WRI COLOMBIA

WORKING PAPER

How to identify critical road safety locations: A Case Study in Bogotá

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Highlights

- Low- and middle-income cities usually have limited resources for road safety, so they need to be able to identify the most critical locations where improving road safety is most urgent and yields the greatest benefits.
- Our methodology uses a combination of geographic concentration (kernel) and spatial autocorrelation analyses (cluster) in arterial and nonarterial roads to identify locations with the highest concentrations of road crash victims in Bogotá, Colombia.
- In Bogotá, these serious crashes are clustered in middle- to low-income areas, where structural inequalities and segregation appear to be related to traffic fatalities and injuries (see Figure ES-1).
- This methodology identified locations in Bogotá where serious crashes have occurred frequently and in a systematic form. In these locations, local authorities should consider future road safety interventions.
- To adapt and use this methodology, other cities need geocoded data differentiated by road types and victims.

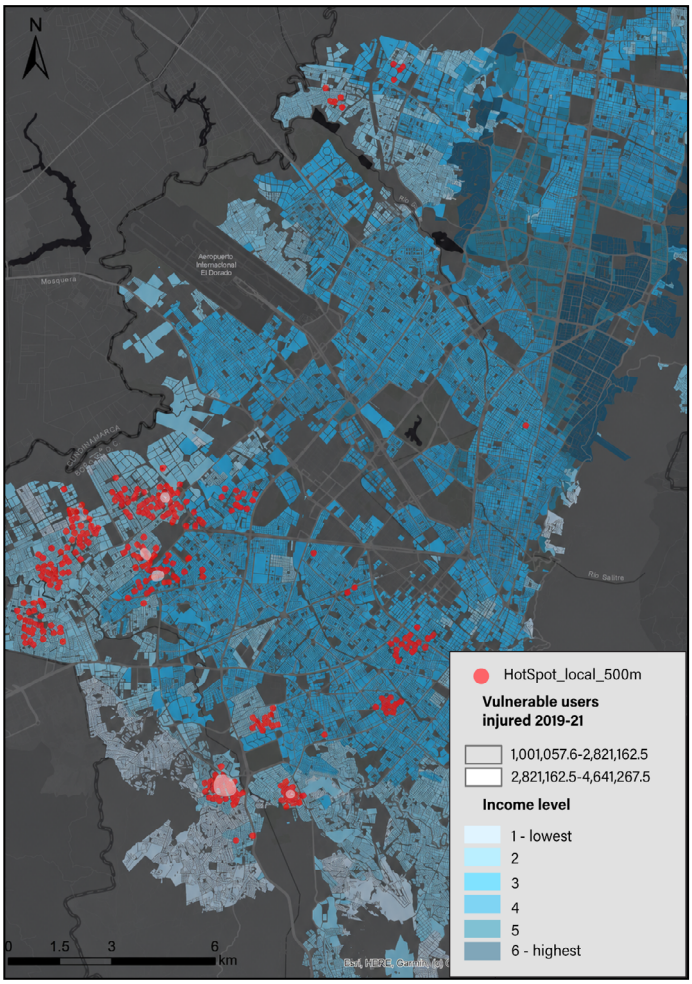
Executive summary

This paper presents a methodology developed in Bogotá to identify critical road safety locations. These are sites with high crash rates of killed and injured pedestrians, cyclists, and motorcyclists, who are referred to in the text as vulnerable road users (WHO 2023). In this document, we analyze georeferenced data on traffic deaths and injuries in Bogotá between 2019 and 2023 on arterial and nonarterial roads to identify critical locations at the city level.

There are five steps defined in the step-by-step process of designing and implementing this methodology. After gathering georeferenced data on serious injuries and fatalities (step 1), the data can be adjusted to different road network scales (step 2); and for the case of Bogotá, we divide the road network into arterial and nonarterial roads. By applying a combination of geographic concentration (kernel) and spatial autocorrelation (cluster) analyses, we can determine where critical corridors and critical spots are located (step 3) and then visualize them (step 4). These analyses can be complemented with additional information available (step 5), such as type and characteristics (such as age, gender, etc.) of road users, land use, income level, speeds, and so forth to have a more comprehensive grasp of where the critical spots and corridors are located, which built environment factors have an influence on their appearance, and whom they affect.

We developed this methodology based on best practices and international references as well as extensive discussions with experts from the Bloomberg Philanthropies Initiative for Global Road Safety and the District Mobility Secretariat of Bogotá (Secretaría Distrital de Movilidad; SDM). It is a tool that can help Bogotá pursue its goal of reducing deaths and serious injuries from road crashes to zero, as stated in the Road Safety Plan (SDM 2023b). Other cities can also use this methodological framework to reduce traffic injuries and fatalities.

Figure ES 1 | **Identification of hotspots in local roads of Bogotá and land classification by income level**



Notes: Light blue represents lower income level, and darker blue represents higher income; hotspots are identified in red.
Source: WRI authors.

Introduction

Road traffic deaths and injuries can endanger public health and economic development. Globally, two-thirds of road fatalities involve people between the ages of 18 and 59, with broad repercussions for families and communities. Pedestrians, cyclists, and motorcyclists remain dangerously exposed, and the overwhelming majority (92 percent) of global traffic fatalities occur in low- and middle-income countries (LMICs) (WHO 2023).

The empirical focus of this study is the city of Bogotá, Colombia, which has severe traffic safety issues. Bogotá is the largest and most populous city in Colombia. With more than 7 million residents in its metropolitan area, it is also the fourth largest city in South America. The city struggles with critical road safety challenges, including a high incidence of pedestrian and cyclist fatalities, which are exacerbated by common traffic violations such as speeding and aggressive or distracted driving. As a member of the Bloomberg Philanthropies Initiative for Global Road Safety (BIGRS), World Resources Institute (WRI) has supported the city's efforts to improve road safety issues since 2016.

Bogotá has averaged 495 fatalities per year over the past five years (2019–23), and 94 percent of the victims have been pedestrians, cyclists, and motorcyclists. Fatalities and injuries are linked to structural inequalities and physical and social segregation in urban planning and development. These factors force the under-served communities to travel farther, use higher-risk transport modes, and navigate areas with inadequate (or nonexistent) safe infrastructure. Motorcyclists are particularly exposed. For each trip, motorcyclists are three to four times more likely to die than pedestrians or cyclists (Bogotá Cómo Vamos 2024). Thus, understanding where these fatal crashes have occurred and which road users are more affected by location is a critical first step for tackling the burden of road fatalities worldwide and helping cities such as Bogotá achieve the Sustainable Development Goal of cutting road traffic deaths in half by 2030.

The Safe System approach (see Box 1) requires us to view the system as a whole and intervene systemically in the entire road network rather than in specific locations; however, systemic change toward safer transportation systems is complex and difficult to achieve. Moreover, countries and cities around the world face frequent challenges related to insufficient resources and/or lack of political will. This reality usually forces decision-makers to intervene first in locations that are considered most critical.

For this paper, we will refer to any location (a spot or a corridor segment) where the counts and spatial concentrations of traffic-related injuries and fatalities can be considered high, or remarkably higher than in nearby locations, as critical locations. What can be considered as high is something that depends on each city's own characteristics, such as population, traffic characteristics, road network and built environment characteristics, and the road users' interactions.

In LMICs where financial resources are limited, it is crucial to identify critical crash locations and to target measures where they offer the greatest potential benefits. Identifying critical locations and their geographical patterns helps the local agencies and authorities determine where to intervene.

A work plan based on stages or phases is necessary and helpful to start working toward systemic change. By identifying critical locations, cities can better understand where the positive impact of any interventions would be greatest. And, beyond the application of reactive or remedial actions, the lessons learned from any intervention actions in critical locations must be applied to the planning and design of safer road infrastructure that protects all road users' lives. This is how applying the Safe System approach in infrastructure planning and design has saved human lives on the roads.

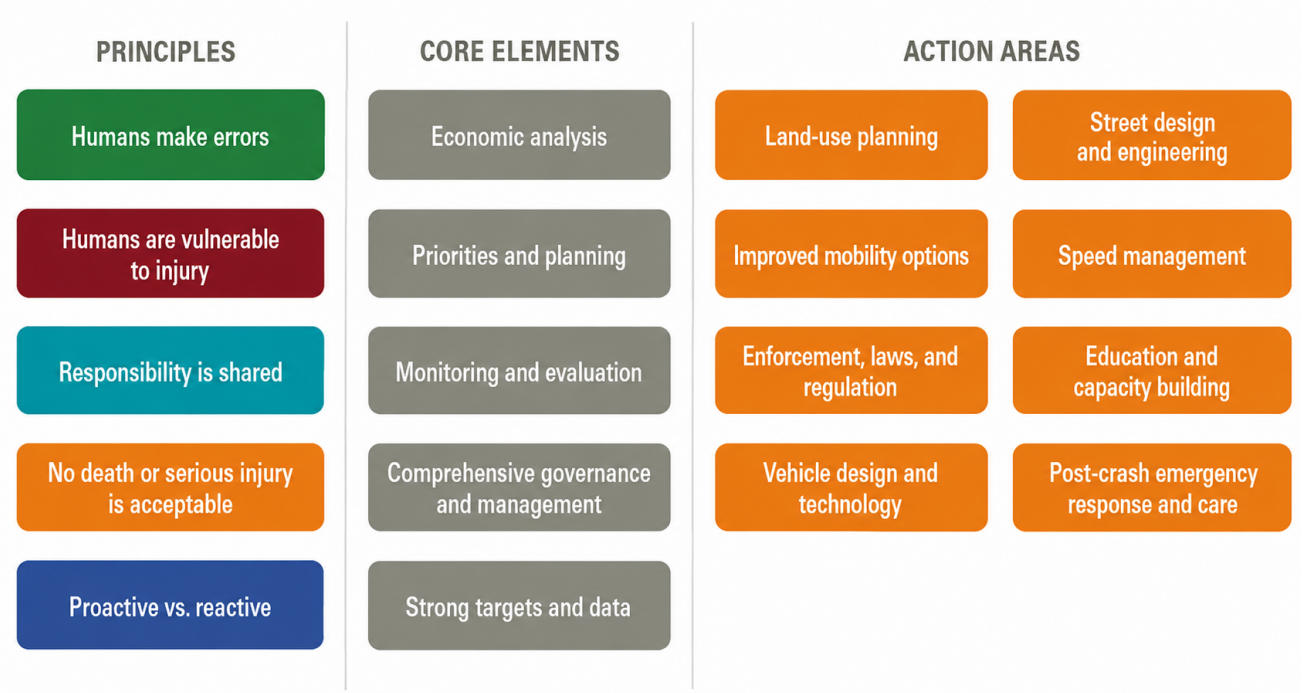
This paper seeks to present WRI's experience in developing a methodology to identify critical locations in Bogotá, thereby enabling local authorities to make decisions and plan more adequate strategies for road safety interventions. We designed this methodology in collaboration with the District Mobility Secretariat (Secretaría Distrital de Movilidad; SDM) and Vital Strategies, based on a comprehensive literature review and international references. From these joint work sessions, we selected the criteria, including tools and algorithms, that best suit Bogotá´s data. We conducted the literature review to align the proposed prioritization methodology, the academic recommendations, and best implementation practices, on selected prioritization methodologies for locations with high crash rates.

The literature review took the form of an integrative review (Booth et al. 2021), of both theoretical and empirical literature that included articles published in indexed journals, recommendation manuals, and road safety programs based on a Safe System approach (see Box 1). The terms hotspot, prioritization, road safety, traffic crash(es), geospatial analysis, and severity index were used in different searches in Google Scholar. Other publications from research institutes or authors relevant to these topics were consulted as well. The review did not specify publication dates but gave preference to recent literature published within the last 10 years because geospatial analyses have evolved alongside advances in computer science. The literature review focused on determining the unit of analysis used for prioritization, the time frame of the data, and the analysis method used for prioritization. Among the 50 publications examined, about half contained information relevant to two or more dimensions of our research.

Box 1 | **The Safe System approach**

The Safe System approach operates on the premise that while human error is inevitable, traffic fatalities and serious injuries are largely preventable. Land-use planning, road design, safe-mobility options, and speed management are all action areas of the Safe System approach. They address systemic and underlying factors that impact road safety and demand mobility systems that do not have death or serious injury as an outcome. Motorcycle safety is a complex and multifaceted issue that cannot be tackled with siloed or isolated efforts. It is a systems issue that requires systems thinking and solutions, with shared responsibility among multiple stakeholders.

FIGURE B1 | Elements and action areas of a Safe System approach to road safety



Source: Welle et al. 2018.

This research uses a descriptive method that identifies locations with the highest concentrations of road traffic deaths and injuries for vulnerable road users (VRUs): pedestrians, cyclists, and motorcyclists. It considers differences in road configurations, mobility dynamics, and possible road safety treatments. We developed methods for analyzing two road types—arterial and nonarterial—and designed a methodology that other cities can replicate if the data are available.

This document is divided into two sections:

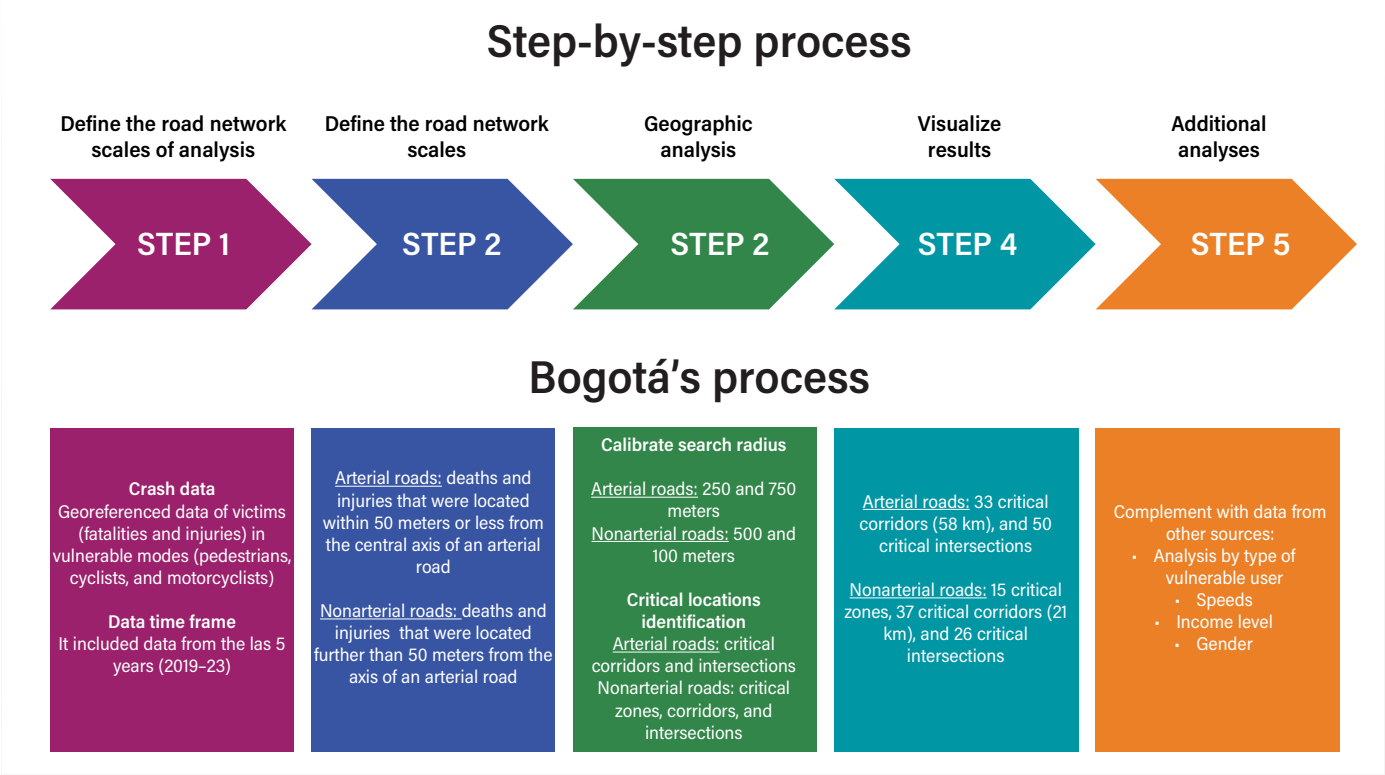
- A step-by-step description of the methodology developed by WRI to identify critical locations, including data collection, geographical analysis, visualization of results, and additional analyses.
- Conclusions and recommendations for applying this methodology in other cities.

