] |
| Type of driver | Human factor | [25] |
| Violation of regulations | Human factor | [26] |
| Vision | Human factor | [11] |
| Vehicle conditions | Vehicle factor | [11] |
| Vehicle design and manufacture | Vehicle factor | [10], [27], [28] |
| Maintenance | Vehicle factor | [10], [29] |
| Vehicle ratio | Vehicle factor | [21], [30] |
| Vehicle type | Vehicle factor | [15], [31], [32] |
| Geometric alignment | Roadway factor | [33] |
| Paved and unpaved berm width | Roadway factor | [34] |
| Berm soundtracks | Roadway factor | [35] |
| Overtaking lane | Roadway factor | [36], [37], [38] |
| Track category | Roadway factor | [39], [40] |
| Running surface condition | Roadway factor | [41] |
| Curve density | Roadway factor | [13], [42], [14], [43], [44] |
| Visibility distance | Roadway factor | [45] |
| Track geometry horizontal curves | Roadway factor | [42], [14], [13] |
| Vertical gradient | Roadway factor | [46] |
| Lighting | Roadway factor | [45] |
| Intersections | Roadway factor | [43], [47], [26] |
| International roughness index (IRI) | Roadway factor | [48] |
| Segment length | Roadway factor | [49] |
| Access points | Roadway factor | [49] |
| Cross section | Roadway factor | [50] |
| Controlled and split access main road | Roadway factor | [10] |
| Climate | Environmental factor | [21] |
| Type of terrain – environment | Environmental factor | [47] |

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| List of factors | Category | Author |
|---|---|---|
| Average daily traffic | Environmental factor | [51], [52], [30] |
| Land use | Environmental factor | [49], [51] |
| Traffic control devices | Institutional factor | [53] |
| Technical-mechanical review | Institutional factor | [47] |
| Visibility | Road/human factor | [54] |
| Surface friction | Road/institutional factor | [48] |
| Number of accesses | Road/institutional factor | [10] |
| Presence of safety barriers | Road/institutional factor | [34] |
| Presence of separator | Road/institutional factor | [47] |
| Signage | Road/institutional factor | [49], [43] |
| Speed | Human factor, vehicle, road, environmental, institutional factor | [21], [50], [35], [44], [13], [12], [54], [24], [51] |

### Validation by expert panel

The road safety expert panel led to the consolidation of 43 critical variables from the 47 initially identified factors, reflecting the complexity of the topic and the need for specific approaches to assess safety on rural roads. The reduction in factors was based on criteria of specific relevance to Colombian tertiary roads, the feasibility of assessment by rural communities, and the applicability in contexts with limited official data reporting.

The factors validated as most influential by the expert panel are presented in Table II, organized by category and prioritized according to their potential impact on tertiary road safety. This validation process allowed refining the assessment instrument while ensuring that it included only variables that could be effectively identified and evaluated by local communities.

**Table II**

**List of factors classified by the expert panel as contributing to road safety incidents on tertiary roads**

| Factor | Category |
|---|---|
| Weather<br>Type of terrain – environment<br>Land Use | Environmental factor |
| Evasive actions<br>Attention<br>Information processing capacity | Human factor |

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| | |
|---|---|
| Ability of the driver to adapt to the geometry/trajectory of the road used | |
| Unsafe behaviors | |
| Precondition for unsafe behaviors | |
| Physical condition of the driver | |
| Mental condition | |
| Psychoactive substance/alcohol use | |
| Distractions | |
| Age | |
| Experience | |
| Drowsiness | |
| Insecure monitoring | |
| Perception-response time | |
| Driving time | |
| Violation of regulations | |
| Vision | |
| Technical-mechanical inspection<br>Vehicle conditions<br>Maintenance<br>Vehicle ratio<br>Vehicle type | Vehicle factor |
| Geometric alignment | Roadway factor |
| Pavement Surface Conditions | |
| Curve density | |
| Visibility distance | |
| Road geometry: horizontal curves | |
| Vertical gradient | |
| Lighting | |
| Intersections | |
| IRI | |
| Access points | |
| Cross section | |
| Visibility | Roadway/human factor |
| Surface friction | Roadway/institutional factor |
| Number of access points | |
| Presence of safety barriers | |
| Signage | |
| Speed | Human/vehicle/roadway/environmental/institutional factor |

