SPATIOTEMPORAL ANALYSIS OF ROAD TRAFFIC CRASHES TO MINIMIZE RESPONSE TIME IN LUDHIANA CITY, PUNJAB

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Dissertation submitted in partial fulfilment of the requirements for the award of the degree of Master of Public Health

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“Every life lost on the road is one too many”

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DECLARATION

I hereby declare that this dissertation titled "**Spatiotemporal Analysis of Road Traffic Crashes to minimize response time in Ludhiana City, Punjab**" is the bona fide record of my original research. It has not been submitted to any other university or institution for the award of any degree or diploma. Information derivedfrom the published or unpublished work of others has been duly acknowledged in thetext.

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June 2024

CERTIFICATE

Certified that the dissertation titled "**Spatiotemporal Analysis of Road Traffic Crashes to minimize response time in Ludhiana City, Punjab**" is a record of the research work undertaken by Dr Ishika Arora in partial fulfilment of the requirements for the award of the degree of "Master of Public Health" under my guidance and supervision.

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GLOSSARY OF ABBREVIATIONS

FIR	First Information Report
GIS	Geographic Information System
HMW	Heavy Motor Vehicle
LMV	Light Motor Vehicle
MDR	Major District Road
MTW	Motorized Two-Wheeler
NATPAC	National Transport Planning and Research Centre
NH	National Highway
NKDE	Network Kernel Density Estimation
ODR	Other District Road
OSM	Open Street Map
OSRM	Open-Source Routing Machine
PHSC	Punjab Heath System Corporation
PRSC	Punjab Remote Sensing Centre
PRSTRC	Punjab Road Safety and Traffic Research Centre
RTC	Road Traffic Crash
RTI	Road Traffic Injuries
SH	State Highway
SHA	State Health Agency
WHO	World Health Organization

ABSTRACT

Background: Road traffic crashes are the 8th leading cause of death globally. Understanding the region-specific epidemiological risk factors is imperative for evidence-informed prevention and control strategies. The present study was conducted in Ludhiana City, Punjab to estimate crash patterns, identify hotspots, and determine potential risk factors for road traffic.

Methodology: Secondary data from the Punjab Road Safety and Traffic Research Centre (PRSTRC) for 2020-2022 was obtained and road network data from Punjab Remote Sensing Centre (PRSC) and Open Street Map (OSM) were used. Primary data was collected through a structured observational checklist, and descriptive, inferential, and geospatial analyses were performed. Quantitative and empirical observation data was summarized using percentages, and associations were tested for significance using the Chi-square test. Geospatial analysis included visualizations using choropleth maps, Network Kernel Density Estimation (NKDE) for hotspot analysis and network analysis for distance and time estimations.

Results: A total of 1,310 reports were analysed; two-wheeler riders (51.2%), along with pedestrians and cyclists (34.8%), were the worst affected victims, and peak crash times were around 8am and 8pm. Weekends recorded more crashes than weekdays. On most occasions (57.9%), the colliding vehicles were four-wheelers or heavy motor vehicles such as trucks. Geospatial analysis revealed clustering of crashes near junctions, national highways and roads with poor pedestrian infrastructure and lighting. The analysis revealed significant variations in travel times within the city, from 6.5 to 40.8 minutes.

Conclusion: Geospatial analysis helps to identify crash-prone locations in the city. Combined analysis of routine traffic data with road network helps in value addition and delineation of travel times for crash casualty management.

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Background

Roads are the arteries through which the economy pulses. They connect producers to markets, workers to jobs, students to schools, and the sick to hospitals. Not only that, but the network of highways is also an indicator of a country's progress, providing enormous social and logistical benefits. As these roads, highways, and railways carry commuters to facilitate them achieve the daily needs and aims of life, the traffic crashes can be understood as ruptures in that social body, the ever-going expansion of the road networks has resulted in innumerable road crashes (Berg et al., 2015). Therefore , this very connectivity brings its own challenges as roads also have traffic and traffic crashes can be understood influx of discontinuities or a punctuated transit (Solomon, 2022).

This interrupted traffic breeds what we call a road traffic “incident,” “accident,” “collision,” or a “crash.” We will be using the term Road traffic collisions/crashes which can be defined as “the product of an unwelcome interaction between two or more moving objects, or a fixed and a moving object”(Whitelegg, 1987),(Loo and Anderson, 2015).

Road traffic crashes may be a common occurrence, but they are both predictable and preventable. These crashes not only result in a significant loss of life but also pose a substantial economic burden on nations. The situation is particularly alarming in one of the world's fastest-growing economies, India. Road traffic fatalities have been on the rise. It has been reported that in India alone crashes take away and disable more than 900,000 lives and cost the country an estimated $156 billion annually, making it

the deadliest place for road users (*Traffic Crash Injuries and Disabilities : The Burden on Indian Society*, 2021)

Furthermore, there is a significant issue with under-reporting of traffic crashes, with studies suggesting that deaths are under-reported by 5% and serious injuries by more than 40% in India (Tiwari et al., 2022).

The relationship between medical research and geography has ancient roots, dating back to Hippocrates, who first described the connection between geographical features and public health in his treatise "On Air, Water and Places" (Littré, 1840). Nowadays, the use of mapping and geographic information has grown, proving invaluable not only for research but also for comprehending disease processes and predicting health burden. But it started in 1854, when English physician John Snow's study on cholera on a map, successfully identified contaminated water as the epidemic's source, and eventually helped contain the pandemic; One thing becomes clear - that as public health professionals , we cannot always look for answers in medicine, looking for solutions to problems needs innovation and to be innovative , there is a need-to-know certain skills. This study aims to address this critical issue by using Geographic Information Systems (GIS) technology as a powerful tool to better understand, prevent, and mitigate road traffic crashes. The study will outline the significance of GIS in tackling the road traffic crash epidemic, the objectives and methodology of the proposed research, and the expected outcomes that can contribute to a substantial reduction in road traffic crashes and their associated consequences.