Step-by-step methodology

Our methodology identifies locations in Bogotá with the highest concentrations of road crashes, with killed and seriously injured victims (severe crashes), and especially where the victims have been VRUs. We decided to use only injury and fatality data for VRUs (pedestrians, cyclists, and motorcyclists) because our focus is on preventing serious injuries and fatalities, which are far more likely to affect road users without the physical protection that a vehicle provides.

The five steps for applying this methodology include a calibration process suited to the specific needs and characteristics of Bogotá (Figure 1). These calibrations come from fatalities and injuries data, data time frame, types of roads, geographical analysis, concentration analysis, and spatial autocorrelation analysis. The elements considered in each process are described below, so other cities can replicate based on the data available and their own contexts.

Figure 1 | **Summary of step-by-step methodological process for Bogotá**



Source: WRI authors.

The five steps of this methodology are part of a process that was refined through a trial and error approach and repetitive practice with a combination of geographic information system (GIS) tools to visualize patterns of traffic crash victims in Bogotá (see "Step 3: Geographic analysis"). The steps propose a more detailed list of parameters to include in the data analysis process, which would lead to the most optimal possible visualization of results.

Step 1: Gather data

The first step is to understand what type of data the city has collected and to determine which datasets a researcher wants to work with and the time frame for the analyses. In other words, researchers must collect any data available of traffic crashes and/or victims, select the information that is useful, clean and transform variables, and even proceed to any calculations necessary. In the subsections of this step, we describe the key aspects to consider when starting an analysis of new traffic crash data.

Crash data: Collection and initial processing

In developing this methodology, we needed to determine which observed variables would best reveal the level of risk in a determined location and which design interventions would most effectively improve road safety; thus, we investigated the actions of other cities and experts. One way of counting is to look at events or the number of vehicles involved. The common practice is to use georeferenced data that track severe crashes leading to serious injuries and fatalities. Crash data focus on the number of people affected; the vehicles involved; the type of crash; the location, date, and time; and so forth (DOT 2018; PIARC 2025; Roe et al. 2010). Another approach is to count victims. Some researchers study victim data that count people affected and expand upon the data above to understand more about who was involved in the crash (age, gender, condition, etc.) (Viola et al. 2019).

A third approach is to count everything, including property damage. Some studies include crashes with minor injuries or crashes with property damage (along with all severe crashes), but they use criteria to weight them by either severity or estimated cost of the road crash to differentiate between low impact, serious, and fatal crashes (AfDB 2014; Cao et al. 2020; Choudhary et al. 2015; Coll et al. 2013; DOT 2018; European Parliament 2008; Manap et al. 2021; PIARC 2025; Tola et al. 2021).

Also, it is important to have a clear understanding of the advantages and limitations for each dataset (Table 1). The type of data that an analyst decides to use can offer advantages or drawbacks. If the city has different datasets, it is important to select the one that best suits the proposed objectives. For

Table 1 | **Advantages and limitations of the different datasets in Bogotá**

	ROAD CRASHES DATA (EVENTS)	VICTIMS DATA	PROPERTY DAMAGES AND MINOR INJURIES DATA
Advantages	It might be possible to find relevant locations for interventions, even with limited data on who is affected and how	Understand better who is involved in road traffic fatalities (road user type, gender, age) and conduct additional analyses, such as gender perspective analysis	Minor crashes/injuries point to road safety issues and might help build a hypothesis on why crashes occur; depending on the analysis and purpose of study, they should be considered[a] Higher frequency of events
Limitations	No details of who is involved in the crash Accuracy of locations of road crashes	Collecting, processing, and maintaining comprehensive victim data can be resource intensive Accuracy of locations of victims' data	A weighting system must be applied to determine severity; this results in an additional step to estimate the weights in a context-sensitive manner Minor crashes might exclude focus from more severe and fatal crash locations Accuracy of locations of property damage and minor injuries

Notes: There are many units of measurement, each with its advantages and limitations, and the one to choose will depend on many factors; however, it is important that researchers understand why to choose one and the limitations of the data.

a. For Bogotá, we did not look at data from property damages because these events excluded focus from the severe and fatal road crashes.

Source: WRI authors.

Bogotá, the SDM collects two types of data related to road crashes: crash data (events) and data on fatalities and injuries (victims). The crash data include information on the location, type of crash, time, and date of the event. The fatalities and injuries data go into more detail, describing the type of victim (whether injured or deceased), the type of road user (pedestrian, cyclist, motorcyclist, passenger, driver), the age and sex of the victim, among other variables[1]. We used the victims data, which permit differentiated analysis by road user, gender, and age.

Although Bogotá collects data on whether there were injuries and/or fatalities, it does not collect detailed information on the severity of injuries; therefore, data on serious injuries cannot be used for the analysis in this case. That is one reason why we are looking specifically at the most vulnerable road users: victims who were not inside vehicles and are therefore most likely to suffer severe injuries. We also decided to work only with VRUs because they are more prone to die after a crash. In Bogotá, they account for 94 percent of the total number of fatalities in traffic crashes, and globally it is estimated at 56 percent (WHO 2023). [2]

In other cities, data may be available on the severity of the victim's injuries; for example, there are classifications distinguishing victims who may only have a neck pain from those who may require surgery and amputation after the event or end up in a critical condition. If this type of data is available, it should be included in the analysis (Viola et al. 2019). Associations between severity of injuries, types of injuries, personal characteristics (gender, age), and types of crashes can be found by having detailed information of injuries available. Such analyses would help to plan better injury prevention strategies.

Considering the available data, we also decided to make two specific adjustments necessary to handle data better and get more representative results: We did not consider victims inside vehicles, such as drivers or passengers, and we eliminated crashes with a concentration and overrepresentation of injuries. By selecting and analyzing the data in this way, we avoided results that overrepresented locations with few crashes but many injuries, such as due to a bus crash that harmed several passengers.

Data time frame

According to all findings examined in the literature review, the recommended time frame varies from the last three to five available years. For Bogotá, the time frame included 2019, 2020, 2021, 2022, and 2023.[3] These years include the COVID-19 pandemic, which may skew the data because the pandemic affected frequencies in regular travel behavior. For this reason, we investigated how crash data were affected by the pandemic's mobility dynamics. Furthermore, we looked at whether the 2020 and 2021 crash data resembled or departed from typical crash patterns in Bogotá. Comparing geographic crash patterns from 2015 to 2018 and from 2019 to 2022 shows that crash patterns in the city remained consistent (see Appendix B). Before, during, and after the pandemic, the hotspots remained the same.

Step 2: Define the road network scales of analysis

After defining which variables and period will be included in the data analysis, it is necessary to visualize where the road crashes are occurring. Any GIS software can elaborate distribution maps and heat maps from geocoded data, and in this publication, we used ArcGIS for the analyses.

However, there is one more aspect that makes a difference in the analysis: road network classification. The traffic characteristics and crash patterns in terms of type, severity, and spatial attributes might be considerably different between roads of minor and major categories. Hence, adequately characterizing each kind of urban road is necessary to evaluate their road safety conditions and make adequate recommendations to improve the road safety performance in those locations.

In most cases, urban roads are classified by four categories: motorways (freeways, highways, or expressways), arterial roads, collector roads, and local roads (residential streets). One might find the categories in a city's land-use plan, but these may vary from city to city and might also be outdated. As cities grow and transform, some roads acquire new uses and different mobility patterns; thus, it is important to carefully review that the assigned road categories correspond to their actual functionality. Functionality is associated with changes in speeds, level of traffic, users, level of connectivity, and other features. The most suitable road safety measures depend on the operational conditions and characteristics associated with each road type.

We looked at the crashes throughout the road network and discovered possible imprecisions in the geolocation. In Bogotá, crash data is geolocated by police officers using the visible address closest to the crash, which could be as far as 120 meters away from the actual crash site—the average length of a city block (Ortíz-Ramírez 2023).

According to Bogotá's land-use plan, roads can be categorized into three groups: arterial, intermediate, and local roads. To account for the different road safety treatments and the georeferencing errors, we separated roads into two categories: arterial and nonarterial roads (intermediate and local roads together). For crashes on arterial roads, we looked at fatalities and injuries that occurred within 50 meters or less from the central axis of an arterial road, considering that the widest roads in Bogotá span up to 100 meters, according to the city's land-use plan. We defined crashes on nonarterial roads as those where fatalities and injuries occurred more than 50 meters from the axis of an arterial road. Decisions about how to categorize arterial and nonarterial crashes will depend on the road classification and the road configuration of each city, legislation on road safety measures, and methods of geolocating road crashes.

To decide what type of radius to use, we experimented with different radii and visualized which worked best. Figure 2 shows an example of the exercise conducted in Bogotá.

Step 3: Geographic analysis

For step 3, we first needed to determine the best methods of data analysis to maximize the usefulness for assessing risk; in this context, risk is understood as the likelihood of being involved in a crash given the historical concentration of crashes at a given location.

Table 2 describes the main characteristics of three common analysis methods, which are contained as part of existing GIS tools for processing traffic and traffic crash data. Our methodology uses a combination of kernel density analysis and cluster analysis as main tools, which are explained with more detail in the description of this step.

Most of the consulted references have used geographic analyses to identify critical locations due to traffic crashes. These analyses include the following:

- Event frequencies (DOT 2018; PIARC 2025).
- A heat map that shows areas where incidents (like road crashes or events) are more common and frequent (known as *kernel density* or *geographic concentration analysis*) (AfDB 2014; DOT 2018; Viola et al. 2019).
- Cluster analysis (known as *hotspot* or *spatial autocorrelation analysis*) that clarifies whether road crash patterns are grouped together or spread out randomly (Dezman et al. 2016; PIARC 2025; Roe et al. 2010).

Figure 2 | **Examples of victim selection using different radii of analysis**



50 meters from the central axis of an arterial road | **100 meters from the central axis of an arterial road** | **20 meters from the central axis of an arterial road**

Notes: To define what radius each city should use, a trial and error exercise can be implemented. For Bogotá, using a larger radius (100 meters) selects fatalities and injuries that occurred on roads other than arterials (local and collector roads), whereas using a smaller radius (20 meters) does not select all fatalities and injuries that occurred on arterial roads. The best fit was a radius of 50 meters from the axis of the arterial road. The same should be done for nonarterial roads.

Source: WRI authors.

Table 2 | **Summary of characteristics of different analysis methods**

METHOD	TYPE	WHAT WE LOOK FOR	METHOD	COMMENTS
Kernel density	Geographic concentration analysis	Locations with high concentrations of victims (fatalities and injuries)	Density of events by type: analyzes what occurs at each location individually	Commonly known as *kernel density analysis*
Cluster analysis (in some references, it is labeled as hotspot analysis)	Spatial autocorrelation analysis	Locations with statistically significant spatial autocorrelations	It measures how the data from one location is statistically related to the data from all the other locations; it shows that locations with similar values are clustered together rather than being randomly scattered, indicating some underlying factor influencing this spatial pattern	Also known as *cluster* or *hotspot analysis*
Index calculation	Combines multiple indicators or variables into a single numerical value	Places with high index value	Assigns index values to each location that measure risk. This is done to simplify complex datasets, making it easier to compare and analyze trends or patterns across different contexts or over time.	Data from property-only-damage crashes and minor injuries can bias the analysis, so it is not recommended; it requires spatial analysis at a very basic level only for identifying that a crash has occurred in a certain location of interest

Source: WRI authors.

Kalinic and Krisp (2018) recommend using both analysis methods (kernel density analysis and cluster analysis) complementarily. It is important to mention that these references use a different search radius depending on the type of location—intersections, sections, or areas (Roe et al. 2010; Viola et al. 2019). The amount of available resources should be factored into the number of locations to be prioritized (PIARC 2025).

Other methodologies consider including additional traffic crash data or the use of statistical models, but they are not considered in detail for the elaboration of this methodology. [4]

Considering the findings of the literature review, and the data available for Bogotá, we developed a methodology based on the combined use of kernel density analysis and cluster analysis (described below) of vulnerable fatalities and injuries,

Figure 3 | **Geographic concentration analysis using victim data in Bogotá**



Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

using data from the last five years. The general assumption orienting these analyses is that distribution of traffic crashes is not always random in low- and middle-income cities. Instead, they tend to follow a nonrandom distribution that depends on variations across the territory (Brunsdon et al. 2002, 2010; Budziński et al. 2018; Fotheringham et al. 2002; Pirdavani et al. 2014). The heterogeneity of the hotspot and cluster analyses of events justifies a geographically focused approach to understand the main differences between these high-risk locations and others (Appendix A).

Kernel density analysis (also known as geographic concentration analysis). Concentrations of road crash victims are identified through a kernel-type analysis (Figure 3). Kernel density estimation methods visualize and analyze spatial data to understand and potentially predict event patterns. These methods are useful for detecting high-risk locations through estimates made on a grid placed over the entire pattern of events. The estimates show the intensity at each location and thus detect high and low densities of event patterns—in this case, crashes with fatalities and injuries. Low concentrations may be eliminated to easily visualize critical locations, based on a threshold (e.g., below the median), resource availability, and/or the goals of the entity.