### Tool development

As a result of the methodological development, a structured tool adapted to the context of rural tertiary roads in the Department of Cauca was obtained, which was aimed at the collection and analysis of road safety information with community participation. The final tool was organized as a practical guide, structured into eight chapters and three interconnected modules, which sequentially reflect the methodology, covering a range aspects from conceptual and contextual elements to operational formats for the identification, recording, and analysis of road crashes. The structure includes clearly defined sections for roadway segment recognition and the characterization of risk factors associated with the road, the vehicle, the human factor, and the environment, as well as the systematic recording of crash events through interviews conducted with the local community.

In designing the tool, specific criteria for our adaptation to the Colombian rural context were implemented, prioritizing clear language, simplified formats, and procedures accessible to individuals without technical training in road safety. These criteria were defined based on a review of national and international guidelines and the characterization of the pilot segment, considering the geometric, topographic, climatic, and operational particularities of tertiary roads, *e.g.*, non-uniform cross-sections, the absence of signage, drainage limitations, and the predominance of motorcycle traffic. As a result of this process, 43 of the risk factors that were previously validated by an expert panel were incorporated and organized into field forms designed for practical application by non-specialist users.

As part of the tool's development, a specific user manual was prepared and integrated into the guide, with the purpose of providing clear and sequential guidance for the correct application of the proposed methodology. This manual includes detailed instructions for each phase of the process, facilitating implementation by the community and ensuring consistency in data collection. In addition, standardized data recording forms were designed to systematize the information obtained during community interviews, incorporating variables related to the individuals involved, the factors associated with the crash, the characteristics of the road segment, geographic coordinates, injury severity, and relevant observations.

Furthermore, a coding system was implemented to organize and clean the collected data, including the numerical identification of participants, the verification of duplicate reported events, and the standardized classification of crash severity. In this context, the integration of the KABCO scale constituted a central component of the tool since it was incorporated as a prioritization system for classifying the severity of injuries associated with road crashes. The application was carried out through contextualized and easily understandable descriptions for rural communities, facilitating the identification of the K, A, B, C, and O categories based on the information provided during interviews and ensuring consistency in the interpretation and analysis of the recorded events.

During the pilot, the events reported by the community were initially located using printed maps and subsequently georeferenced using conventional mobile devices, allowing for the collection of precise geographic coordinates. Additionally, standardized photographic recording protocols were established, facilitating the generation of orthophotographs and heat maps, from which spatial patterns of road crashes were identified, revealing a significant concentration of events on horizontal curves along the pilot segment.

As part of the validation process, preliminary usability tests were conducted during the pilot of the guide on the selected road segment, in order to assess the comprehensibility of the formats, the clarity of the instructions, and the feasibility of the data collection process by the community. Based on this experience, adjustments were made to the wording of the questions, the organization of the forms, and the sequence of application, with the aim of improving process coherence and reducing potential ambiguities during completion.

Finally, the development of the tool incorporated specific adjustments derived from the conditions of the Colombian rural context, such as the limited availability of official traffic data, the absence of vehicle counting stations, and the need to complement technical information with local community knowledge. These adjustments made it possible to consolidate a flexible, operational, and contextualized tool aimed at supporting the identification and prioritization of road safety risks on tertiary roads, which serves as an input for technical decision-making by specialized professionals.

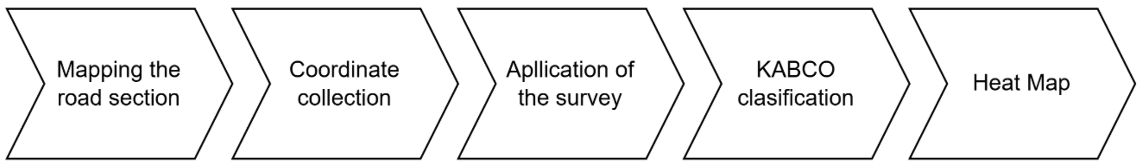


**Figure 4.** Phases of the tool's application

## Pilot application and community validation

### *Characterization of the studied section*

The pilot was implemented in an approximately 1 km-long section of the tertiary road called *La Tetilla-Puente Zaté*, enabling a practical and context-specific application of the proposed tool. This section features an average carriageway width of 4.5 m, a mean longitudinal gradient of approximately 5%, an unpaved surface composed of granular material, and the absence of basic drainage infrastructure and sewer networks—conditions representative of the rural tertiary road network in the Department of Cauca.