1.2 Review of literature

1.2.1 Purpose of literature review

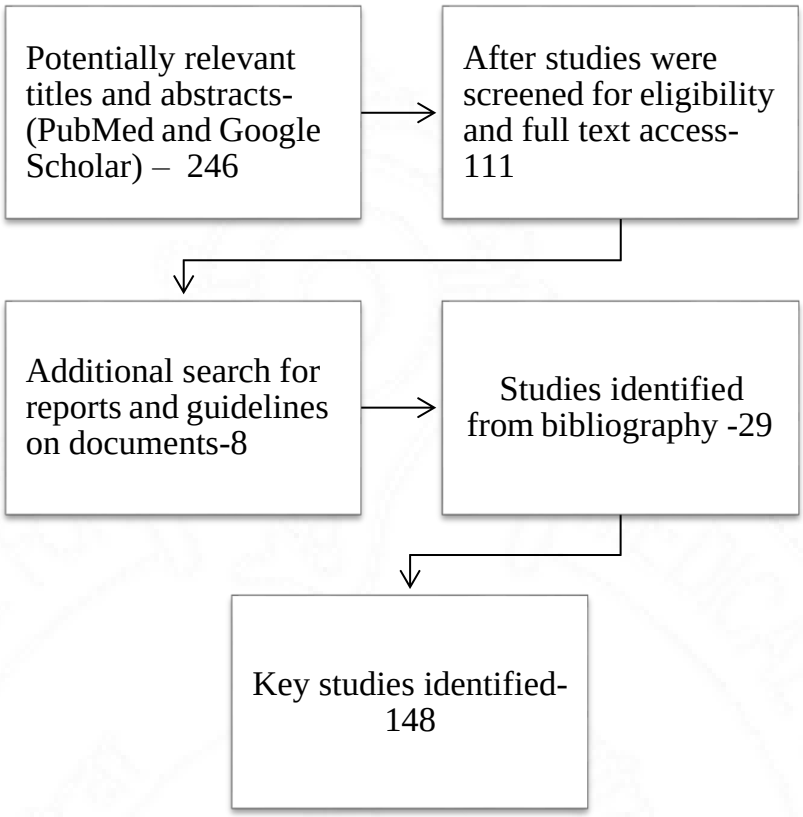
This literature review aims to identify relevant publications in peer reviewed journals, reports and books that shows detailed exploration of associated theories, concepts, and

approaches aimed to address the occurrence of road traffic crashes. Special attention was given to the concept of geographical spatial analysis, emphasizing its capacity to incorporate spatial variation, distribution, temporal considerations, and demographic composition related to road traffic crashes. The review also proposes to identify any gaps in the available knowledge.

1.2.2 Literature review process

A literature search on PubMed and Google Scholar was done for last 23 years (1.10.2000 to 01.01.2024) using key words key words “road traffic injuries” , “road traffic accident” , “road traffic crashes” , “road safety” and “geographic information system” , “geospatial analysis” and “emergency medical services” were reviewed. Additionally, the bibliography section of each article was looked at to recognize studies that could have beenleft out during database search. The flowchart of literature review process is shown in figure1.1.

Figure 1.1 Literature review process



1.3 Road Traffic Crash Epidemic

1.3.1 Understanding scope : Globally

Road traffic crashes are globally the biggest cause of death among children and young adults, and the 8th leading cause of death among all age groups accounting for around 1.3 million avoidable deaths and 50 million injuries annually. It has been predicted to become the 7th leading cause of death by 2030. If this trend continues, road crashes can hamper sustainable growth especially in low- and middle-income nations, and result in an additional 13 million fatalities and 500 million injuries over the course of the next ten years (*Global status report on road safety 2018*, 2018).

Vulnerable road users (VRUs) like pedestrians, cyclists, and motorcyclists face particularly high risks, accounting for more than half of all deaths on roads. Road traffic crashes (RTCs) in all take a toll on humans by causing loss , serious injuries

and disturbing mental health of affected families. It also imposes considerable financial burden on healthcare system.(Balakrishnan and Karuppanagounder, 2020; Sajith Kumar et al., 2023).

LMICs bear economic burden of crashes as these preventable incidents cost around 3% of their GDP on an average. All these factors emphasizes the urgent need for comprehensive measures to prevent and mitigate the incidence of road crashes(*Global status report on road safety 2018*, 2018),(Chen et al., 2019).

1.3.2 Regional and Local Crash Dynamics

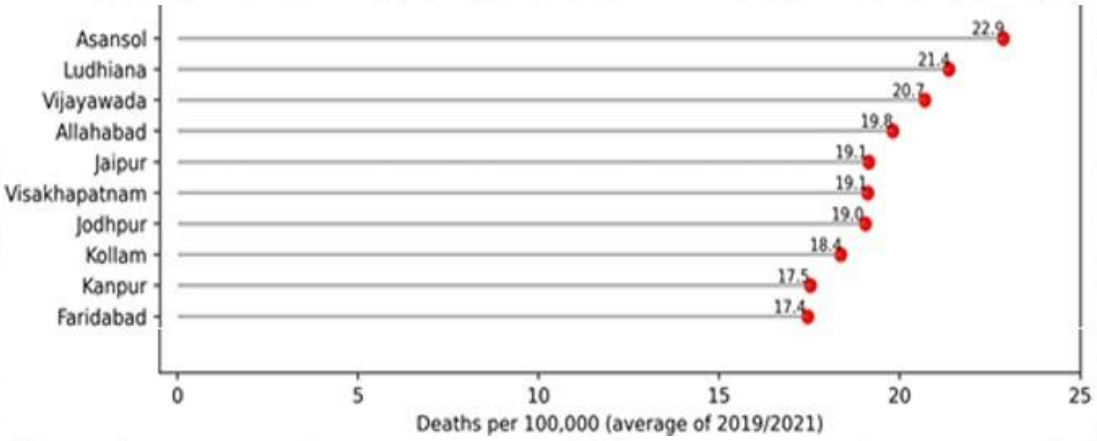
The Ministry of Road Transport and Highways (MoRTH) released official statistics revealing that 153,972 people lost their lives in traffic crashes in 2021 which is about 11.3 fatalities per 100,000 people. RTCs are the 13th leading contributor to the health burden in India. A Global Burden of Diseases, Injuries, and Risk Factors Study,reports 159,343 fatalities (95% confidence interval: 159,343 – 250,315) in India in 2019. This indicates underreporting as this estimate exceeds the number of deaths stated by the government by 40%(Tiwari et al., 2023),(Global Burden of Disease Study 2019 (GBD 2019), 2020).