Cluster analysis (also known as hotspot or spatial autocorrelation analysis). The cluster-type hotspot analysis identifies areas with statistically significant concentrations of crashes, meaning that they have a high or low road crash concentration that is not random (Figure 4). This tool groups crashes with victims into points, counts the number of events within a certain distance of each point, and identifies whether each point is part of a zone with a high or low concentration of killed and seriously injured VRUs, according to statistical significance. According to Kalinic and Krisp (2018), cluster analysis involves conducting a statistical test between values from different areas to test if a statistical correlation exists between each area and its neighbors.

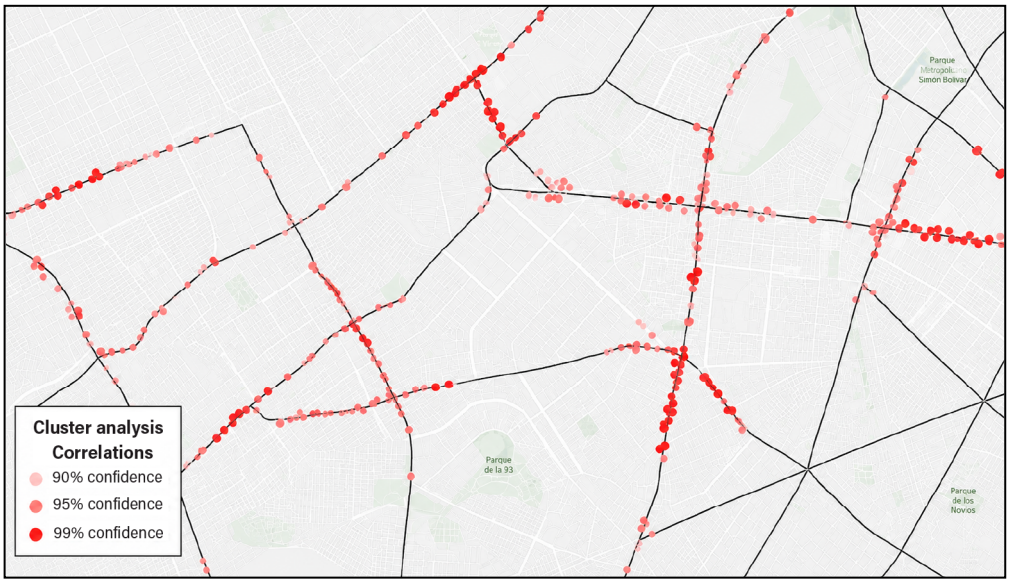
Calibrate search radius: Sensitivity analysis

The search radius (also known as the bandwidth or distance band) is a critical parameter that defines the area around each point where the density is calculated. In kernel density analysis, it determines how far the influence of each point extends when estimating the density surface. In cluster analysis, it is a parameter that determines how features (events or victims) spatially interact with each other, defining the maximum distance within which features are considered neighbors and contribute to the hotspot analysis.

The search radius was calibrated using a sensitivity analysis. This involved a trial and error analysis in which different search radii were tested to understand which range performed better based on the scale of the analysis, enabling identification of corridors and spots (see "Classifying corridors and spots").

One consideration in selecting the search radius was the distance between arterial corridors, with two purposes in mind: to avoid overlapping in the geographical analysis and to avoid using a shorter distance than the estimated precision of the geocoded data.

Figure 4 | **Spatial autocorrelation analysis using victim data in Bogotá**



Note: To be able to do both analyses, geographic information system software tools are necessary.
Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

These are a couple of the findings from the sensitivity analyses:

- A smaller search radius captures localized clusters (e.g., crashes at a single spot).
- A longer search radius highlights broader trends (e.g., high-risk road corridors).

For each method (cluster and kernel), different radii need to be calibrated. Hereafter, we show examples of sensitivity analyses that were conducted using data from Bogotá.

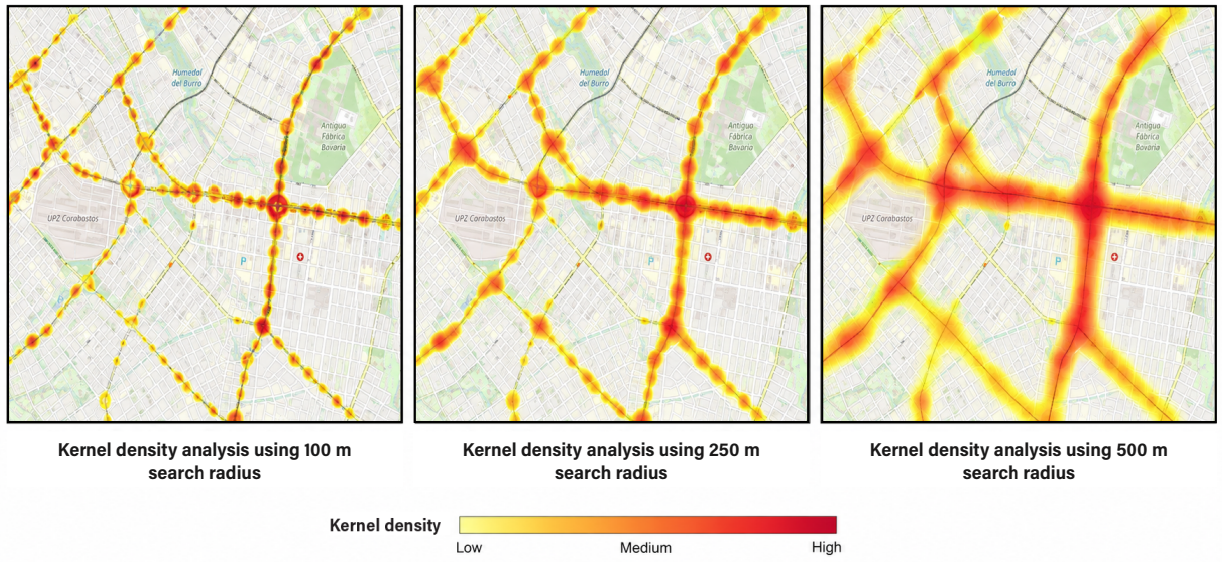
In the first example, different search radii were used for the kernel density sensitivity analysis in arterial roads (Figure 5). Using a small radius (100 meters), the analysis shows densities more focused at a spot level; using a radius of 250 meters, the analysis shows densities at the corridor level; and using a longer radius (500 meters), the analysis shows densities at a larger area level, even overlapping densities when roads are very close to each other. In Bogotá, a 250-meter search radius was determined to be the best choice for geographical concentration analysis because a larger radius overlapped with other arterial roads.

In the second example, we changed the search radii for a cluster sensitivity analysis on arterial roads (Figure 6). Using a small radius (100 meters), the analysis shows concentrated clusters at a spot level; using a radius of 250 meters, the analysis shows fewer and more geographically dispersed clusters; and using a longer radius (750 meters) the analysis shows more dispersed clusters at the corridor level. For the spatial autocorrelation analysis, a 750-meter search radius was used to identify critical corridors and a 250-meter search radius was used to identify critical spots in arterial roads.

The third example shows a kernel density sensitivity analysis on nonarterial roads (Figure 7). Using a small radius (20 meters), the analysis shows scattered densities; at first glance, neither corridors nor spots can be identified. Using a radius of 100 meters, the analysis shows corridor-level densities; and using a longer radius (500 meters), the analysis shows densities at a larger area level.

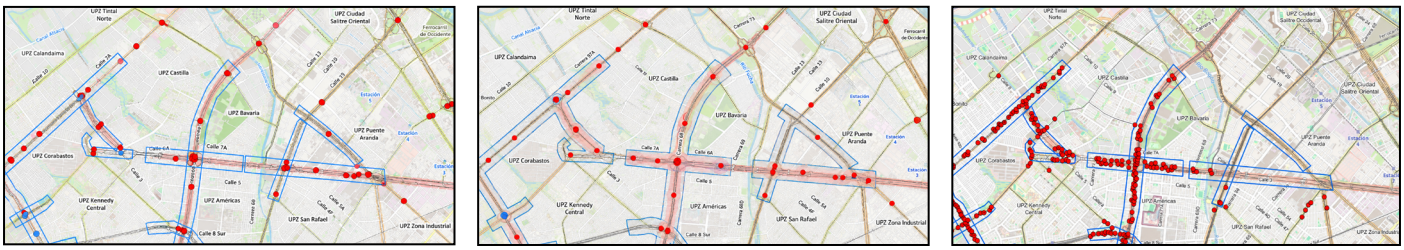
In the last example, we show a cluster sensitivity analysis on nonarterial roads (Figure 8). Due to a software error, analysis is not possible when using a small radius (20 meters). Analysis

Figure 5 | **Kernel density analysis using different search radiuses in arterial roads**



Source: WRI authors (2025), based on 2024 data from the District Mobility Secretariat.

Figure 6 | **Cluster analysis using different search radii in arterial roads**

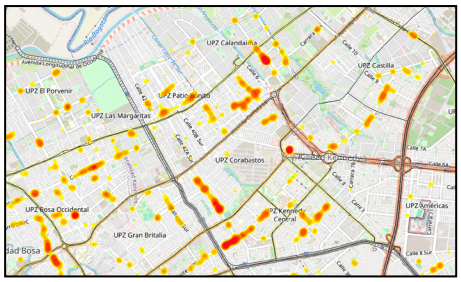


Source: WRI authors (2025), based on 2024 data from the District Mobility Secretariat.

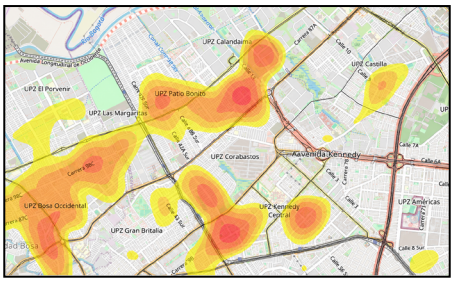
Figure 7 | **Kernel density analysis using different search radii in nonarterial roads**



Kernel density analysis using 20 m search radius



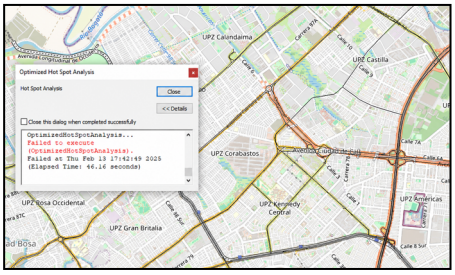
Kernel density analysis using 100 m search radiusa



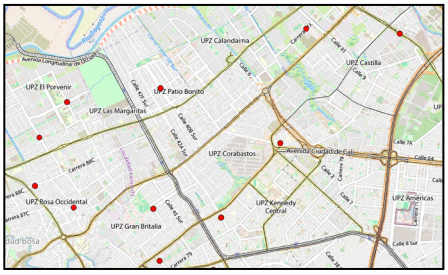
Kernel density analysis using 500 m search radius

Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

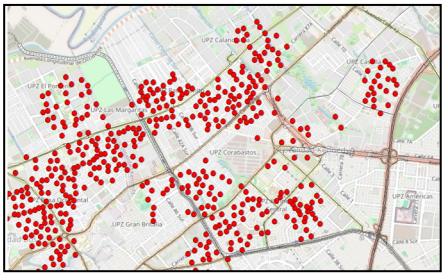
Figure 8 | **Cluster analysis using different search radius in nonarterial roads**



Cluster analysis using 20 m search radius



Cluster analysis using 100 m search radius



Cluster analysis using 500 m search radius

Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

using a radius of 100 meters shows dispersed clusters at the spot level; and when using a longer radius (500 meters), the analysis shows clusters distributed in larger area levels.

From this type of analysis and the results shown in the examples, we found that in nonarterial roads, the search radius can be reduced to 100 meters to identify concentrations at road segments and spots with statistically significant autocorrelations (Figures 9 and 10).

The adequate search radii may vary for each city due to differences in density of roads per area unit and data accuracy. Based on this sensitivity analysis, each analyst or technical team should decide what radius works best. We suggest doing as many trials as necessary to observe the differences, overlaps, or possible errors and to better understand which radius is most appropriate to use.

Classifying corridors and spots

Once locations with high concentrations and spatial correlations have been established, we can identify critical corridors or critical spots at different road network scales. For Bogotá, we focused the analysis on these two categories for two different types of roads: **arterial and nonarterial roads**. Each city that applies this methodology can choose the most appropriate road network hierarchy system for this analysis.

As an example, we found that crashes in Bogotá tend to be clustered along the length of certain corridors, and previous studies showed that this clustering occurred more specifically for motorcyclists (López et al. 2021, 2023). Given the increasing use of motorcycles and the number of victims of crashes involving these vehicles in Bogotá, it was important to have a corridor-level perspective; that is why we started focusing the analysis on whole road sections rather than just on spots along them (see Appendix A).

It is necessary for every road in a city's road network to be classified under a clear category within a road hierarchy. Then, for each road category, an analysis should be conducted to find critical corridors and spots (Figure 9). We define corridors as a set of critical locations that are "uniformly spilled" throughout a homogeneous road segment in terms of its infrastructure and operational characteristics; spots are defined as individual locations that appear highlighted in the analyses that are located outside the critical corridors.

In the following subsections, we elaborate on how to identify corridors and spots for arterial and nonarterial roads in Bogotá.

ARTERIAL ROADS

In this section, we describe the process followed to identify critical corridors and critical spots that belong to arterial roads only. The general flowchart that describes the process can be observed in Figure 10, and the description of the process for identifying corridors and spots can be found below.

Critical corridors on arterial roads. Critical road segments on arterial roads can be identified by grouping high concentrations and locations with high correlations of statistically significant victims on an arterial road section—that is, segments where both analyses (kernel density and cluster) overlap (see Figure 11).

Critical spots on arterial roads. It is also necessary to identify critical spots on arterial roads, which refers to locations with high correlations of statistically significant victims that cannot be grouped as part of a critical corridor (Figure 12). In Figure 12, the gray points (in the right panel) indicate critical spots already located within an identified critical corridor (outlined in blue). Since these points are within areas that have already been identified as critical, they must be excluded from this category to prevent double counting.

NONARTERIAL ROADS

For nonarterial roads, the process is similar to the one followed for arterial roads, with a few specific changes in how the analysis is conducted during each stage. To identify corridors, only kernel analysis was used because cluster analysis would not have yielded any clearly identifiable results. Therefore, the search radius must be adjusted, and its magnitude must be lower than the radii used for arterial roads. The flowchart of the process is presented in Figure 13, and the following section details the process for identifying critical corridors and critical spots in nonarterial roads.