The pilot's application involved the participation of 15 members of the local community, aged between 25 and 45 years, with an average educational level corresponding to secondary education (high school). Prior to data collection, a structured community training process was conducted in two sessions: an initial three-hour session focused on understanding the analysis scales—particularly severity classification using the KABCO system—and a second session of approximately thirty minutes focused on the general use of the final tool and the completion of the data collection forms. The pilot was assessed over a single day, during which data were collected through face-to-face interviews, the recording of crash events reported by the community, the identification of risk factors associated with the road section, and the georeferencing of critical points. This process made it possible to validate the clarity of the formats, the participants' understanding of the instructions, and the operational feasibility of the tool in a real-world context, ensuring its coherence with the technical and social conditions of the studied section.

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**Figure 5.** Satellite image of the studied section, coordinates: 2°31′21.96″ N, 76°41′14.03″ W

## Identification and georeferencing of critical points

The application of the tool by the local community resulted in the identification and georeferencing of seven critical points distributed along the studied section. Each critical point was classified according to the KABCO scale and categorized by the predominant type of risk factor, generating a systematic database to support the prioritization of interventions.

**Table III**

**Geographic coordinates of the reported road traffic crashes**

| Reporting individual | Roadway element where the crash occurred | Latitude | Longitude |
|---|---|---|---|
| 41 | Curve | 2°31’18.32” N | 76°61’16.77” W |
| 42 | Curve | 2°31’14.71” N | 76°41’23.91” W |
| 44 | Curve | 2°31’19.76” N | 76°41’16.10” W |
| 46-1 | Curve | 2°31’16.43” N | 76°41’15.22” W |
| 46-2 | Curve | 2°31’32.09” N | 76°41’3.68” W |
| 46-4 | Curve | 2°31’46.31” N | 76°40’57.89” W |
| 5-1 | Curve | 2°31’19.73” N | 76°41’13.73” W |
| 62-1 | Curve | 2°31’18.62” N | 76°41’16.92” W |

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| Reporting individual | Roadway element where the crash occurred | Latitude | Longitude |
|---|---|---|---|
| 62-2 | Curve | 2°31’18.35” N | 76°41’15.20” W |
| 62-3 | Curve | 2°31’28.99 N | 76°41’12.32” W |
| 62-5 | Curve | 2°31’20.98” N | 76°41’11.31 W |
| 65 | Curve | 2°31’15.66” N | 76°41’23.81” W |
| 68 | Curve | 2°31’44.21” N | 76°41’2.17” W |

The spatial analysis of road traffic crashes, conducted through the generation of heat maps, showed a significant concentration of events in the curved sections of the studied segment, particularly those with smaller curvature radii, in contrast to the straight sections of the roadway. This spatial pattern suggests a direct relationship between road geometry and the increased risk of crash occurrence, with a greater impact on motorcycle users, who represent the main type of traffic along the analyzed segment.