The severity of traffic crashes, is determined by the number of fatalities per 100 incidents was recorded to be 36.5 nationally in 2022. A further look at the state-wise distribution of crashes revealed that Mizoram (85) had the greatest crash severity followed by Bihar (82.4) and Punjab (77.5) (Road accidents in India - 2022, 2022). Even though the total number of crashes is not as high as Tamil Nadu (14%) which reported the highest number of crashes in 2022, higher fatality is still concerning. About 65-75% of Punjab's total traffic deaths during the past five years (2017-21) have happened on the 5.6% of the states road network, which consists of National and

State Highways(Report on Punjab Road Accidents and Traffic-2021, 2022; Road accidents in India - 2022, 2022).

Looking at urban scenario , a two-year average fatality was recorded for 53 cities with a population of 1 million or more . With an average mortality rate of 21 per 100,000, or nearly twice the national average, Asansol, Ludhiana, Allahabad, Vijayawada, and Jaipur were the five cities with the highest death rates. Ludhiana ranked the second with an average of 21.4 per 100,000 (fig1.2).

Figure 1.2 Two-year average fatality rate per 100,000 population



1.3.3 Beyond the Driver: A Multifaceted Look at Road crash Risk Factors

Traffic crashes are a complex phenomenon where there is not a single factor but a horde of factors are responsible. The traditional understanding of crash causation is supported by the perception that the driver or other road user error was the cause of most crashes and was therefore the major issue that is needed to be addressed. While it is true that road user error is a contributing factor to many crashes, literature challenges this statement; Blaming the driver/rider (human behaviour) and the associated notion that human behaviour can easily be altered (Road safety manual : A manual for practitioners and decision makers on implementing safe system infrastructure !, 2024)

While driver behaviour often takes centre stage (speeding, intoxication, distraction)(Imamaliev et al., 2021), a closer look at the literature reveals a broader range of risk elements that demand attention.

Here's a breakdown of key risk factors beyond the driver:

1. **Road Design:** The very structure of the road can significantly influence crash risk. Poorly designed curves, inadequate sightlines, and sharp inclines can all create hidden hazards that lead to driver confusion and misjudgement, in fact (Garnaik et al., 2023; Suraji and Mulyono, 2022) noted a positive correlation between geometric elements and accident rates meaning deviations from established road design guidelines are particularly concerning, as they introduce unseen dangers into the driving experience and the accident risk increases linearly.
2. **Infrastructure and Development:** The broader infrastructure surrounding the road is another factor. Poorly designed intersections, inadequate lighting in low-visibility areas, road surface (low friction), low curve radius, the presence of guardrails, number of lanes, absence of paved shoulders, narrow shoulders, different junction types and a lack of pedestrian crossings can all contribute can affect the severity of both single-vehicle and multi-vehicle crashes(Garnaik et al., 2023; Papadimitriou et al., 2019; Rúa et al., 2022) . Additionally, the level of motorization in a region and the overall state of the road network plays a role in accident rates (Cadar et al., 2021).
3. **Environmental Conditions:** Weather conditions like rain, fog or low visibility can significantly hinder a driver's ability to see and react to hazards (Jeuris et al., 2023).Uneven Road surfaces or debris left on the road can also create unexpected challenges for drivers as they reduce how well tires grip the road, making it harder to control the vehicle(Rajczyk et al., 2018).

4. **Vehicle Factors:** The type and condition of the vehicle can also plays a role – Heavy motor vehicles (HMVs) are more prone to causing accidents (Benallou et al., 2023). (Török, 2020) states that the age of a vehicle has an emphatic role in the occurrence of crashes, suggesting that older vehicles may have lower safety performance as they might lack essential safety features like airbags or anti-lock brakes, while poorly maintained vehicles could experience mechanical failures that contribute to crashes.
5. **Human Characteristics:** Factors beyond deliberate behaviour come into play. Neuro-cognitive disorders like ADHD, learning disabilities, and age-related cognitive decline can all impact a driver's ability to react safely on the road (P. Ulzen, 2020). Fatigue is another major concern, as it impairs judgment and slows reaction times, increasing crash risk (Mabry et al., 2022; Roy, 2022).

1.4 Rethinking Road Safety Management

Traditional strategies for preventing RTCs have always placed a strong emphasis on modifying human behaviour and minimizing human error probably because they are thought as incidents caused by human faults. However, this is starting to change as everyone is realizing the seriousness and extent of the problem at hand (Gopalakrishnan, 2012),(Jha et al., 2004). As (Safarpour et al., 2020) pointed out, the fundamental ideas guiding the public health approach to road safety have evolved in an intriguing way.

Safety approaches have evolved over the years , today there is more emphasis on identifying hidden factors than assigning blame, safety interventions now are implemented for entire population rather than individuals(Elvik et al., 2009; Jha et al., 2004; Khorasani-Zavareh, 2011). The approaches are now based on data and

research instead of guesswork. Data analysis has lend a hand in identifying patterns, risk factors and evaluation (Imamaliev et al., 2021; Mabry et al., 2022; Papadimitriou et al., 2019).

A scoping review by (Safarpour et al., 2020) described common safety approaches around the world which helped look at the evolution of frameworks over time.

Road safety and strategies can be classified in three themes: traditional approach, systemic approach, and vision zero(Khorasani-Zavareh, 2011).

1.4.1 Road Safety Frameworks

Traditional Approach: Focuses on modifying human behaviour and minimizing human error through education, advertising etc, as the basic principle believes that road crashes are caused by human error and road crashes are inevitable. This approach is further divided into road user appoach and causal approach wherein the former focuses on changing human behavior through monitoring , regulations and training while the latter tries to identify factors to inform prevention strategies.

Systemic Approach: This approach recognizes road safety as a multifaceted issue influenced by factors beyond the user such as infrastructure , vehicle safety, post crash care , regulations etc.

Dr. William Haddon was the first to propose a holistic approach to road crashes prevention using the Haddon matrix.

Haddon's matrix: This matrix integrates various factors such as human factors, environment, and causative agents interacting pre-crash, crash, and post-crash. The matrix's ability to separate crashes into pre-, crash, and post-crash stages makes it a great tool to conduct in-depth crash analysis (HADDON, 1972). It makes it easier to assess the different elements that are involved in each step and classifies them into

three categories: environment, vehicle and equipment, and human (Rustagi et al., 2018). Carol added onto the Haddon's matrix stating that in order to make decisions and implement successful interventions, the value criteria for every given intervention, including its cost, efficacy, freedom, equity, and other recognized criteria, must be measured (Runyan, 2015).