Critical corridors on nonarterial roads. Critical road segments on intermediate and local roads can be identified by grouping high concentrations of victims in intermediate and local areas. A kernel-type analysis with a 100-meter search radius yielded the best visualization results for Bogotá's nonarterial road network (Figure 14).

Critical spots on nonarterial roads. Critical spots on intermediate and local roads are locations with high correlations of statistically significant victims that are outside critical corridors on nonarterial roads. As done previously with arterial roads, technical teams in charge should use a cluster analysis and identify the spots that do not belong to established critical corridors to find critical spots in nonarterial roads (Figure 15). In those locations, road safety measures that are more focused on the spot level can be considered because it is assumed that the high numbers of crash victims are not attributable to corridor properties but rather to characteristics that are unique to each location.

Additional remarks

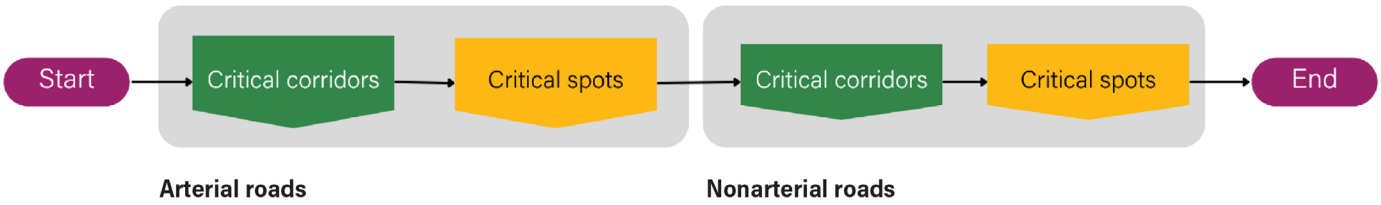
It is strongly recommended that the decisions from the sensitivity analyses (search radii adjustment) and the criteria for grouping locations as critical corridors (or even critical zones in the case of a combination of nonarterial roads located closely together) must be determined by each city's technical team. The boundaries of the corridors or areas can be determined by a combination of factors, such as intersections, road network configuration, land use, traffic characteristics, operational aspects of the roads, and any other additional relevant landmarks in the surrounding areas.

The identification of critical locations is just a starting point, enabling cities to better understand where road safety action is needed. Any intervention in the streets needs to be accompanied by road safety inspections and further research and analysis, and these efforts should ideally be framed under a Safe System approach strategy. The definition of spots and corridors (or areas) should preferably be done under this context, based on the types of remedial measures that should be taken for improving a given location's road safety performance. A corridor or a spot does not need to be mutually exclusive because there are locations that might require measures for both intersection improvement and corridor-level management.

Step 4: Visualize results

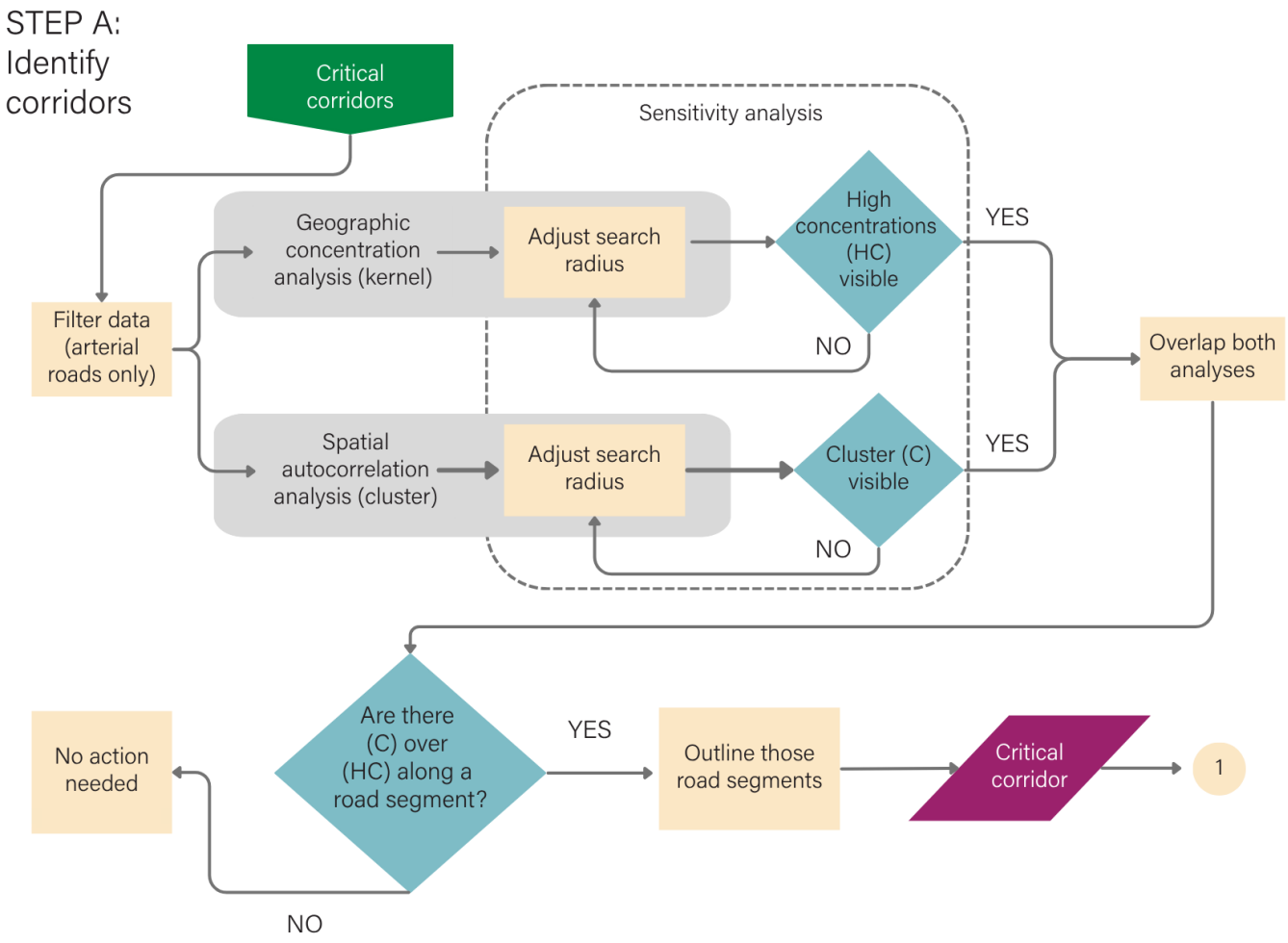
After selecting the crash data, choosing the best possible data time frame, and establishing the parameters for geographical analysis, we need to visualize the results in a clear form that is useful for planners and decision-makers. The identification results for both arterial and nonarterial roads in Bogotá are presented in this section.

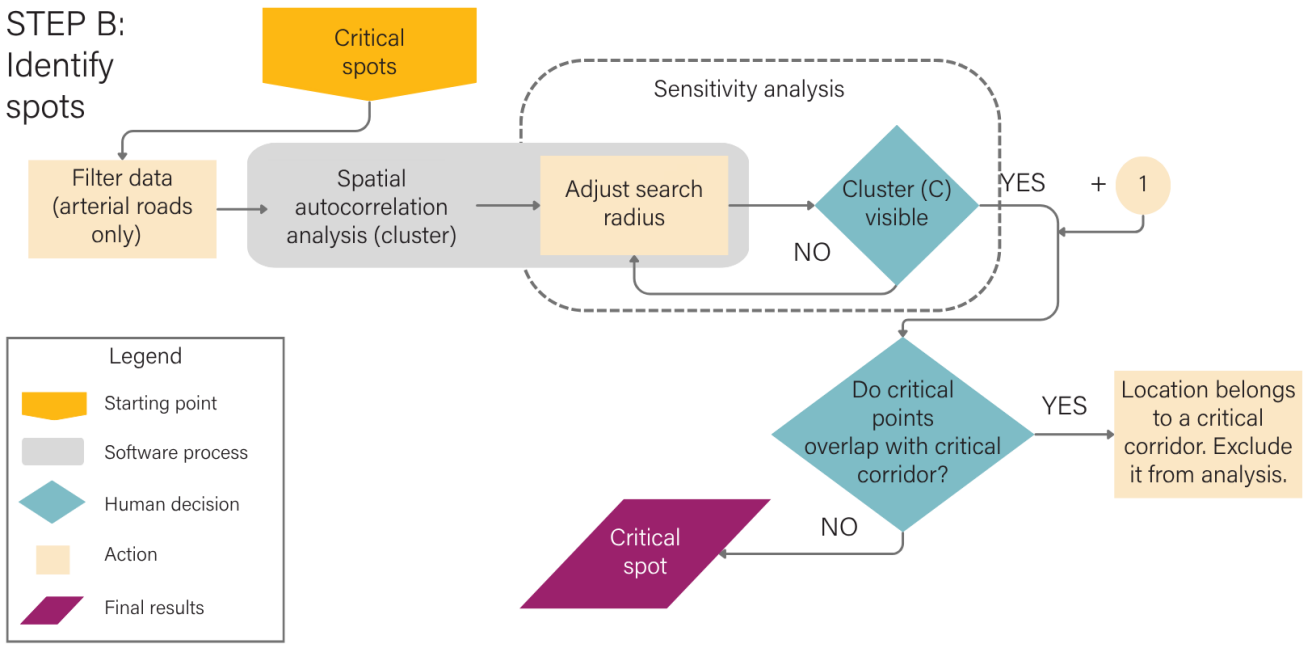
Figure 9 | **Classification process of critical corridors and spots for Bogotá**



Source: WRI authors.

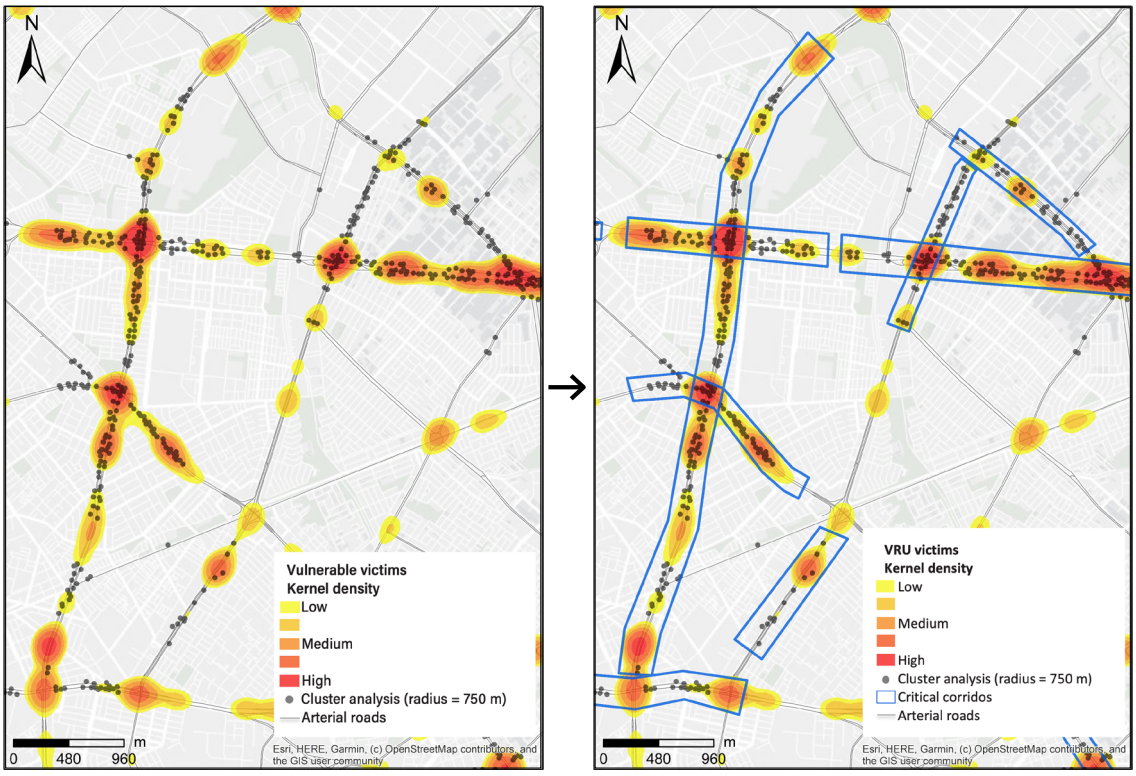
Figure 10 | **Process flowchart to find critical locations in arterial roads**





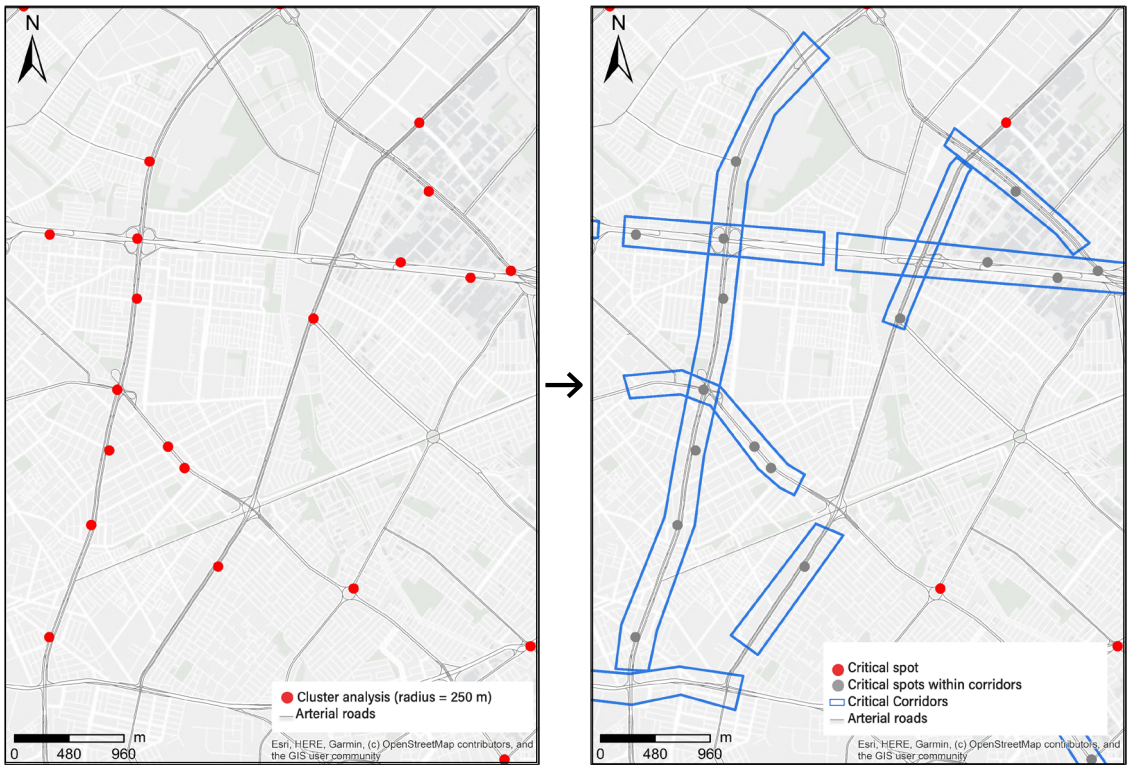
Source: WRI authors.

