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Evaluation of road infrastructure in Yerevan, Armenia through the lens of pedestrian and child safety: a school-based analysis

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Abstract

Introduction Traffic-related injury is a leading cause of morbidity and mortality globally, especially among children. In Armenia, traffic-related mortality rates are the second highest among European Union and former Soviet countries. Currently, there are no published studies on pedestrian safety in Armenia and no notable examinations of pedestrian safety infrastructure. This manuscript describes an audit of Armenia's infrastructure using a modified Inventory for Pedestrian Safety Infrastructure (IPSI) in the Yerevan city center, focusing on areas surrounding schools.

Methods Intersections ($n = 379$) and roadways ($n = 623$) shared by pedestrians and drivers in Yerevan's center were audited using a 36-item modified ISPI and paired with cloud-based smartphone application QField between October 2023 and February 2024. Visual analysis of data was conducted using the open-source software QGIS with statistical analysis in R. Inter-rater reliability of the audit was calculated using Cohen's Kappa and intra-class correlation coefficients. Incidence of each feature surrounding schools was compared to incidence overall using a one-sample z-test for continuous variables and a two-sample test of proportions for binary variables.

Results Many of the features audited were not observed consistently across the audited area and were not more prevalent near schools. Lower inter-rater reliability was found with roadway and midblock data, resulting in analysis of primarily intersection features. Speed limits surrounding schools varied from 20 to 60 km/hr (12.5–37 mph). When compared to the overall audited area, crosswalks near schools demonstrated similar occurrence for traffic lights with crosswalk markings (23.3%, 95% CI: 0.157–0.309), speed bumps (11.9%, 95% CI: -0.139- 0.0338), and pedestrian signals (12.9%, 95% CI: 0.0709–0.194). Of the analyzed items, only bus stops were observed significantly more often near schools (19%, 95% CI: 0.00930-0.220).

Conclusions The audit revealed an inconsistent presence of safety infrastructure, with infrastructure near schools largely reflecting the overall audited area. However, analysis was limited by low inter-rater reliability for many roadway and midblock features audited. Based on these results, infrastructure changes targeting lower speed limits and increased traffic calming measures are recommended to improve safety in school zones. Given a paucity of studies in LMICs, further work must be done to identify which high-yield features should be targeted in LMICs to prevent injury.

Keywords Traffic injury, Pedestrian safety, Child safety, Safety infrastructure, QGIS, Global injury

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Introduction

Traffic-related injury accounted for 1.19 million preventable deaths and over 30 million injuries per year in 2021 [1]. Of the deaths from traffic accidents, 90% were in low- and middle- income countries (LMICs) [1]. In Armenia, a high- middle income country in the southern Caucasus, 13.6 out of 100,000 people died in 2021 from traffic-related accidents [2]. This represents the second-highest rate among all European Union and former Soviet countries. Of those traffic-related deaths, 32% were pedestrians [3]. Road injury is also the leading cause of death in school-aged children and young adults ages 10–19 years old in Armenia [3] as well as worldwide [1]. These trends of traffic injury have continued, with Armenia's Ministry of Internal Affairs reporting 333 traffic-related deaths in 2024 [4, 5], or around 11 out of every 100,000 people. In the first three months of 2025, there were 988 accidents resulting in 60 deaths [5], or around 2.1 out of every 100,000 people. However, data is not made available regarding how many of those deaths were pedestrians or the ages of those injured.

To try to address these rates of pedestrian traffic-related injury, it is first important to review what policies and infrastructure impact traffic injury. In addition to laws and enforcement, pedestrian safety is impacted by roadway infrastructure that allows both drivers and pedestrians to safely coexist [6]. While there is a lot of available evidence supporting infrastructure features that improve pedestrian safety in high income countries (HIC), there are many gaps in research when it comes to safety interventions and infrastructure in LMICs [7, 8]. A recent scoping review examined the association between certain features and vehicle-pedestrian injury (VPI) rate in LMICs [8]. While traffic signals and marked crosswalks improved pedestrian safety in high-income countries (HICs), they had no effect on VPI rate in LMICs. Rather, decreased speed limits, speed bumps, narrowing of roads, and improved pedestrian visibility were more effective at reducing VPIs. However, the quality of evidence in LMICs available for review was low, and authors of the review cited a need for higher quality evidence in LMICs to better understand which features impact pedestrian injury. Another review that specifically examined safety of child pedestrians also found that infrastructure features such as presence of sidewalks, crosswalks, traffic calming measures, lower vehicle speed, and traffic control devices improve safety in school zones [9]. They also report that there is a lack of well-maintained traffic crash data in LMICs and note that children in LMICs are more at risk due to walking to school in unsafe conditions and unsafe crossing behaviors,. This is supported by a another study in India, which employed a questionnaire of school children and identified that road user behavior was an important consideration affecting child safety [10]. Overall, while there is existing evidence that supports certain infrastructure features improving pedestrian and child safety in HICs, more high-quality evidence is needed to identify which features should be targeted for improvement in LMICs such as Armenia.