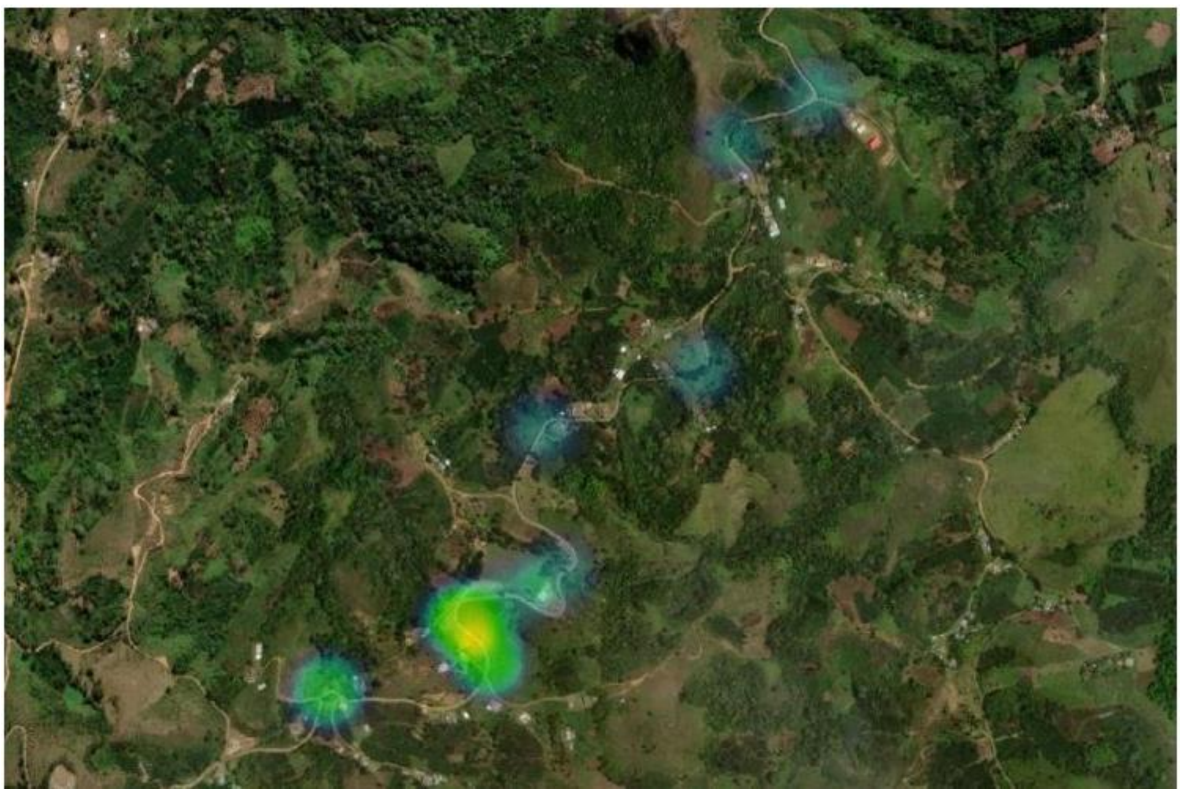

**Figure 6.** Heat map of road traffic crashes along the segment.

Additionally, the information collected during community interviews made it possible to identify that human behavior constitutes a determining factor in the occurrence of the recorded events, mainly associated with the speeds that are inadequate for the geometric and operational conditions of the roadway. The combination of unfavorable geometric design of curves and risky driving behaviors increases the likelihood of vehicle loss of control, especially in the context of limited road infrastructure.

Likewise, variations were observed in the intensity of the critical points among the different curves identified, suggesting that specific factors such as curvature radius, superelevation, visibility conditions, and roadway surface conditions influence the level of risk associated with each segment in a differentiated manner. These factors, when interacting with driver behavior, particularly travel speed—contribute to the generation of conditions conducive to road traffic crashes.

Complementarily, the analysis of injury severity, classified using the KABCO scale, showed a correspondence between areas with higher crash density and the occurrence of more severe injuries. In particular, the critical points with the highest concentration of events predominantly coincided with crashes classified in Category A (incapacitating injuries), which supports the prioritization of these segments as critical areas for the formulation and implementation of intervention measures aimed at improving road safety on rural tertiary roads.


**Figure 7.** Distribution of crash classification according to the KABCO scale

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### Analysis by factor categories

The main findings identified in each category during the pilot application were as follows:

**Human factors.** Speeding was the factor identified by community participants as the most recurrent behavior among motorcyclists, present at six out of seven critical points. Additionally, during the site visit, the presence of pedestrians traveling on the roadway was documented, which increases the risk of crashes. The inadequate use of personal protective equipment by motorcyclists and reckless driving behaviors on curves with reduced radii were also identified.

**Vehicle factors.** During the site visit, motorcycles operating with overloads and in poor mechanical condition were observed, affecting braking capacity and stability on curves. The absence of preventive vehicle maintenance in the rural area was a recurrent factor identified by the community.

**Road factors.** The absence of signage on sharp curves, the loss of granular material on the roadway, and deficiencies in drainage capacity were observed, contributing to the formation of critical areas that are prone to crashes. Inadequate roadway geometry was identified as a high-risk factor at three specific points.