There are various subthemes under the systemic approach such as sustainable safety approach which originated from Netherlands and focused on safer road design and user awareness; And the Vision zero approach from Sweden whose philosophy emphasizes on the inherent value of human life and aims for no fatalities or serious injuries in the road system (Kristianssen et al., 2018). It is noteworthy to mention about the Safe systems approach .

Safe systems approach: Originating in Sweden and the Netherlands in the mid-1990s, the safe system method was later applied in Australia between 1999 and 2002. With this approach, road traffic injuries are no longer seen as logical, but rather as events including intrinsic dangers. This represents a substantial shift in the way road safety is seen. This approach acknowledges the inherent risks of road crashes and focuses on designing systems that are safe despite human errors (International Transport Forum, 2016).

A safe system is based on four key principles: the possibility of human error causing injuries from traffic crahes, the body's limited capacity to endure force from crashes, people's shared accountability for preventing injuries from traffic crashes, and interconnection of these principles(Ederer et al., 2023; Road safety manual : A manual for practitioners and decision makers on implementing safe system infrastructure !, 2024).

The safe system approach emphasizes key elements such as safe roads, safe vehicles,

safe speeds, and safe road users, with the addition of a post-crash response pillar introduced by the UN in 2010. A growing number of nations have already implemented and are implementing this approach, which serves as the foundation for the UN Decade of Action for Road Safety (Second Decade of Action for road safety, 2021), figure 1.3.

Figure 1.3 Safe Systems Approach

1.5 GIS : A powerful tool for crash analysis

Geographic Information Systems (GIS) is a computer tool employed for the storage, visualization, analysis, and interpretation of geographic information. Geographic data, also known as spatial or geospatial data, serves to pinpoint the geographic coordinates of various features. The core of a GIS system is a spatial database that makes it easier to store and retrieve information defining the lines, points, and borders

of the spatial entities under study (Gimond, 2023).

In a road crash , identifying high-risk areas can prove to be extremely useful in addressing the concerning trends. To put clearly, crashes in a location don't happen at random and Tobler's first law of geography can be applied here: "Everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). The reasons for that can be plenty as described in the previous section. Crashes tend to be clustered at specific sites, the locations of areas with greater concentrations of traffic collisions are of interest to engineers, public policy makers, and road crash investigators. Also known as "Hazardous Road Location (HRL)" is a region where the average number of traffic crashes is higher than it is. This higher-than-average "cluster" is referred to by several different names in the literature and studies. "Black spot," "hazardous road locations," and "hotspot" (Le et al., 2020; Loo and Anderson, 2015)

Hotspot analysis was initially used by (Chainey et al., 2008) for crime analysis and the concept came from (Chakravorty et al., 1995) but there are various ways to identify hotspots for crashes today.

(Amiri et al., 2021) categorised mapping techniques into three categries: spatial analysis methods, interpolation methods, and mapping cluster methods.

Spatial analysis involves examining connections within spatial data , it includes kernel density estimation (KDE), point density estimation (PDE), and line density estimation (LDE).

The second category, interpolation, entails estimating surface values at unknown points based on known values from surrounding points. Inverse distance weighting (IDW), Kriging, spline, and natural neighbor interpolation are well-known techniques in this category.

The third category of hotspot mapping, mapping clusters, refers to the degree of concentration of spatial features and associated data values. Average nearest neighbor, Getis-Ord (Gi*), and Moran's I are among the most widely recognized mapping cluster techniques (Chainey et al., 2008).

Out of these, Kernel Density Estimation is a common method of hotspot estimation on road networks (Kazmi et al., 2022a; Le et al., 2020; Loo and Anderson, 2015; Xie and Yan, 2013). Some studies have been summarised below in table 1.1:

Table 1.1 KDE for Hotspot analysis: Studies from around the world

Author and Year	**Study setting**	**Methods used**	**Major findings**
(Sandhu et al., 2016)	Gurgaon-Jaipur Highway, India	The Methodology adopted to analyses the accident data collected from 2010 to 2012 collected from NHAI. In this study, GIS Software is used to map, visualize, and examine the accident data. Further, Kernel Density Estimation method, Moran's I statics and Get-Ord Gi* Statics are used for critical analysis.	The analysis of crash data using spatial autocorrelation and clustering techniques can provide insights into the patterns and hotspots.
(Xie and Yan, 2008, 2013)	Bowling Green, Kentucky area.	Papers proposed that new network KDE is more appropriate than standard planar KDE for density estimation of traffic crashes, since the latter covers space beyond the event context (network space) and is likely to overestimate the density values.	The network space is represented using linear units of equal network length called "*lixels"*, which allows for systematic selection of regularly spaced locations along the network for density estimation
(Le et al.,	Hanoi,	GIS-based statistical analytic	The comap method was

2020)	Vietnam	techniques to investigate the influence of accident Severity Index (SI) on temporal-spatial patterns of accident hotspots related to the specific time intervals of day and seasons in Hanoi, Vietnam showed that both analyses determined the relatively similar hotspots, but the rankings of some hotspots were quite different due to the integration of SI (severity index)	utilized to analyse the intensity and spatial distributions of RTCs in Hanoi. The three-year RTC data were divided into specific time intervals of a day and seasons of a year, and the Kernel Density Estimation (KDE) method was applied to compute and analyse the intensity of each subset.

1.6 Timing Matters: Estimating Travel Time for Emergency Response

The major concern following a road crash is reaching the hospital as minutes can mean the difference between life and death when it comes to post-crash care and survival. Therefore, suitable, integrated, and coordinated treatment needs to be given as soon as possible. For this, there is need for a comprehensive care system for injury prevention, pre-hospital and acute hospital treatment but the systems are still underdeveloped in India (Kobusingye et al., 2006; Pal et al., 2019). Enhancement of post-crash care requires prompt post crash acess in such a situation. Through UN General Assembly Resolution 74/299 — a Second Decade of Action for Road Safety 2021–2030 with the explicit target to reduce road deaths and injuries by at least 50% during that period. The global plan is structured around the five "Safe Systems" pillars and post-crash access is one of them. (Second Decade of Action for road safety, 2021).