Some efforts have been made to address the rates of traffic-related injury in Armenia specifically, such as increased enforcement of traffic rules and programs to increase use of seatbelts [11]. Additionally, a project between the World Bank and the Republic of Armenia occurring between 2020 and 2022 worked to improve road quality in rural Armenia, focusing on paving "lifeline" roads and installing traffic signs while targeting accident-prone areas [12]. The program, called the Armenia Lifeline Road Network Improvement Project, also worked in villages to install road safety measures such as speed bumps, raised pedestrian crossings, and traffic signs near schools. While these measures were deemed to be acceptable based on reported satisfaction of villagers, national traffic injury rates have continued to be elevated. The success of these interventions is also difficult to track, as traffic injury rates by region are not measured or reported in a transparent or easily accessible way. Additionally, Armenia's population is most concentrated in the city of Yerevan, which was not targeted for improvement in this project as their focus was outside of the capital. Finally, those efforts did not include a survey of existing infrastructure features prior to or after implementation of their changes.

To date, no dedicated studies related to pedestrian safety in Armenia have been published, including no existing studies on infrastructure in Armenia nor examination of the causes of pedestrian injury. This study aims to be the first to evaluate the pedestrian safety infrastructure in the densely populated central district of the capital city of Yerevan, Armenia, with a particular focus on school zones where there are a high number of vulnerable road users.

There are several objective infrastructure audits available to examine environmental features in a city [13]. Of these audits, very few have been applied in an LMIC, such as the NEWS audit employed in India and in Africa [14, 15]. However, the NEWS audit focuses more on walkability of a city and not specifically pedestrian safety. Another tool, The Inventory for Pedestrian Safety Infrastructure (IPSI), is validated to evaluate street-level infrastructure features that specifically affect pedestrian safety [16]. The IPSI includes questions regarding several traffic calming measures, such as reduced speed limits, speed bumps, and crosswalks, that have been found to improve pedestrian safety. It also includes a comprehensive set of features, allowing for broad evaluation of existing infrastructure, as it is not known which specific features should be targeted for improvement. While the IPSI has not been validated in an LMIC, it serves as an effective tool for accomplishing the aims of this paper.

As a result, this study uses the IPSI, with slight modification to add features that were deemed pertinent to a Yerevan-specific audit, to evaluate infrastructure in Yerevan for the first time. Subsequent analysis of the audit results focuses specifically on infrastructure surrounding schools. After discussion of the audit's results, this paper then provides recommendations for policy and infrastructure changes in Yerevan to improve child and pedestrian safety.

Methods

Measures

Audit

This project conducted a paired in-person audit with a modified IPSI tool (Additional File 1) to audit the central region of the city of Yerevan, Armenia. Fifteen auditors were recruited through the Armenian healthcare organization BIL: Armenia. Auditors underwent online training and were provided with an electronic copy of the training guide (Additional File 2), which was adapted from the original IPSI guide to reference during the audit. Auditors were divided into pairs to conduct two independent observations of each item, each saving their data to a separate version of the project in the QField Application (project A and project B) to ensure auditors could not access the other set of data. The two datasets were used to assess inter-rater reliability of findings for validation. This manuscript uses primarily dataset A's data unless otherwise specified.

Pedestrian infrastructure scale

Two four-item scales that assess overall intersection and roadway safety infrastructure were created in the original IPSI study after exploratory factor analysis [16]. This study employed the intersection scale but not the roadway scale in its analysis due to audited roadway items having decreased inter-rater reliability during validation of the audit, as discussed below. The four intersection items in the scale are: number of marked crosswalks at intersections at the site of a walk signal, stoplight, or stop sign, number of pedestrian crossing signals, number of streets with traffic lights, and number of streets with stop lines set back from crosswalk.