**Environmental factors.** We identified areas with active erosion and accumulation of sediments on the roadway due to runoff, causing instability of the running surface. We also identified adverse weather conditions during rainy periods as factors that exacerbate other risk conditions.

**Institutional factors.** The absence of traffic enforcement personnel and the lack of road safety education campaigns within the community were confirmed, negatively impacting compliance with road safety regulations. The lack of systematic maintenance plans was identified as an underlying critical factor.

### Effectiveness evaluation of the tool: community validation of results

The evaluation of the tool's effectiveness was conducted through a validation process that involved the participating community, considering specific metrics related to its applicability and comprehension. The average time required to complete the thorough assessment of the segment was approximately two hours. This demonstrates the operational viability of the tool in rural contexts where time and resources are limited.

Regarding comprehension, community users exhibited a high level of understanding of the tool's content, instructions, and formats. This result can be attributed to the use of plain language, the sequential structuring of the methodological process, and the support of graphical and cartographic elements. Such understanding was evidenced by the accurate execution of risk identification stages, crash classification, and the georeferencing of critical points (black spots).

Furthermore, total consistency was observed among the different community evaluators, achieving 100% inter-rater reliability in the generated reports, in both the identification of critical points and their classification via the KABCO scale. This homogeneity in the results

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confirms the replicability of the instrument and its capacity to mitigate the variability associated with subjective interpretation.

Finally, the results derived from the community application showed strong alignment with the risk factors previously defined from a technical standpoint. This validated the relevance of the collected data as a reliable input for subsequent analysis by road safety professionals. This community validation process confirms the effectiveness of the developed participatory assessment tool as a mechanism for identifying and prioritizing road risks on rural tertiary roads**.**

**Main validated contributions**

*Systematization of community data.* The tool enabled the collection of information that had not been documented in official records, validating the importance of local participation in road safety assessment. 100% of the risks identified by the community were not present in previous institutional databases.

*Georeferencing of critical points.* Segments with a higher concentration of risks were identified, facilitating the prioritization of infrastructure interventions. The georeferencing precision achieved through mobile devices proved sufficient for territorial planning purposes.

*Adaptability to the rural context.* Unlike other methodologies, the tool was designed while considering specific environmental and social variables, which enabled its application in environments with scarce official data. The tool demonstrated to be comprehensible and applicable by users with diverse educational levels.

**Future work**

Based on the results obtained in this study, we identified several lines of future work aimed at strengthening, validating, and expanding the scope of the developed tool for the participatory assessment of road safety on rural tertiary roads. First, we recommend expanding the sample of test segments, incorporating roads with different geometric, topographic, and operational characteristics, as well as collecting information at different times and under varying weather conditions. This would allow for the evaluation of result stability and the establishment of replicability metrics in rural contexts with similar conditions.

Additionally, it is pertinent to conduct a comparative analysis between the proposed tool and traditional road safety diagnostic methodologies, in order to evaluate differences in terms of implementation time, the level of detail of the information obtained, and technical requirements. In this regard, the pilot experience demonstrated that the community application of the tool can be completed in an average time of two hours, representing a significant reduction compared to the times associated with conventional evaluations carried out exclusively by specialized technical teams.

As a complement, we propose the implementation of a continuous monitoring system based on periodic community feedback, allowing for the update of information on crash rates and emerging risks. The feedback obtained during the pilot's application suggests a positive perception of the tool's usability, highlighting the clarity of the formats, the ease of application, and understanding of the generated results—aspects that support its potential sustained adoption over time.

Furthermore, there is an identified need to strengthen coordination with government entities, non-governmental organizations, and institutional actors linked to road safety to guarantee larger-scale implementation, as well as the allocation of resources for its updating and maintenance. In this context, future studies could incorporate a cost-effectiveness analysis, comparing the community application of the tool with traditional technical methods, considering variables such as operating costs, specialized personnel requirements, and territorial coverage.

Finally, we recommend conducting a comparative study that follows the intervention proposed by *CDT Vial* on the test segment, enabling the evaluation of changes in crash levels and injury severity, thereby verifying the impact of the implemented improvement alternatives. Together, these lines of future work consolidate the tool as a structured, replicable, and cost-effective mechanism for monitoring and improving road safety on rural tertiary roads.