There are two approaches to post-crash care globally , one is “scoop and run” while

the other is to “stay and stablize”, but scoop and run is better in a country like ours where the infrastructure is still developing (Ahuja et al., 2019). Therfore reducing time to hospital is an important strategy for improving outcomes.

We now know that that the impact of road crash data is spatial, so GIS may be used effectively and efficiently to regulate and prevent road crashes (Baskar and Ramesh, 2010; Haynes et al., 2006; Mohammadi et al., 2021). Travel time estimation can help improve heathcare accessibility. A study by (Fu et al., 2023) compared six approches namely- Google Maps API, Bing Maps API, Esri Routing Web Service, ArcGIS Pro Desktop, OpenStreetMap NetworkX (OSMnx), and Open Source Routing Machine (OSRM) to estimating travel time using geospatial data in United states and concluded OSRM offers a low-cost, accurate, and effective approach for computing journey time from geospatial big data. Studies recommend that when transport times are higher than 60 minutes, patients would benefit from visiting the nearest hospital, but when it is less than 30 minutes, it is good to bypass smaller hospitals and visit the tertiary care institution (Harrington et al., 2005).

1.7 Rationale/ Justification of the study

Road traffic crashes present a substantial risk to public safety and welfare on a global scale. Despite efforts to tackle this issue, precise data collection and analysis remain a hurdle, resulting in an underestimation of reported crashes and injuries. Geographic Information Systems (GIS) offers as a tool to analyse spatial data and pinpointing crucial areas for intervention. This explanation emphasizes the importance of performing a research study on road traffic crashes using GIS and the possible impact on improving road safety and public health.

1. Addressing Data Limitations:

The reports available from the National Crime Records Bureau (NCRB) and the

Ministry of Road Transport and Highways (MoRTH) frequently lack precise statistical breakdowns of road collisions, particularly concerning the categories which involve vulnerable road users . This underreporting leads to a biased comprehension of the issue and obstructs the formulation of effective interventions. Through the utilization of GIS, this investigation aims to bypass these data constraints and offer a more nuanced insight into road traffic crashes, encompassing the categories of road users impacted and the spatial distribution of collisions.

2. Localized Analysis for Targeted Interventions:

Undertaking the study within a limited region or a condensed timeframe enables more precise data gathering and analysis, leading to insights that are pertinent and actionable at the local level. By concentrating on specific regions or time spans, it is possible to pinpoint challenges and prospects for intervention, and tailoring strategies to cater requirements of the community.

3. Integrating Spatial Accessibility and Healthcare Provision:

Recent development in GIS has facilitated the integration of spatial accessibility and potential problem clusters , presenting a comprehensive framework for scrutinizing the interplay between demand (here , population affected by road crashes) and supply (here , healthcare facilities). can identify areas with limited access to medical care and prioritize efforts to improve emergency response and medical facilities. This comprehensive approach ensures that interventions target not only the occurrence of crashes, but also the effectiveness of emergency response and healthcare delivery.

4. Gaps in Research:

There are many studies on hotspot identification and travel time approximation, but there is dearth of studies that amalgamate these methodologies to estimate travel time

to hospitals from crash hotspots. This study fills this void by offering an exhaustive analysis of road traffic crashes, encompassing hotspot identification, travel time approximation, and spatial accessibility to healthcare facilities. Through the amalgamation of these elements, the study presents a fresh outlook on road safety and furnishes valuable insights for both researchers and policymakers.

Conclusion:

In conclusion, conducting a research study on road traffic crashes using GIS is imperative for addressing the limitations of current data, pinpointing localized challenges, and enhancing the efficacy of interventions. By harnessing GIS and integrating spatial accessibility, this study has the potential to inform ways to diminish road traffic crashes and enhance the overall welfare of the community.

1.8 Objectives

Primary objectives:

1. To explore the geospatial pattern of Road Traffic Crashes (RTC) in the Ludhiana city using secondary data.
2. To study the predisposing factors of the location of crashes through primary data collection.

Secondary objectives:

1. To spatially map the facilities that provide emergency care services for Crash victims in Ludhiana CP.
2. Estimate the average time duration required to transfer a victim from the accident hot spot to the nearest healthcare facility offering emergency trauma care services.

CHAPTER - 2

METHODS

2.1 Study Design

It is a descriptive analytical study, using primary and secondary data. The secondary data were extracted from Punjab Road Safety and Traffic Research Centre (PRSTRC) , using data extraction template and primary data were collected by observation check list after visiting the selected traffic locations (from selected hotspots and matched cold-spots). Information on all reported traffic crashes were extracted from PRSTRC for the period, January 2020 to December 2022. Age and sex of the victims were not present in the source data, so they were extracted for a subset of records from the respective First Information Reports (FIRs) which are available in the public domain.

2.2 Study setting

The study was conducted in Ludhiana city which is part of Ludhiana district in the state of Punjab. Ludhiana district, located in the Malwa region of Punjab, is the most centrally situated district in the area. Within the district, Ludhiana city lies at 30^{o}-34' & 31^{o}-01' North and 75^{o}-18' & 76^{o}-20' east latitude. To the north, district is separated from Jalandhar city by the Sutlej River, and it shares its borders with the districts of Rupnagar, Moga, Sangrur, and Patiala.