QGIS

The free, open-source global information system (GIS) software QGIS (v3.28, QGIS Development Team, Boston, Massachusetts) was used along with the cloud-based smartphone application QField to conduct the audit. Auditors collected data in QField and pushed their changes to the QField Cloud, which was then accessed through QGIS. The QField application has each feature marked on a map of Yerevan as well as notes the user's current location, allowing auditors to walk around the city and record data for each individual feature as they pass it. For those auditors with poor internet connection, data was able to be collected offline and saved to the QField Cloud later when connection improved.

Study area

The downtown area, or central (*Kentron)* region, was delineated for audit purposes due to its high pedestrian and vehicular traffic and high population density (Fig. 1). QGIS algorithms identified intersections and roadways, which were manually edited for accuracy. Intersections were defined as any point where greater than one roadway intersect at which both pedestrians and vehicles cross. Midblocks were characterized as the segment between intersections. Unique identifier codes were assigned to each feature, which were then divided by geographic region among auditors, ensuring a separate auditing area for each auditor pair. Features were given different colors on the QField map, so auditors knew which features were assigned to them.

Statistical analysis

Visualizations and analysis were initially conducted in QGIS with further statistical analysis in R (v4.3.3, R Core Team, Vienna, Austria). Initial audit data was analyzed for inter-rater reliability using Cohen's Kappa (κ) [17] for categorical responses and two-way random average measure consistency intra-class correlation (ICC 2,1) coefficients for continuous responses [18] (Additional File 3). Subsequent analysis for feature prevalence focused on items that showed high (substantial or almost perfect) agreement between raters, characterized by higher ICC and κ scores after inter-rater reliability calculation [19]. Generally, intersection features were more reliably recorded between auditors. Sub-analysis examined the prevalence of pedestrian safety infrastructure in Yerevan near schools.

School zones

Locations of schools noted during the audit were cross-referenced with those reported on Open Street Map (OSM), an open-source map database [20]. This was done due to only moderate inter-rater reliability found between auditors regarding the locations of schools. OSM has been found to be accurate, especially in urban settings, for reporting precise locations of city features and has been used in other environmental surveys [21–23]. Since analysis requires accurate data on school locations, OSM was considered to be more reliable than audited school locations. Intersections and roadway/midblock data with high inter-rater reliability from those features near schools were selected in QGIS to analyze

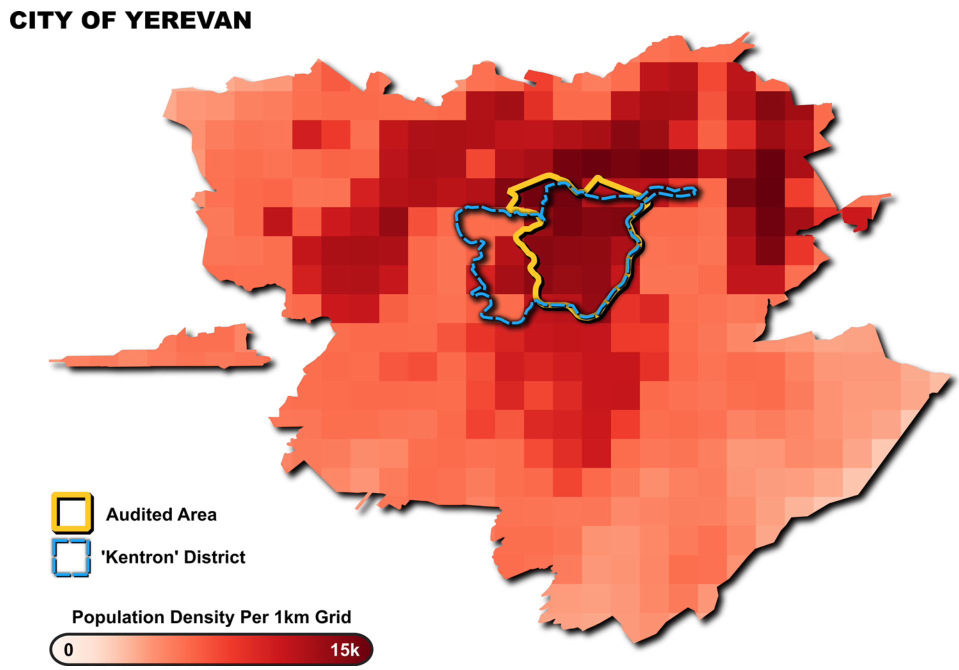

Fig. 1 Yerevan's population density as compared to audited area. Audited area highlighted in yellow, whereas official borders of Yerevan's *Kentron* are delineated in dashed blue. Darker red indicates higher population density

feature prevalence. Proximity to schools ("school zones") was defined as the two blocks and intersection adjacent to a school at an intersection or the adjacent single block and two closest intersections to a school located in the middle of a block (Fig. 2). A one-sample z-test was calculated in R to compare the prevalence of features near schools to that of the entire audited area for continuous variables. For discrete, binary (yes/no) variables, a two-sample proportion test was used.