Figure 11 | **Identification of critical corridors on arterial roads**



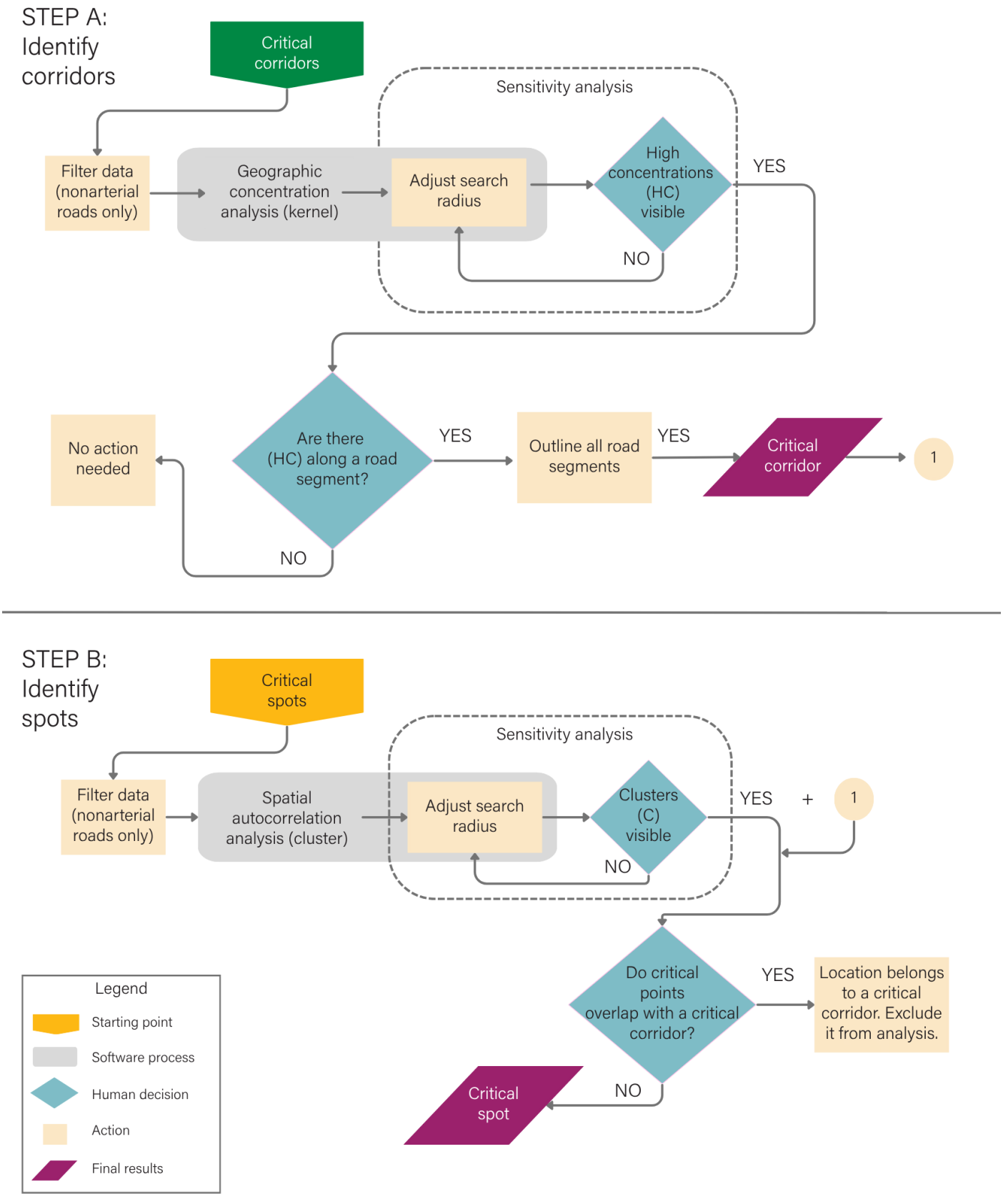
Source: WRI authors.

Figure 12 | **Process for identifying critical corridors in arterial roads**



Source: WRI authors.

Figure 13 | **Process flowchart to find critical locations in nonarterial roads**



Source: WRI authors.

Table 3 | **Fatalities registered in critical corridors and spots in arterial roads (2019–2023)**

A: Critical spots (56 locations)	178 (11%)
B: Critical corridors (58 km)	484 (29%)
A & B: Critical spots and corridors	662 (40%)
Total fatalities in arterial roads—Bogotá	1,664

Note: It is important to note that critical spots located within an identified critical corridor were excluded to avoid double counting: in other words, critical spots (56) are only those that stand by themselves.

Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

ARTERIAL ROADS

We applied the methodology on arterial roads by using the two types of geographic analyses (kernel density and cluster) with fatalities and injuries of VRUs. The result is presented in Figure 16, which shows the locations of the critical corridors at the city level.

However, considering a more comprehensive approach in road safety, we must consider that not only corridors but also some specific locations should be intervened, as shown in Figure 17. In the case of spots, locations with high numbers of victims within a 250-meter radius were identified.

After grouping the critical locations, it is useful to determine the extent to which both the critical locations cover the road network and the vulnerable victims are concentrated in the critical locations, according to what each city needs to highlight. For example, in Bogotá we found that 40 percent of the fatalities on arterial roads between 2019 and 2023 were concentrated in the identified critical spots and corridors, which cover 56 spots and 58 kilometers of arterial corridors, which is equivalent to 10.5 percent of the total arterial road network (Table 3).

NONARTERIAL ROADS

The results of applying the methodology on nonarterial roads through kernel density and cluster analyses of vulnerable fatalities and injuries are shown in Figure 18, which highlights corridors with the highest numbers of victims within a 100-meter radius.

For critical spots on nonarterial roads, locations with statistically significant correlations of victims within a 100-meter radius were prioritized (Figure 19).

After applying this methodology to nonarterial roads in Bogotá, with the locations of fatalities and injuries between 2019 and 2023, we were able to identify 37 nonarterial corridors and 26 critical spots on nonarterial roads. We found that 11 percent of the fatalities on nonarterial roads between 2019 and 2023 were concentrated in those identified critical spots and corridors in nonarterial roads (Table 4).

Step 5: Additional analyses

Analysis by type of vulnerable user

ARTERIAL ROADS

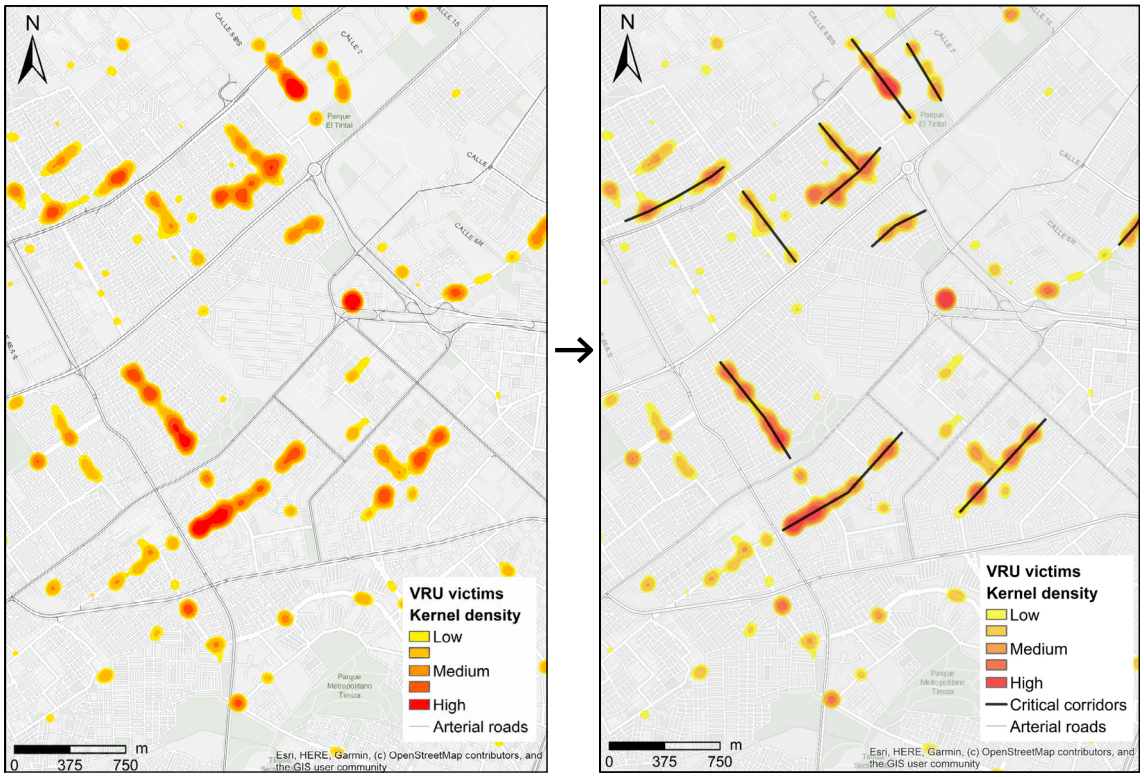
To differentiate by type of road user, analysts must consider that victim concentrations are not comparable to each other. Concentrations depend on the total number of victims by type of road user; thus, if an analysis uses data from two different types of road user, it may overrepresent the type with fewer total victims. In 2023, for example, 11 percent of all fatalities in Bogotá involved cyclists (63 fatalities) and 45 percent involved motorcyclists (243 fatalities). If an analyst were to use both types of road users in the same analysis, the joint analysis would show a higher-than-real representation of cyclists' fatalities, which would distort the resulting analyses. When additional analysis is needed for each type of road user, kernel density and cluster analyses should be conducted

Table 4 | **Summary of the results in critical corridors and spots related to fatalities in nonarterial roads (2019–2023)**

A: Critical spots (26 locations)	14 (2%)
B: Critical corridors (21 km)	68 (9%)
A & B: Critical spots and corridors	82 (11%)
Total fatalities in nonarterial roads—Bogotá	717

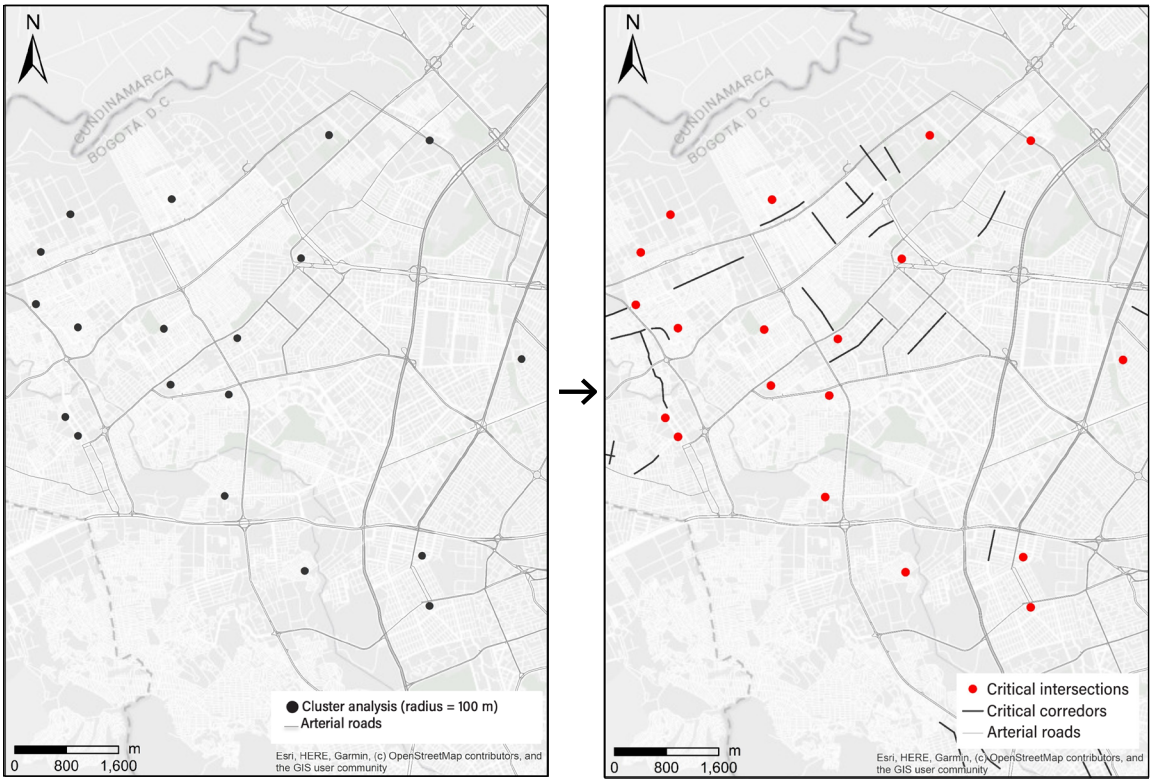
Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

Figure 14 | **Identification of critical corridors on nonarterial roads**



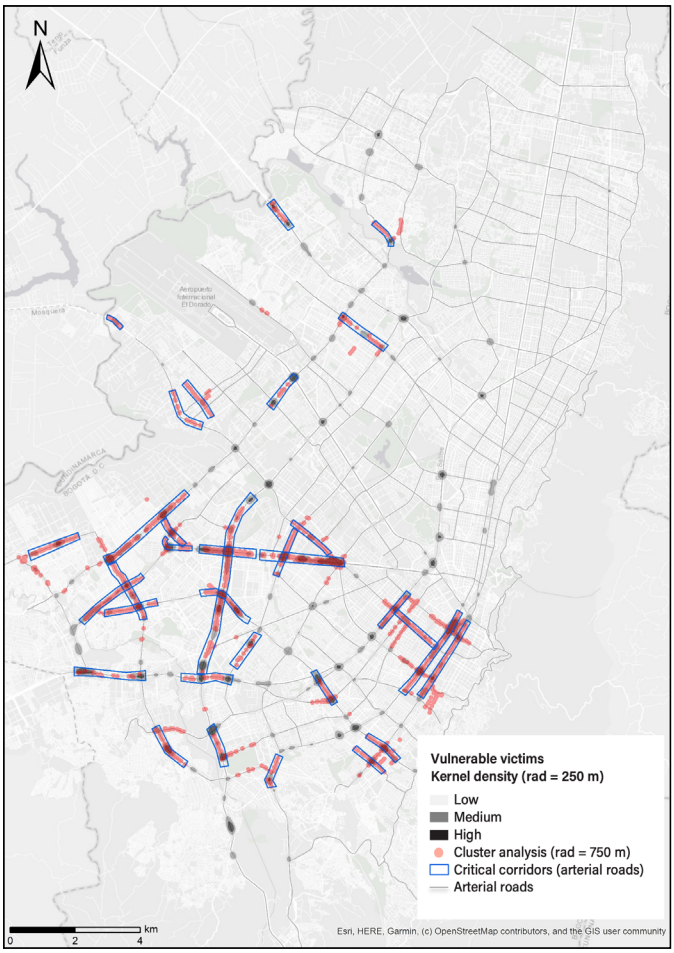
Note: VRU = vulnerable road user.
Source: WRI authors.