Ludhiana is the largest and most densely populated city in the region, with an estimated population of 16.18 lakh in 2021. It covers an area of 158 km^2 and is renowned as a significant industrial centre, often referred to as "Manchester of India". The city, situated on the former bank of the Sutlej River, boasts excellent

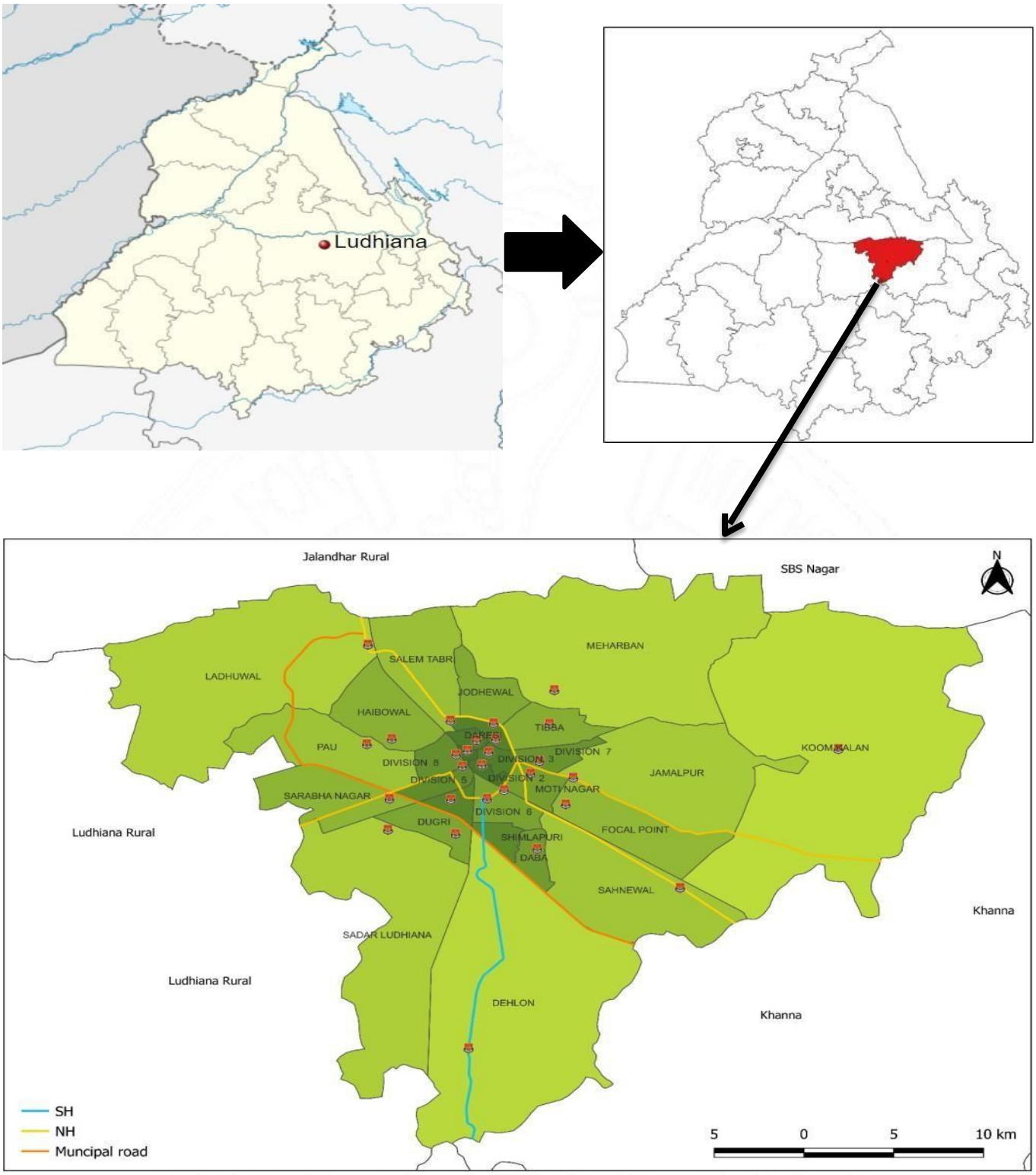
transportation links via roads, with national routes NH 44 and NH 5 (formerly NH1, NH95), as well as state highway SH 11, facilitating bus transportation to other cities in Punjab and neighbouring states, operated by Punjab Roadways and private bus services. Ludhiana's road network comprises several key arteries:

National Highways: NH 44, connecting Delhi to Amritsar via Jalandhar, and NH 54, connecting Ludhiana to Bathinda and Chandigarh, serve as crucial intercity connectors, bringing in traffic from diverse regions.

State Highways: SH 1 and SH 2 facilitate regional connectivity, while SH 11 provides access to Khanna and Samrala. These highways contribute to intra-state traffic flow and influence local congestion patterns.

Internal Roads: Ferozepur Road, G.T. Road (Canal Road), Ferozepur Bypass, Pakhowal Road, and Chandigarh Road form the city's internal circulatory system. They manage intra-city traffic movement, connecting residential areas, commercial hubs, and industrial zone.

Figure 2.1-2.3 describes the study setting within the Ludhiana district in the state of Punjab.



Sources: By Milenioscuro - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=53093319, Punjab Road Accidents Report2021, Punjab Police Ludhiana CP Report 2021

Figure 2.1 Ludhiana within the state of Punjab,
Figure 2.2. Ludhiana CP region within Ludhiana district
Figure 2.3 Ludhiana CP region/city

2.3 Study population

The study population consists of records of crashes reported in digitalized police records available with the Punjab Road Traffic Safety Research Centre for road traffic crashes in Ludhiana CP throughout a three-year period, from January 1st, 2020 to December 31st, 2022.

Inclusion Criteria: Crashes reported within the Ludhiana Commissionerate of Police geographical boundaries.

2.4 Data Collection

2.4.1 Pre-Data Collection: Stakeholder Meetings to Identify Data Sources

The following data sources were identified:

1. **Punjab Road Safety and Traffic Research Centre:** They were the primary source of crash data as they collect and maintain information from FIRs such as accident location (date, time, coordinates), crash severity (fatal, serious, minor, no injury), type of collision etc.
2. **Punjab Remote Sensing Centre (PRSC):** They were the primary source for road network data which is crucial for network analysis and hotspot identification. PRSC is the apex body in the State for all Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS) related works.
3. **State health agency:** This agency was identified as a potential source for ambulance and hospital data related to RTCs.

A series of stakeholder meetings were held to gather critical data from identified institutions which can help in the research of road traffic crashes in Ludhiana CP. The Punjab Road Safety and Traffic Research Centre (PRSTRC), the Punjab Remote Sensing Centre (PRSC), and the State Health Agency were all met once. These meetings were critical for describing data requirements, clarifying data access protocols, and ensuring a thorough understanding

of the data obtaining process. Each session included presentations describing the purpose of this study, followed by discussions about data quality, limitations, and variable definitions. These meetings permitted the collection of critical crash data, road network data, and ambulance and hospital data relating to road traffic crashes, which formed the foundation of the research project.