Population density measures were taken from WorldPop [24]. The population density was then mapped onto the Yerevan shapefile and converted to a heatmap using QGIS, as shown in Fig. 1.

Results

Audit data was collected in pairs for 379 intersections and 623 midblocks/roadways. Visual representations of key features along with locations of schools are presented in Fig. 3.

Given the collected data only had moderate agreement for the location of schools, school locations were taken from OSM for analysis of the data [20], which also aided in accurate visualization (Fig. 3A). Incidence of features across audit as compared to schools are presented in Table 1 and visually in Fig. 4.

Crosswalks

When examining intersections near schools, many of the intersections had crosswalks without traffic signals (Fig. 3B). On average, only 23.3% of crosswalks in school zones were both marked and associated with a traffic light. This percentage is not significantly different from incidence across the total audited area (Figs. 3B and 4; Table 1). Additionally, only 12.9% of crosswalks also had pedestrian crossing signals (assuming a maximum of 2 signals per crosswalk), which again did not differ significantly from incidence across the entire audit. Finally, evaluation of intersections using the 4-item intersection scale also did not find significantly different scores near schools (3.44) as compared to those of the overall area (2.66, Fig. 3C). Overall, these results suggest that intersection safety features audited had the same incidence regardless of proximity to schools.

Speed limits and calming measures

Very few schools had a speed limit sign posted on the same block (10.7%), which was similar to the observed incidence of speed limit signs throughout the audit. This means that around 90% of blocks did not have any speed limit marked. Posted speed limits observed ranged from 20 to 60 km/hr. The overall average posted speed limit was 34.4 km/hr, with speed limits most often posted at 40 km/hr by schools (Fig. 3D). This average does not represent the actual speed limit on all school roads, only the average for those blocks that had a speed limit sign observed. Speed bumps were observed on 11.9% of adjacent roadways, which was not significantly different from the 10.5% incidence across all roadways audited (Fig. 3E). Overall, speed limits and speed-calming measures were not found at significantly different (higher or lower) rates