Figure 15 | **Process for identifying critical spots in nonarterial roads**



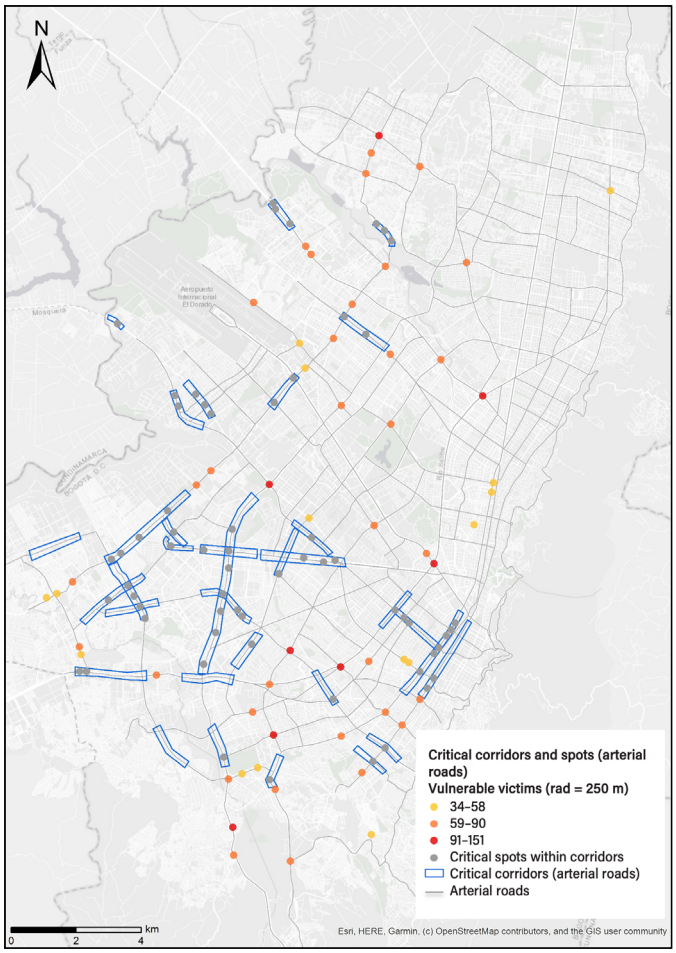
Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

Figure 16 | **Critical corridors using high densities of vulnerable victims and statistically significant correlations (2019–2023)**



Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

Figure 17 | **Critical spots and corridors in arterial roads**



Notes: The gray points indicate critical spots located within an identified critical corridor (outlined in blue). Since these areas have already been identified as critical, they were excluded from the list to prevent double counting.

Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

separately by type. Independent analyses for different types of road users can later be visualized on the same map, as shown in Figure 20.

NONARTERIAL ROADS

We also performed kernel density analysis by type of VRU (pedestrians, cyclists, and motorcyclists) on nonarterial roads. According to Figure 21, the density of victims by type of user varies depending on the location; for example, in locations west of the city, cyclist victims are almost exclusively present.

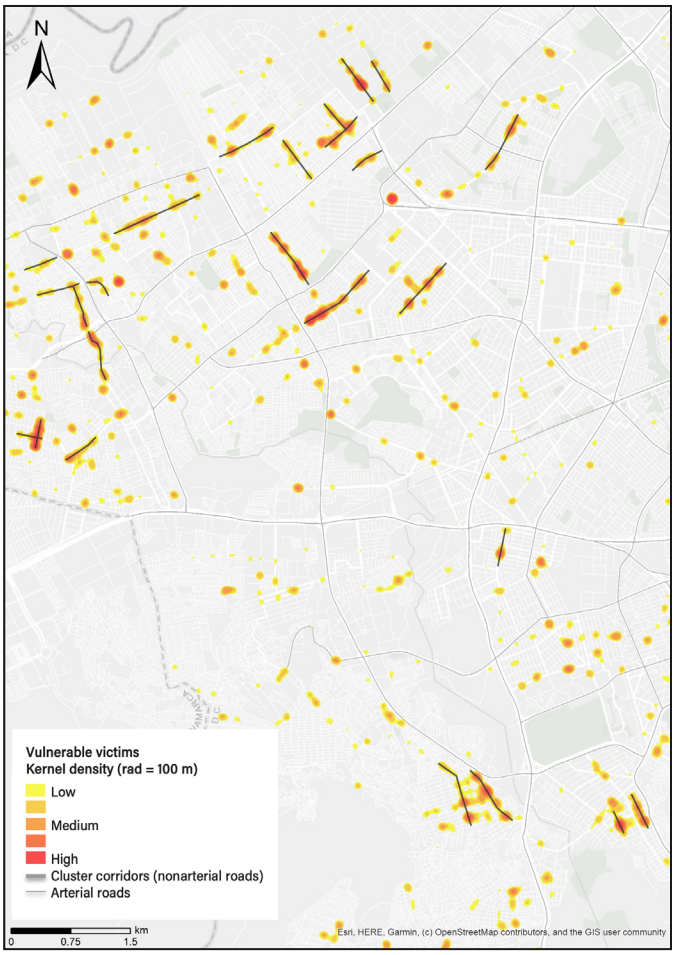
SPEEDS

Speed has been consistently identified a key factor in the severity of road crashes (WHO 2017). Target speeds depend on variables such as the current level of speeding and the context of the road. From a citywide analysis of speeds using data from Google's Distance Matrix API platform and overlaid with critical cluster analysis, we can see the corridors where it is more likely to have no congestion at any given time and also where drivers are most likely to exceed speed limits.

It could be beneficial to look at speeds in the road network. Usually, high speeds are directly associated with the presence of critical corridors or spots, but in some cases (as shown in Figure 22), speed might not be the main contributing factor to high counts of traffic crashes.

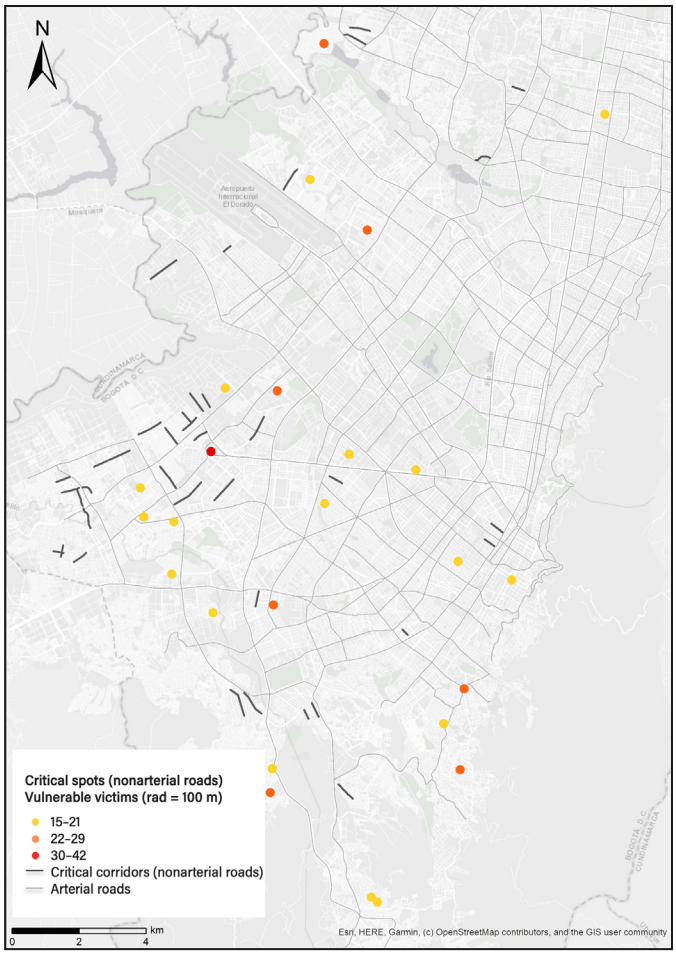
In most cases, speeding and road crashes overlap, as speed is usually a primary contributing risk factor. Thus, implementing comprehensive speed management measures is a necessary step to reduce the number of traffic-related victims. This combined analysis is useful to highlight the streets where speed management measures are most needed and can be the most effective. However, there are critical locations where high speeds are not a frequently observed risk factor. In these cases, additional analysis is needed to understand the underlying causes.

Figure 18 | **Close-up of critical corridors using high densities of vulnerable victims within 100 meters (2019–2023): South and southeast Bogotá**



Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

Figure 19 | **Cluster-type hotspots using statistically significant correlations of vulnerable victims within 100-meter radius (2019–2023)**



Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

Therefore, to better understand the specific conditions under which speeding behaviors are more directly associated with road injuries and fatalities, we must examine differences in road infrastructure aspects between critical and non-critical locations.

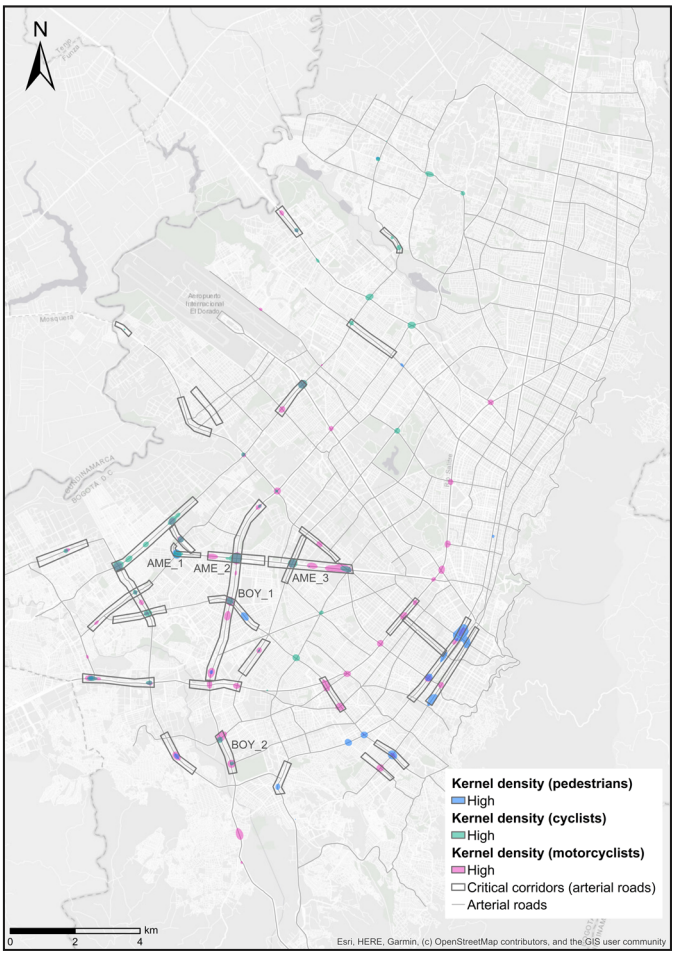
INCOME LEVEL

Figure 23 overlays information on income level with data on clusters in Bogotá. This figure reveals that in critical locations on arterial roads, the most serious and fatal crashes take place in middle- to low-income city areas. This has a strong equity implication, showing a disproportionately higher risk in these areas.

GENDER

When the hotspot analysis is differentiated by gender, it shows that injuries and deaths among both males and females are concentrated along the critical corridors in the arterial roads identified above (Figure 24). It also reveals that 20 percent of the fatalities are women and 74 percent are men (the remaining 6 percent consists of data with no available information), and these percentages are very similar to those across the city. We must always consider that gender-based road injuries could be associated with different mobility patterns (modes of transport, pendular movements, multidestination movements, etc.). Bogotá shows how critical locations for female victims could be considered a subgroup of overall critical locations. In other words, some specific locations that are dangerous for men could be dangerous for women as well, but every location where women are under greater risk will be dangerous for men as well. Therefore, this kind of analysis can help add layers of information and context to analyses based on road user type, which are necessary to target particular groups of vulnerable users.

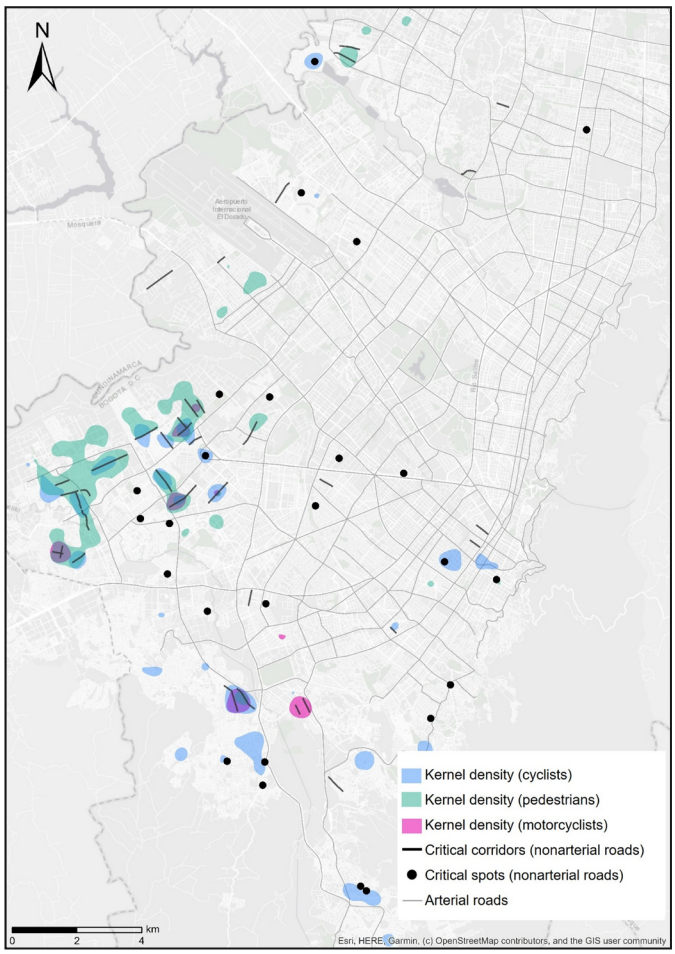
Figure 20 | **Concentration of victims (kernel density) by type of vulnerable user**



Notes: These analyses were done independently and visualized on one map. The victims represented on the map are the victims above the medium of the kernel density for each vulnerable road user.