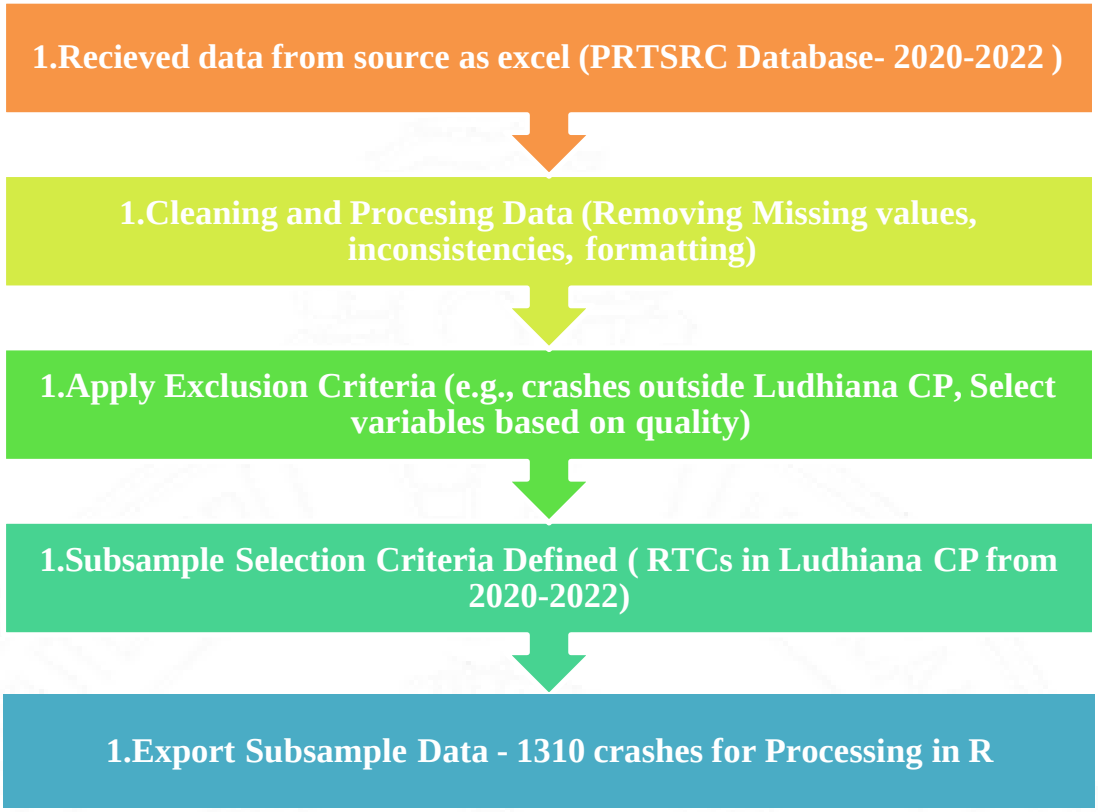
2.4.2 Data Collection: Secondary Data

This section details the data extraction process used for analysing road traffic crashes. It focuses on creating a subsample dataset for in-depth analysis from a larger dataset spanning 2020-2022 and the data collection tool used for primary data collection. The process of subsample analysis has been summarized in flowchart in figure 2.4.

1. Secondary Data Collection Process:

Source Description: The Punjab Road Safety and Traffic Research Centre (PRSTRC) , in collaboration with Punjab police , uses digitalized police data to conduct macro and micro-level analyses of traffic and road safety conditions throughout the state of Punjab, right down to the police station level. This digital data is meticulously examined to confirm the absence of duplicate records. The data provides details on various variables summarized in the next section. The data also provided FIR details which could be accessed through public domain. This was useful to extract information on age and gender which was absent in the present dataset.

Figure 2.4 Data Extraction Template for Quantitative Study (Subsample Analysis)



1. Data Processing and Subsample Selection:

Data for 2020-2022 was selected for analysis since the records were of better quality with minimal missing values. It was also done to focus better on recent trends and to complete analysis within the time frame of the dissertation. The data extraction template with list of all variables has been listed in table 2.1.

Table 2.1 Data Extraction Template

Sr.no	Variable	Sub-categories recorded
1	fir_no	
2	ipc_sections	279,283,304A,323.336,337,338,427,506, CrPC 174
3	date_of_offence	DD-MM-YY
4	date_of_fir	DD-MM-YY
5	police station	
6	day	Monday – Sunday
7	time_of_offence	HH:MM
8	type_of_collision	Hit from Back , Hit Pedestrian Hit fixed object etc.
9	place_location_of_occurrence	
10	latitude	
11	longitude	
12	road_category	NH, SH, MDR,ODR,Muncipality , Village Road
13	total fatalities	
14	total_serious_injuries	
15	total_minor_injuries	
16	medical response	Pvt , Emergency medical service
17	type_of_crash	Fatal, Serious , Minor, No injury
18	first vehicle	Collision By- Car , Bus etc.
19	second vehicle	Collision Into- Pedestrian, Two-wheeler etc.
20	hit-and-run	Yes , No
21	maneuver_type_as_per_fir	Overspeeding , Rough Driving etc.
22	male_fatalities	0=No, 1=Yes
23	female_fatalities	0=No, 1=Yes
24	intersection_mid_block	Midblock , Intersection , Unknown
25	junction_type	T type, Y type, Others, NA
26	vehicle_used	Ambulance,Privatevehicle, Police vehicle

2. Data Management:

The data was saved as a csv file and exported to R for further processing.

a) Secondary Data Collection Process: Ambulance dataset

The ambulance dataset was obtained from State health agency (SHA) through Punjab health systems corporation (PHSC) . The Department of Health & Family Welfare, Government of Punjab provides ambulance to all the citizens in the state. The service is free-of-cost , 24/7 emergency medical assistance accessible through a dedicated emergency number 108. These Ambulances shift the trauma cases and other emergency in the designated earmarked health institutions and the locations were available since they were being monitored through GPRS. The data for the whole state was obtained as excel and processed to obtain a list for the study region.