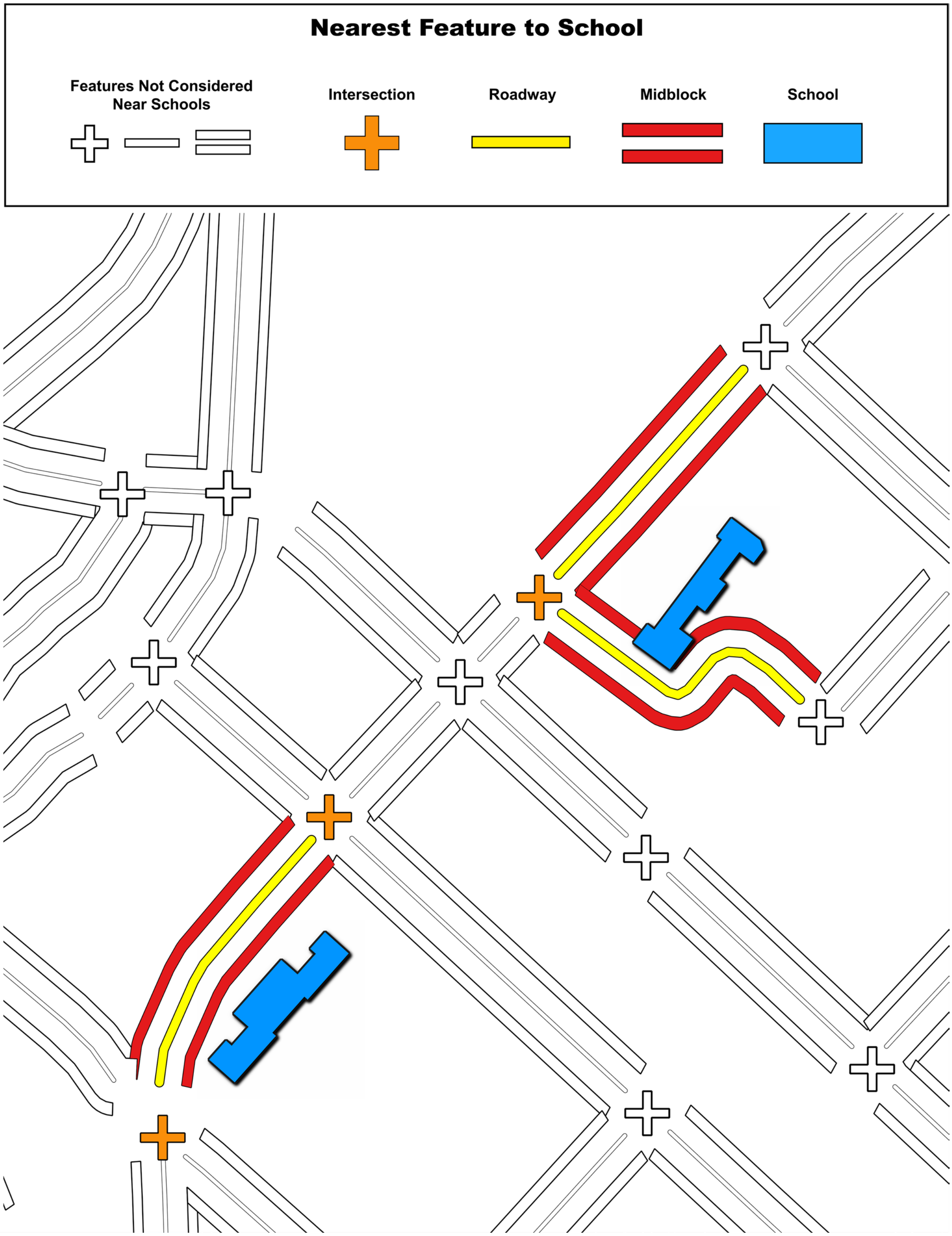

Fig. 2 Definition of school zones for analysis. Schools indicated in blue, whereas intersection, midblock, and roadway features included in "school zone" analysis are delineated in orange, red, and yellow, respectively. School on the left is provided as an example for school zones when a school was found within a block, whereas the school on the right illustrates school zones when a school is at an intersection