Source: WRI authors, with 2024 data from the District Mobility Secretariat.

Figure 21 | **Concentration of victims by type of vulnerable user**



Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

Adapting the methodology to other cities

Although this methodology was developed for Bogotá, the analysis and processes described (see Figures 1, 9, 10, and 12) can be applied to other cities as long as the methodology is contextualized to each city´s available data. In other words, its applicability does not depend on similarities between cities but rather on the type and quality of data available. As the methodology is based on kernel and hotspot analyses, it will work better on cities with high rates of road fatalities and injuries. In cities with lower rates of road crashes, few or no clear hotspots or patterns might become evident.

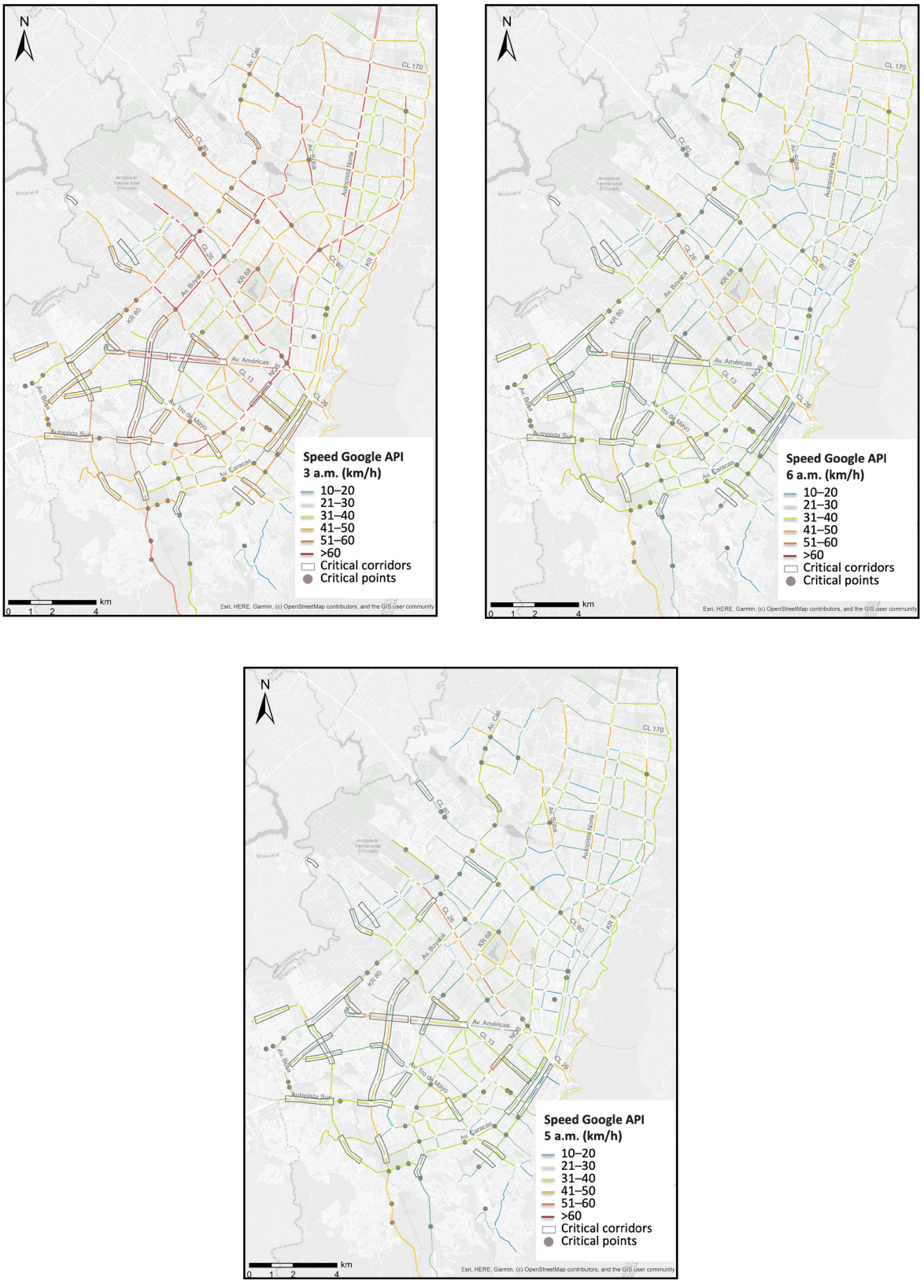
The steps for applying the methodology in any city of interest would remain the same as those mentioned in the previous sections:

1. Gather georeferenced crash data, and define a proper time frame.
2. Define the road network and scales of analysis.
3. Perform geographical analyses by calibrating adequate search radii values.
4. Visualize the results discriminated by different types of roads, road users, and geographic scales.
5. Include other additional analysis that might be relevant to the context by revealing actionable information that leads to more robust findings.

The following are additional requirements and suggestions:

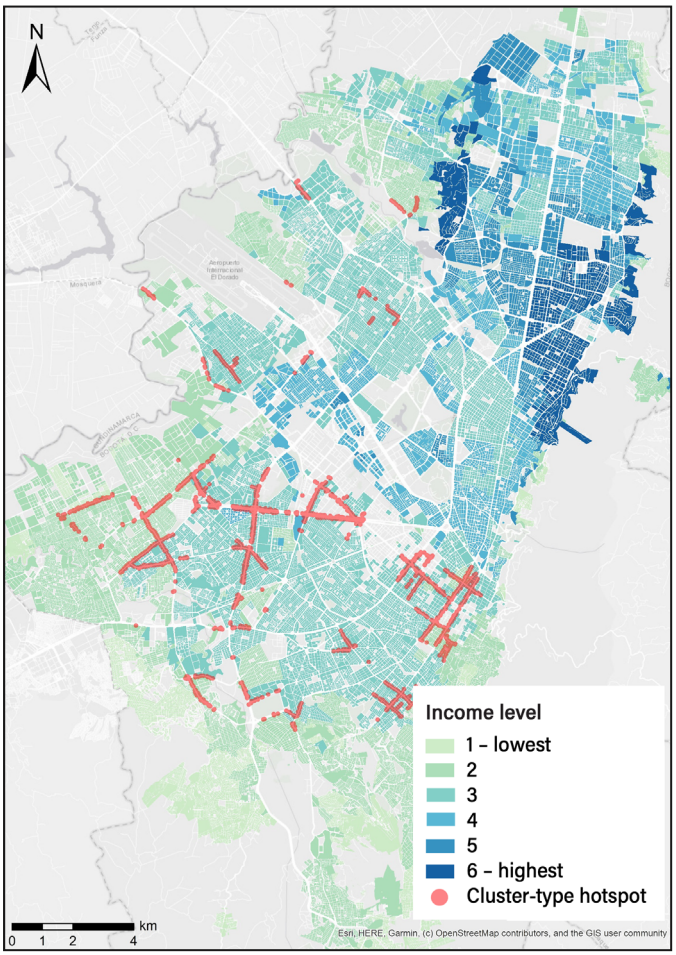
- **Saving lives cannot wait for years.** Even if available data are not excellent, cities must act in places where risks are evident. Decisions can be better oriented if they are informed with data-oriented analyses.

Figure 22 | **Average speeds in Bogotá's arterial road network**



Note: Speeds were calculated for free flow conditions (left, at 3 a.m.) and peak hours (center, at 6 a.m.; right, at 5 p.m.).
Source: WRI authors, based on 2024 data from Google Distance Matrix API.

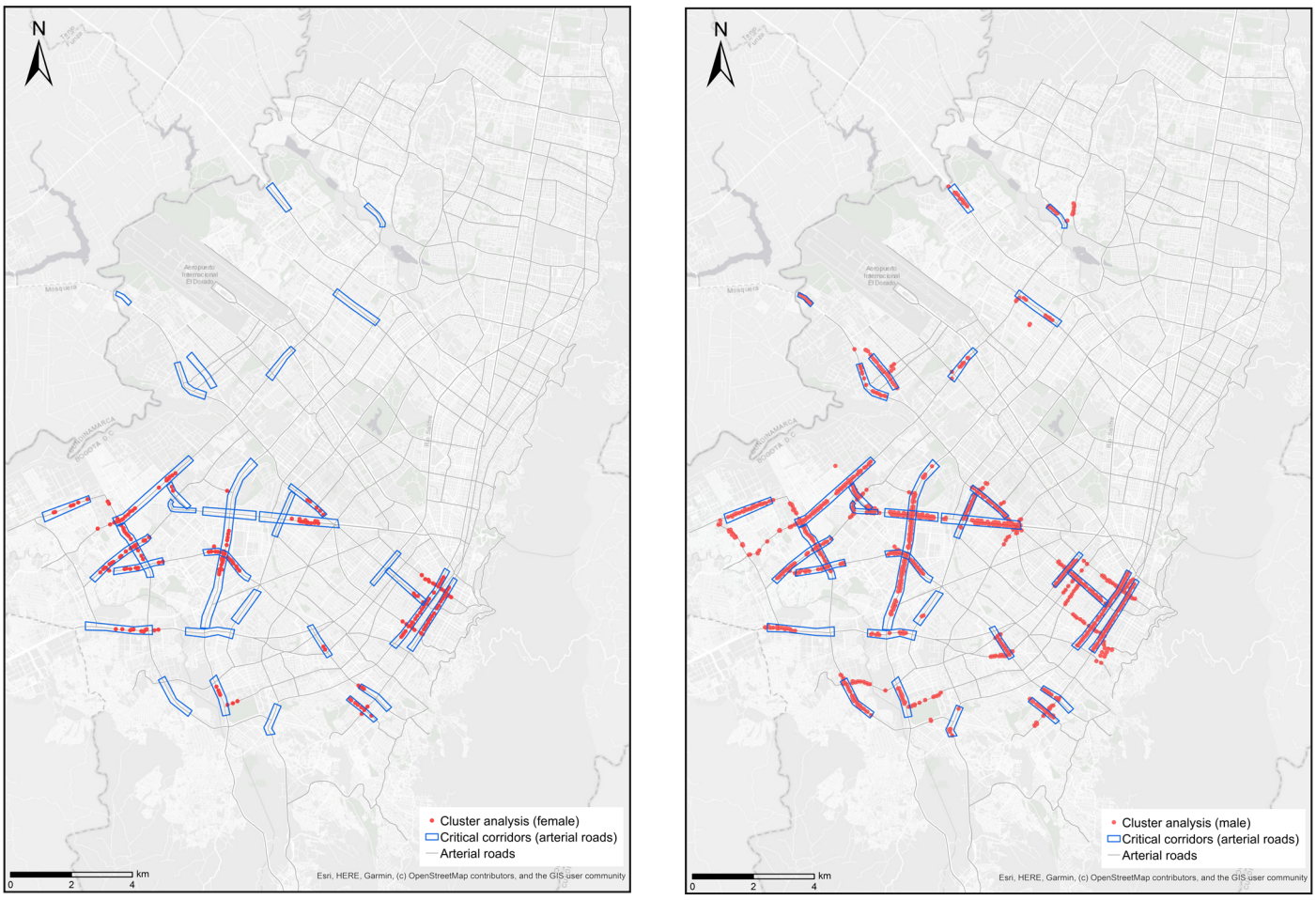
Figure 23 | **Locations with high correlation of vulnerable victims (> 90 percent) on arterial roads and income level**



Source: WRI authors, based on 2024 data from the District Mobility Secretariat and the District Department of Planning.

- **Geocoded data on road crash victims must be available.** To apply this methodology, georeferenced data on road crashes must be available at the city level and broken down by user type (pedestrians, cyclists, motorcyclists, passengers, drivers) or crash severity (fatal, serious/minor injury, damage only). If data by user type are not available, the methodology can only give information on the locations where crashes are most likely to occur.
- **Time frame of the data must be assessed.** Cities must assess whether phenomena at national or global scales, such as COVID-19, changed mobility dynamics and road crash patterns. These tests can reveal whether patterns identified during those years were aberrations. If so, like in the case of COVID-19, cities may decide to analyze only the years after the pandemic, under the premise that mobility dynamics are not going to go back to prepandemic patterns or use data from three years before the pandemic. Furthermore, changes resulting from a surge in remote working can be associated with changes in mobility patterns that might affect road safety (Pirdavani et al. 2014). Hence, comprehensive surveys assessing the effects of the pandemic on commuting patterns might reveal whether a decline in commuting affected the number and locations of crashes.
- **Geocoded data on types of roads must be available.** Different cities may have different types of roads, according to their land-use plans. Each type of road and its characteristics must be analyzed to determine how to group the road network. Given that road classification might be scarce in some contexts, open sources such as OpenStreetMap can be useful to define the "arterial roads" of a city. It is important to emphasize that the official road classification might not be updated, and using road characteristics might be a more optimal approach.
- **Search radii of the analysis must be calibrated.** Calibrations to decide the search radii of the statistically significant concentrations and correlations analysis must be conducted. This calibration process may consider geolocation errors and different types of road data available for each city. Assessing the data using adaptive bandwidth analyses can help optimize the radii values of the analyses. Fotheringham et al. (2002) provides information on how to estimate the adaptive bandwidth. It is also crucial that the data analysis be carried out using GIS (e.g., ArcGIS or QGIS).
- **Speed data should be considered.** Speed has been proven as the main risk factor for serious crashes and must be understood and addressed accordingly. Therefore, the more data on traffic speeds available for the road network, the better. The use of platforms such as Waze or Google Distance Matrix API (now Google Legacy) provide reliable information on traffic speeds. However, cities should try to understand how speeds can be differentiated by type of vehicle and by type of road. Measurements of spot speeds—with people in the field or by the use of remote technologies like speed radars or speed cameras—and the use of techniques such as floating car data can also facilitate access to valuable information at relatively low cost.

Figure 24 | **Locations with high correlation of female victims (left) and male victims (right) and critical corridors**



Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

Conclusions

This paper presents a study case for a methodology adapted by WRI to identify critical road crash locations in the city of Bogotá. It could be adopted by other cities—especially in LMICs—to help them identify with more clarity where road safety interventions are most needed, making effective use of their limited resources. Critical locations on arterial and nonarterial roads were identified in Bogotá through kernel-type concentration analysis and cluster-type hotspot analysis of georeferenced data on vulnerable fatalities and injuries.