**Synthesis of results by phase**

The sequential implementation of the four methodological phases enabled the systematic construction of a tool validated both technically and by the community. Phase 1 established the theoretical foundation by identifying 47 risk factors. Phase 2 refined this set to 43 critical factors through expert validation. Phase 3 materialized these factors into a practical tool adapted to the rural context. Finally, Phase 4 demonstrated the applicability and effectiveness of the instrument through its successful community implementation in identifying seven georeferenced critical points.

## Discussion

The results of this study demonstrate that road safety on tertiary roads in the department of Cauca is influenced by multiple factors, among which infrastructure deficiencies, adverse environmental conditions, and the lack of institutional regulation stand out. The validation of risk factors with an expert panel enabled the consolidation of a total of 43 critical variables, reflecting the complexity of the problem and the need for specific approaches to evaluate safety on rural roads. Furthermore, the field application of the tool allowed detecting risks that were undocumented in official records, highlighting the fundamental role of community participation in identifying road issues.

When comparing these findings against those of previous studies on road safety in rural areas [37], we confirmed that the lack of signaling, deficient drainage, and poor road conditions are recurrent factors contributing to the occurrence of crashes. Previous research has indicated that inadequate infrastructure and the accelerated deterioration of roads create high-risk conditions, especially in regions with frequent rainfall and erodible soils [47], as is the case in Cauca. However, unlike traditional methodologies that rely exclusively on official databases, the tool developed in this study integrates empirical data collected with the community, allowing for a more detailed and contextualized characterization of local risks.

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## Conclusions

Due to the lack of institutional presence in rural areas of Colombia, the community adjacent to the selected rural road became the primary source of information for the development of a database aimed at analyzing road safety in this area. The tool presented herein represents an initial structured approach to extracting information from the community and translating it into terms easily understood by them, facilitating analysis and decision-making in the subsequent stages of road interventions by the competent authorities. Based on the review of the expert panel, the risk factors with the greatest impact on the safety of tertiary roads were synthesized. Its field application demonstrated the tool's capacity to systematically identify these risks, providing reliable data in a context where the underreporting of incidents remains a recurrent issue.

The findings confirm the need for accessible and structured tools for data collection regarding crashes on tertiary roads, as official records are limited and do not accurately reflect the reality of road safety. The implementation of road safety measures, infrastructure improvements, and road education are fundamental for reducing the incidence and severity of crashes. In this sense, the proposed tool facilitates the identification of critical points and provides clear instructions for its application, allowing for its replication in other rural environments with similar characteristics.

While this study represents an advancement in the evaluation of road safety on tertiary roads, we acknowledge the importance of comparing the effectiveness of the tool with conventional risk analysis methodologies. Future studies could focus on establishing objective performance metrics and evaluating their impact on crash reduction. Additionally, the tool can be used to monitor improvements in road infrastructure, allowing for safety assessments before and after interventions, which makes it a potential instrument for longitudinal studies on rural road safety. Our results strengthen the understanding of risk factors on tertiary roads and lay the foundation for the creation of road safety strategies adapted to these environments. The combination of a participatory approach, expert validation, and the use of georeferencing tools reinforces the potential of this methodology to contribute to the planning and management of road safety in rural communities.

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## Author contributions

*Author 1:* writing (original draft, review, and editing).

*Author 2:* writing (original draft, review, and editing).

*Author 3:* methodology, formal analysis.

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### Statement on artificial intelligence

During the elaboration of this work, the authors used Claude by Anthropic to improve the organization and clarity of the text. The authors reviewed and edited all AI-generated content and took full responsibility for the accuracy and integrity of the final manuscript.

### Conflict of interest

The authors declare that they have no conflicts of interest that could have influenced the research process.

### Data availability statement

The tool developed in this study is available for consultation and use by researchers, public policymakers, and professionals interested in improving road safety in rural areas. This resource provides structured guidelines for identifying risk factors on tertiary roads and facilitates data collection in regions with limited official records. To access the tool and related documentation, please visit the following link: https://drive.google.com/drive/folders/1MLCgQVB0BJQZKh6yYwE-_JWNOsc7V-99?usp=sharing

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