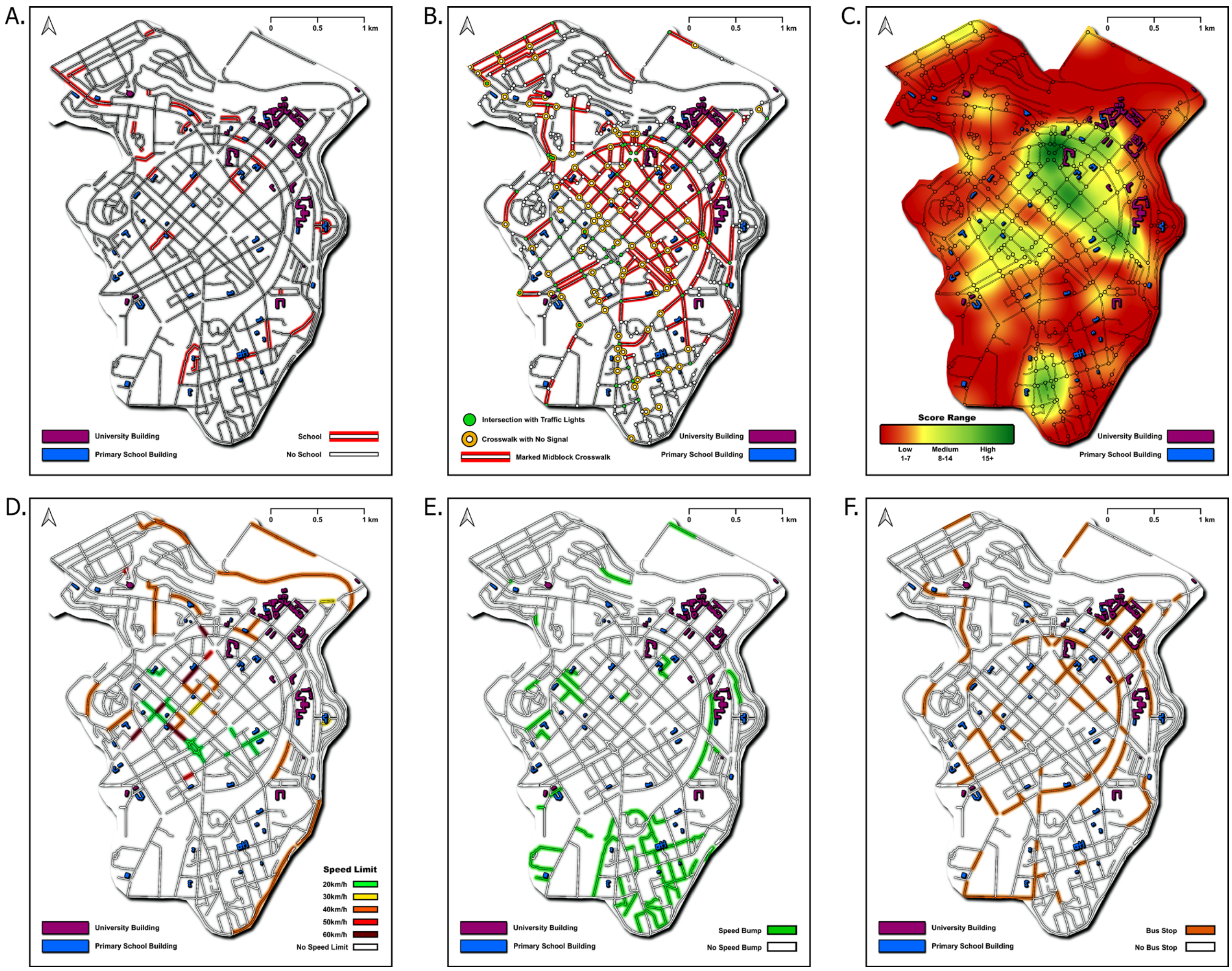

Fig. 3 Maps of observed features in audit. **A**) OSM-reported schools (blue and purple) as compared to blocks with observed schools during the audit (red). **B**) OSM schools as compared to blocks with marked crosswalks (red), intersections with traffic signals (green filled circles) and intersections with marked crosswalks without traffic signals (orange unfilled circles). Those intersections with both orange and green indicate some crossings with traffic signals and some without. **C**) 4-item intersection scale sums represented visually by score per intersection. Green correlates with higher scores and red correlates with lower scores. **D**) OSM schools as compared to posted speed limit (green for 20 km/hr, yellow for 30, orange for 40, red for 50, and dark red for 60 km/hr). The default city speed limit in Yerevan is 60 km/hr [25], meaning those streets with no posted speed limit (white) either continue the previously posted limit or have a limit of 60 km/hr [25]. **E**) OSM schools and speed bumps observed on a block (green). Green blocks do not indicate how many speed bumps, just the presence or absence (white). **F**) OSM schools compared to bus stops observed on a block (orange)

in school zones as compared to across the audited region. Finally, 19% of roadways in school zones had a bus stop, which is significantly higher than the incidence of bus stops across the entire audit (Fig. 3F).

In summary, of the analyzed features, only bus stops were found more often in school zones as compared to the overall audit. This finding has significant implications for pedestrian safety in school zones in Yerevan.

Discussion

This study aimed to assess road infrastructure in the city center of Yerevan through the lens of pedestrian and child safety. Examination of safety feature prevalence throughout the city yielded several significant findings. Notably, there was little difference between key items such as crosswalks and speed in the overall audit versus the analysis near schools. This indicates a lack of enhanced safety measures to protect school-aged children.

Some general observations from the audit should be highlighted. While there were intersections across the city with both traffic lights and marked crosswalks, most of them were near the more popular areas for tourists and pedestrians in the city of Yerevan, such as near the Opera building or near Republic Square. Speed bumps were more commonly observed in the outer areas of the audited area as compared to the center, though these areas did not have an increased prevalence of schools.

Table 1 Summary of feature incidence near schools as compared to overall audit

Feature	Incidence near schools	Incidence of overall audit	95% Confidence interval	P-value
Marked Crosswalks with Traffic Lights	23.3%	17.6%	0.157, 0.309[a]	0.14
Crosswalks with Pedestrian Crossing Signals	12.9%	10.8%	0.0709, 0.194[a]	0.43
4-Item Intersection Scale Average	3.44	2.66	2.16, 4.72[a]	2.3
Speed Limit Posted	10.7%	7.65%	-0.0815, 0.0475[b]	0.76
Speed Bumps	11.9%	10.5%	-0.139, 0.0338[b]	0.31
Bus Stops	19.0%	11.7%	0.00930, 0.220[b]	0.0069*

*Indicates statistical significance with p-value < 0.01

[a]Confidence intervals for continuous variables represent interval for population means if a sample is likely taken from that population. If the "school zone" incidence falls within the 95% CI, then it is likely not significantly different from that of the overall audit

[b]Confidence intervals for binary features (last three features in table) represent interval for estimation of difference in proportion, where an interval that includes zero indicates no significant difference between the two

Additionally, there were very few speed limit signs both surrounding schools as well as observed across the audit.