This methodology is based on a literature review and includes specific considerations for the Bogotá study case: the type of georeferenced dataset to use (victims, road crashes, minor crashes), the time frame (three to five years), and the type of geographic analysis (geographic concentration, cluster, probabilistic models, geographically weighted regressions). The criteria were developed jointly between WRI, SDM, and experts from the BIGRS. If the necessary data are available, this same methodology could be implemented in other cities, as shown in the case study of Kumasi (see Box 2).

In collaboration with local governments, stakeholders can identify potential solutions (infrastructure changes, enforcement, regulation, etc.) for the causes of traffic-related casualties, which must be suited to the characteristics of each location under analysis.

Once the potential solutions are put in place, the local governments and authorities should monitor any changes and evaluate whether the changes have had a positive impact. The use of this methodology allows interested parties to monitor and recognize how these changes have occurred, whether unexpected or not, as in the example of Avenida Ciudad de Villavicencio in Bogotá (see Box 3).

Although the Safe System approach calls for a holistic view of the road network and systemic interventions, implementing such broad changes is often challenging—particularly in countries with limited resources or weak political commitment. In this context, a phased or step-by-step work plan becomes both practical and strategic to begin advancing toward systemic change. Identifying critical locations allows cities to prioritize areas where interventions can have the greatest impact, serving as an entry point for broader transformation.

Box 2 | **Application of the methodology: Kumasi, Ghana**

In 2023, the city of Kumasi crafted a Speed Management Plan (SMP) with the purpose of providing guidance to city authorities and diverse road sector agencies for speed management in the city. The SMP, rooted in the Safe System approach, underscores the importance of establishing a forgiving system that acknowledges human error, aiming to eliminate fatal crashes and reduce serious injuries. This plan was also in accordance with the National Road Safety Strategy IV (2021–2030).

Furthermore, an analysis of the cumulative relative frequency of crashes by location revealed that 50 percent of the crashes in the prioritized area are concentrated in seven locations. By focusing efforts on these specific locations, Kumasi could potentially halve the number of serious injuries and fatalities from road crashes involving vulnerable road users.

The data for analysis were obtained from official police crash reports. Kernel density (250 meters) and hotspot analysis (750 meters) were used to analyze the city's crash data between 2020 and 2022. This methodology aimed to identify locations where more crash incidents resulted in at least one injury or fatality. Data on property-damage-only crashes were therefore excluded from the analysis. From this analysis, 11 critical corridors and 20 critical spots were identified.

With the purpose of updating the data analysis to redefine a new version of the Kumasi SMP, the methodology was applied again in 2025, using data from 2020 to 2024. In the new analysis, 15 critical corridors and 4 critical spots were identified.

This analysis reveals both the systemic and dynamic nature of serious traffic crashes in the city. Although some corridors remain as critical, new critical corridors have also appeared where only spots were found before, such as the arterial corridors in the southwest side or the east side of the city's main ring road (Figure B2-1).

FIGURE B2-1 | Critical location analysis for Kumasi for the period 2020–2022 (left) and 2020–2024 (right)



Source: WRI authors, based on data from Kumasi City Police.

More importantly, a reactive approach is still a necessary step in cities where infrastructure planning and construction have not been guided by what we consider today to be proper road safety standards. In other words, many cities built their roads based on outdated road safety standards or without deep consideration of potential road safety risks.

A proactive approach is necessary for road safety. Therefore, cities are encouraged to learn from the lessons of remedial processes and to include built environment measures in every road infrastructure project. By doing so, they will become aligned with the principles of the Safe System approach to road safety. That is how we hope to influence cities in the medium and long term—a more proactive approach aligned with the principles of the Safe System approach.

Limitations

After discussing the importance of this methodology and the possibilities it offers, it is important to also be aware of its limitations.

This methodology is descriptive and is based on the combined use of GIS software tools. These tools are useful to identify spatial patterns and relationships associated with crashes, injuries, and fatalities; however, the methodology alone does not provide a means to prioritize interventions or actions. Other factors of analysis must be included in different stages of analysis by the local authorities, who are in charge of prioritizing actions and making decisions that affect the road safety environment.

Box 3 | Application of the methodology: Case study in Avenida Ciudad de Villavicencio, Bogotá

Most of the deaths and injuries in Bogotá have occurred on arterial roads, and road use victims vary depending on the locations or road segment. To better understand where different vulnerable road users (VRUs) were being killed, we performed the kernel density analysis by type of VRU (pedestrians, cyclists, and motorcyclists) on arterial roads. It is important to highlight that critical spots and corridors are not comparable with each other in terms of the problem. For example, the density of victims by type of user varies depending on the corridor or critical spots. In the city center, for example, pedestrians are almost exclusively the victims; in other areas, an overlap of VRUs can be seen, as is the case of Avenida Ciudad de Villavicencio.

Avenida Ciudad de Villavicencio has historically concentrated pedestrian and motorcycle victims. This arterial road goes through a residential and commercial area, and it is a transport hub that connects the neighborhood to the public transport terminals. This means that a lot of pedestrians cross the high-speed avenue. Ten deaths and 188 injuries were reported from January 2019 to February 2025. Once this corridor was identified as a critical location, we conducted more thorough analyses on road crashes and speed, performed site visits and road safety inspections, counted pedestrian and vehicle traffic volumes, and worked closely with the District Mobility Secretariat (Secretaría Distrital de Movilidad; SDM) to design infrastructure measures for speed management that could help mitigate the risks and conflicts identified.

Two of the key risk factors identified were excessive speeding—with one in three four-wheeled vehicles and two in three motorcyclists exceeding speed limits—and infrastructure conditions that failed to properly protect most VRUs. These issues were particularly concerning given the dynamic nature and complex social context of the corridor. More specifically, this zone is a low-income area that has high population densities, the presence of schools and communal centers, high traffic volumes, high shares of motorcyclists and heavy-duty vehicles, and mixed residential and commercial land uses that blend formal and informal trading activities.

As we had observed in the city and analyses conducted by López et al., motorcycle crashes were occurring at a corridor level;a therefore, interventions had to be designed with a corridor-based perspective. Jointly with the SDM, World Resources Institute proposed and participated in the design of six speed humps on the 700-meter critical corridor of Avenida Ciudad de Villavicencio (Figure B3-1).

FIGURE B3-1 | Speed hump intervention on critical corridor of Avenida Ciudad de Villavicencio





Source: WRI authors.

After implementation, zero deaths have been reported, injuries dropped 75 percent, and the average speed of all vehicles decreased by 28.8 percent, with a notable reduction among motorcyclists (29.1 percent). The percentage of vehicles exceeding the speed limit dropped from 69.9 percent to 18.0 percent.

This is an example of the methodology's usefulness. Through its application, traffic authorities in Bogotá were able to target a risky area and make investments in road safety interventions in locations with the highest potential for saving lives.

Source: a. López et al. 2021, 2023.

This methodology only serves to identify risky locations to consider for future actions. It does not help identify the solutions or measures to be taken to rectify problem locations. Solutions or measures must be tailored to each location based on allocation of resources, data analyses, road safety audits, and other investigations.

It is important to make clear that this methodology does not consider discussing causal factors or formulating hypotheses associated with serious traffic crashes on urban roads. Its purpose is to help identify the corridors and spots where this phenomenon has been repetitive and systematic and the road users who are usually involved (pedestrians, cyclists, motorcyclists, and others). This enables decision-makers to conduct in-depth analyses in those locations and promptly take remedial measures.

Recommendations

Using this methodology to identify critical locations is the first step to understand where possible road safety interventions need to be implemented. It provides an overview of the road safety issues based on elements such as the type of actor involved (pedestrians, cyclists, or motorcyclists), the type of problem (spot or corridor level), and the type of road (arterial or nonarterial).

Database information must be reasonably accurate and cover at least a period of several years prior for this methodology to reflect meaningful results. Any results that are the product of missing or inaccurate data—which might occur—must be carefully interpreted.

This methodology for identifying locations for crashes should be complemented with the following:

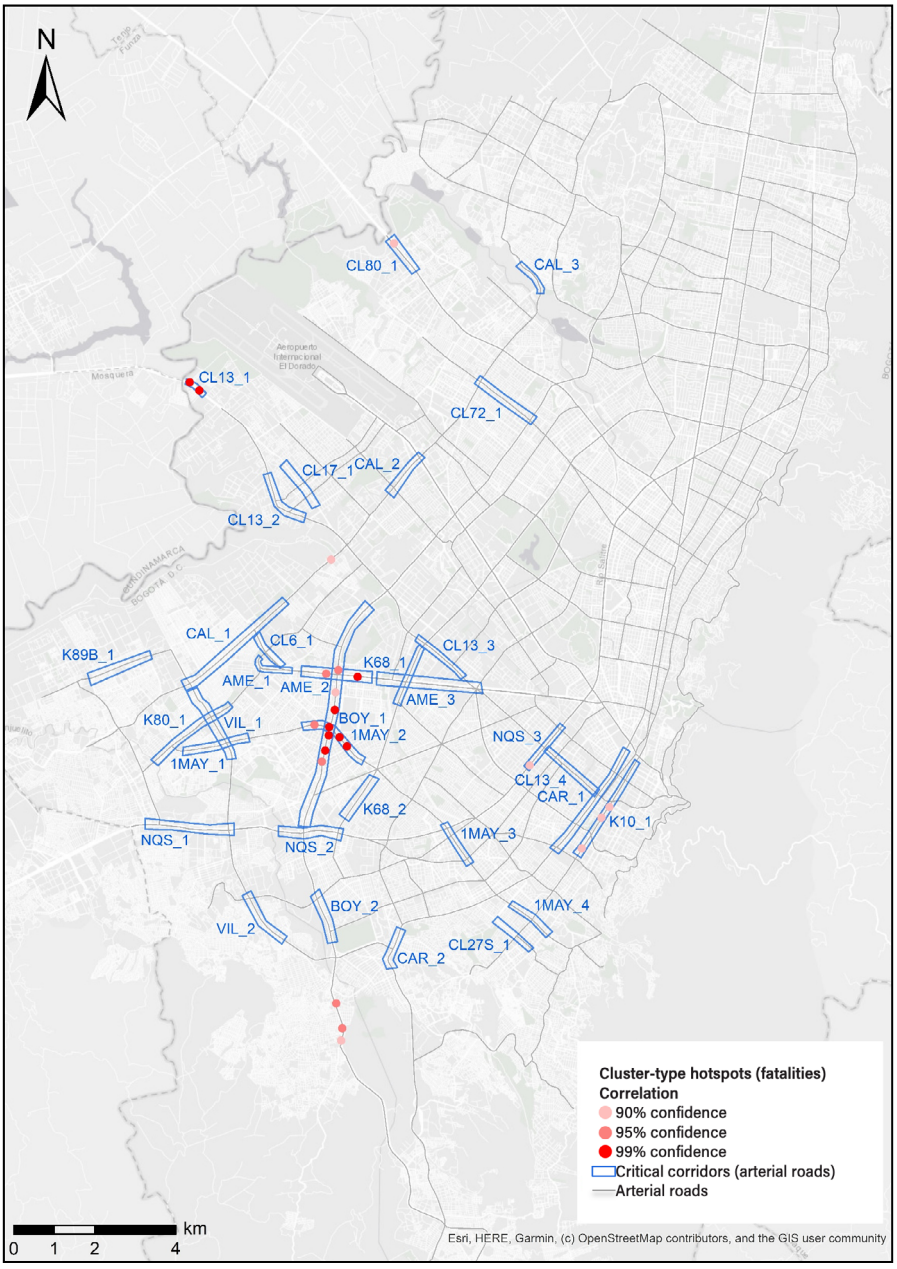
- In-depth crash analysis.
- Field inspections, which allow understanding of the dynamics, contexts, and needs of each location.
- Analysis of spot speeds and travel speeds, through speed measurement in the field, speed observations in selected corridors and areas, platforms such as Google's Distance Matrix API, or speed systems such as Traffic Now.
- Analysis of information such as land use or socioeconomic data.

We recommend that city officials review the results obtained by this methodology every three or four years or as soon as any progress is made in implementing road safety interventions in identified locations.

Appendix A. Association between fatalities of vulnerable road users

For verification purposes, Figure A-1 presents the cluster analysis alongside the critical corridors identified based on VRU incidents. The map demonstrates that most of these high-incidence locations fall within the identified critical corridors, reinforcing the need for a more comprehensive, corridor-level approach rather than focusing solely on individual hotspots.

Figure A-1 | **Locations with fatalities of VRUs and critical corridors identified**



Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

Appendix B. Comparison of geographic crash patterns between 2015 and 2018 and 2019 and 2022

Figure B-1 compares the 2015–18 and 2019–22 crash patterns and shows that despite the changes in mobility caused by the COVID-19 pandemic, the geographic patterns of crashes in the city remain the same.

Figure B-1 | **Locations with high concentrations of fatalities and injuries for 2015–2018 (left) and 2019–2022 (right)**



Source: WRI authors, based on 2024 data from the District Mobility Secretariat.

Abbreviations

BIGRS	Bloomberg Philanthropies Initiative for Global Road Safety
GIS	Geographic Information System
LMIC	Low- and Middle-Income Country
SDM	Secretaría Distrital de Movilidad (District Mobility Secretariat)
SMP	Speed Management Plan
VRU	Vulnerable Road User

Endnotes

1. Data on fatalities and injuries are from the SDM's data portal: https://datos.movilidadbogota.gov.co/search?groupIds=d3812f8315054cdc84cf744680103713.
2. Injury data have a higher participation of drivers and occupants of light vehicles and public transportation compared to fatality data. Although the participation of VRUs represents 94 percent of fatalities between 2019 and 2023 (39 percent for motorcyclists, both drivers and passengers; 39 percent for pedestrians; and 16 percent for cyclists), their participation in injuries is 72 percent (44 percent for motorcyclists, 16 percent for pedestrians, and 12 percent for cyclists). This may be due to the need for police reports to access administrative procedures, such as insurance claims. This can lead to the inclusion of a higher number of minor injuries in the data for injuries in light vehicles and public transportation.
3. See the SDM's data portal: https://datos.movilidadbogota.gov.co/search?groupIds=d3812f8315054cdc84cf744680103713.
4. Other prioritization methodologies have calculated indexes by considering additional road crash and context data (Coll et al. 2013) or statistical models with socioeconomic data (Dezman et al. 2016). An index is a numerical value that indicates—in this case—how safe or risky a location is expected to be. Probabilistic models help us make predictions based on the likelihood of different outcomes. Instead of giving a single answer, they estimate the chances of various possibilities happening, which helps us make better decisions when we are uncertain about the future. Geographically weighted regressions look at how relationships between factors (e.g., weather, traffic, or population) change depending on the location. This helps us understand how things vary from place to place, so we can make more accurate predictions or decisions for specific areas. Both are common approaches among these econometrical methods (Washington et al. 2011), but not all the cities have this information.

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