Safety features near schools

Sub-analysis of areas surrounding schools revealed that incidence of traffic lights and marked crosswalks, pedestrian crossing signals, and speed bumps was not significantly different when compared to the general audit of the city of Yerevan. This finding is significant when considering that existing literature highlights traffic infrastructure such as lights and crosswalks as well as speed-calming measures as the most pertinent features that affect traffic injury. Similarly, the four-item intersection scale yielded a low average score of 3.44 near schools which again did not differ from intersections audited overall.

Only bus stops were significantly more prevalent near schools and were observed in 19% of the adjacent blocks. Increased incidence of bus stops improves accessibility to schools for children and can increase safety because children using buses will not be traveling on foot until they arrive at school. However, children arriving at bus stops across the street or across an intersection will still require additional safety infrastructure in the area to cross the street safely. Additionally, despite buses increasing child accessibility to schools, one study found that bus stop incidence was correlated with higher crash rates [26]. One reason could be that buses tend to be taller than cars, resulting in lower visibility of smaller, shorter pedestrians such as children. While this finding is just a correlation, it could suggest that increased bus stops in school zones may not be protective for child pedestrians.

Speed reduction

While the default city speed limit in Yerevan is 60 km/hr (about 37 mph) [25], some variability with regards to residential, high pedestrian volume, and school areas would be expected. Speed limit signs were often not posted near schools, suggesting that the limit was likely the default 60 km/hr. When speed limits were posted, they were often above 30 km/hr, which is the WHO recommended maximum speed limit for areas with vulnerable populations on roads [27]. Given studies showing significant decrease in crash incidence and mortality with decreasing speeds [28], legislation and interventions focused on speed control and calming around school zones could yield substantial improvement in pedestrian-related morbidity and mortality.

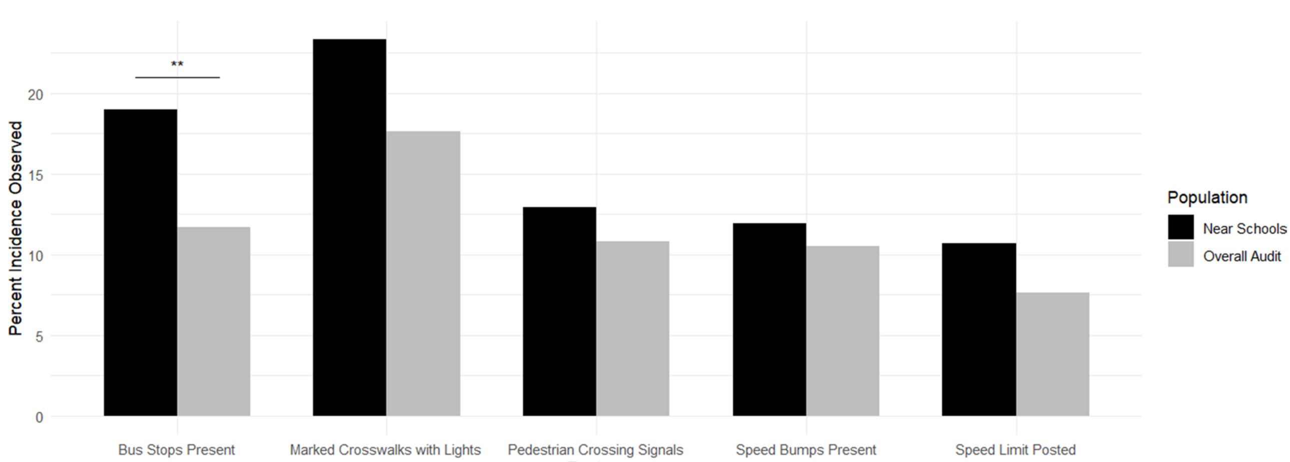

Fig. 4 Comparison of observed feature incidence of overall audit and incidence near schools. Significance level of $p < 0.01$ indicated as **

Future applications and policy recommendations

This study's use of a formal auditing tool to evaluate safety infrastructure in Yerevan provides valuable data which can be used to inform future changes in infrastructure and help improve urban planning in Yerevan as more residential areas are developed. With improvements in infrastructure, future work can identify decreases in traffic-related injury in areas where the improvements occurred. The use of a smartphone application and cloud-based data collection software provides a dynamic platform that will facilitate both updates to infrastructure data as changes are made and the addition of any other features that were not initially audited. Finally, the use of the IPSI in Armenia with validated results provides a model for its use in other LMICs, offering a low-cost method of surveying to target interventions.

Based on a review of existing literature and the results of this study, there are several policy and infrastructure recommendations that can be made to improve Yerevan's pedestrian and child safety. Though more high-quality evidence is needed, existing studies suggest that reduced speed limits, crosswalks, traffic lights, speed bumps, sidewalks, and increased pedestrian visibility are protective against pedestrian traffic injury in LMICs. Reducing the speed limit in all school zones to 30 km/hr, in accordance with the WHO recommendation, can be one initial step to improve pedestrian safety near schools. Installing additional speed calming measures such as speed bumps can further help reduce speeds, as this study's results suggest a lack of speed bumps in school zones. Additionally, all school zones should have crosswalks, traffic lights (including pedestrian crossing lights), and signs indicating pedestrian crossings. In addition to increasing appropriate safety infrastructure, increased enforcement is needed, as lack of enforcement is one barrier LMICs often have to effective interventions [7]. Having accurate and available reporting of statistics regarding traffic injury rates, rates of which populations are injured (such as pedestrians, school children, etc.), and where those traffic injuries are taking place will aid in evaluation of where to target for intervention. Finally, pedestrian education, though not surveyed in this study, is also required to decrease risky pedestrian behaviors and ensure traffic infrastructure compliance to prevent injury.

Limitations

Many of the limitations of the IPSI tool itself were detailed in the original study [16]. In terms of this study's limitations, this analysis was limited to mainly intersection features due to decreased reliability found between auditors for non-intersection features. As a result, detailed analysis of roadway and midblock features audited was not conducted. Future work should address those additional features, especially if they are identified as high-yield to be targeted to improve safety. Additionally, due to only moderate reliability between auditors on school locations, the authors of this paper opted to instead use OSM-reported schools for more accurate analysis. While there is precedent for using OSM data in environmental audits, using open-source data potentially confounds findings, as the school locations may not be accurate and the methodology used for gathering this data is not controlled for. Finally, some data collection was limited by temporary infrastructure changes such as roads closed, construction, and blocked pedestrian access which would not reflect permanent infrastructure in that area.

Conclusions

This study is the first to audit the infrastructure of Yerevan and applies the IPSI tool in an LMIC for the first time. The IPSI audit of Yerevan revealed inconsistent incidence of safety infrastructure, with infrastructure near schools largely reflecting that of the entire audited area and not reflective of the established need for enhanced safety measures surrounding vulnerable populations. This study's novel use of cloud-based data collection and analysis using a GIS platform allows for initial evaluation and iterative improvement of infrastructure. Based on the results of this study, decreases in speed limits, increases in traffic calming measures such as speed bumps, and increased traffic infrastructure such as traffic lights and crosswalks are recommended for implementation around Yerevan's school zones. Finally, this study also serves as a model for other LMICs to adopt similar audit strategies to address child pedestrian safety. Future work must be done globally to further identify which high-yield features should be targeted for improvement to prevent pedestrian and child traffic-related injury in resource limited settings often encountered in LMICS. Coupled with legislation and enforcement, this provides an additional tool to address a critical public health issue that is expected to worsen with increasing urbanization worldwide.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Author contributions

ET and SC conceived, planned, and executed the study. HM created and oversaw the entire QGIS component, including creating the audit shapefiles, creating the QGIS visualizations, and converting data to .CSV for statistical analysis. JJ oversaw auditor recruitment, organization, and communication. ET, HM, and JJ oversaw data acquisition. ET, HM, and AG conducted the statistical analysis. ET wrote the manuscript with support from HM and SC. ET, HM, SC, AG, and JJ made critical edits and reviewed the final manuscript.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. Map data copyrighted OpenStreetMap contributors and available from https://www.openstreetmap.org.

Declarations

Ethics and consent to participate

Not applicable.

Consent to publish

Not applicable.

Competing interests

The authors declare no competing interests.

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