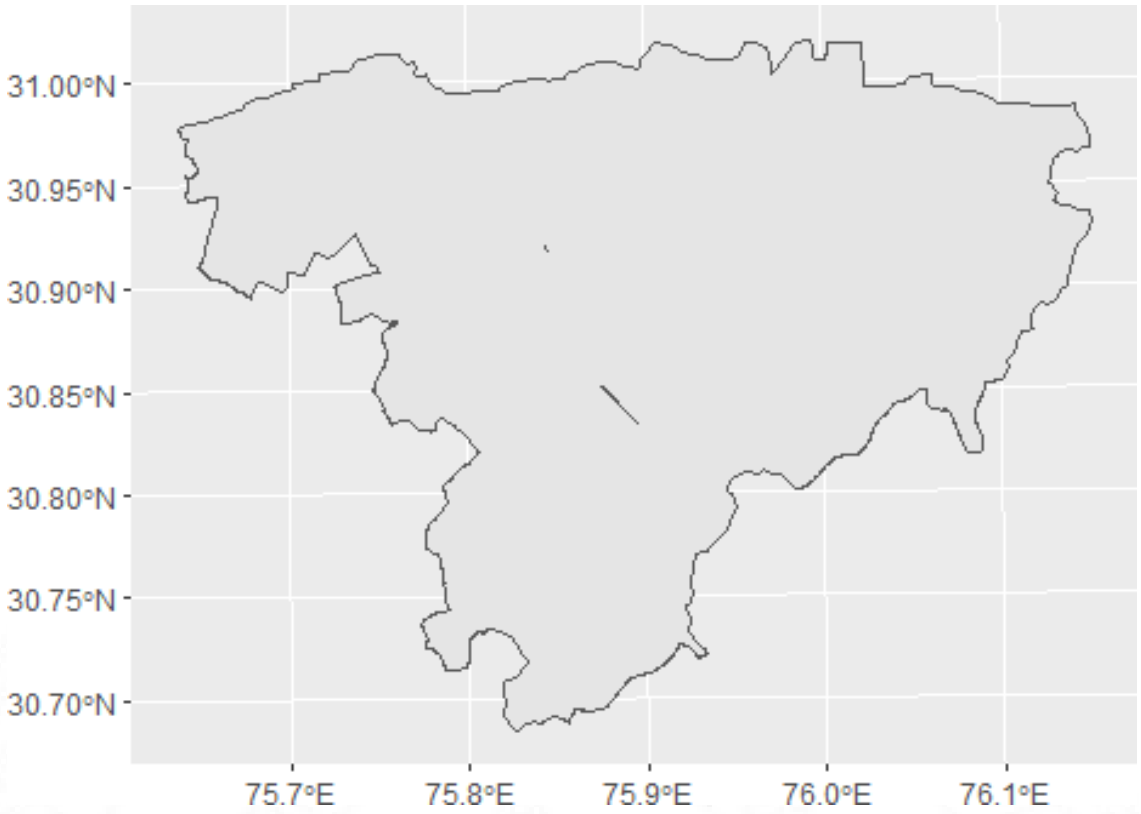
b) Secondary Data Collection Process: Hospital dataset

Like the ambulance dataset, a hospital dataset was obtained from the State health agency for the whole state preprocessing of which is explained further in the chapter.

2.4.3 Data Pre-processing for secondary data

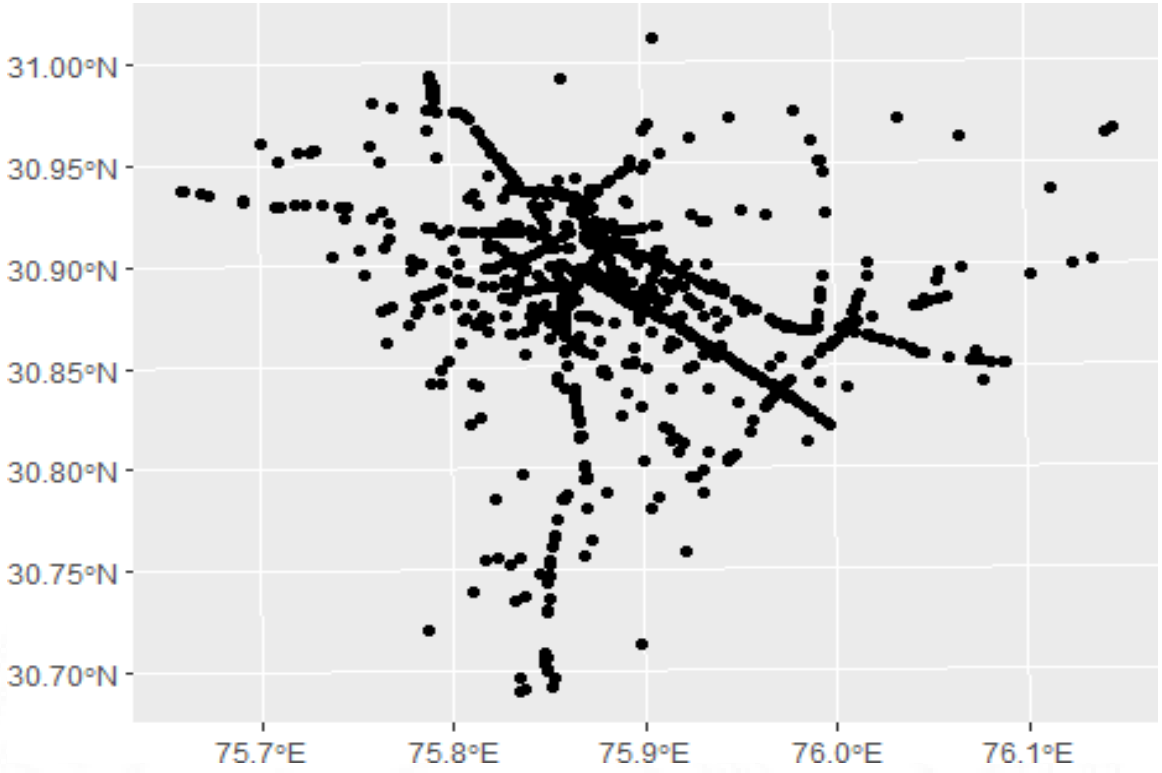
Using the shapefile for Ludhiana city obtained from Punjab Remote sensing centre, the precise perimeter of the analysis area was defined by using Ludhiana city boundary shapefile. (Fig.2.5)

Figure 2.5 : The boundary shapefile defining the geographical extent of the study area



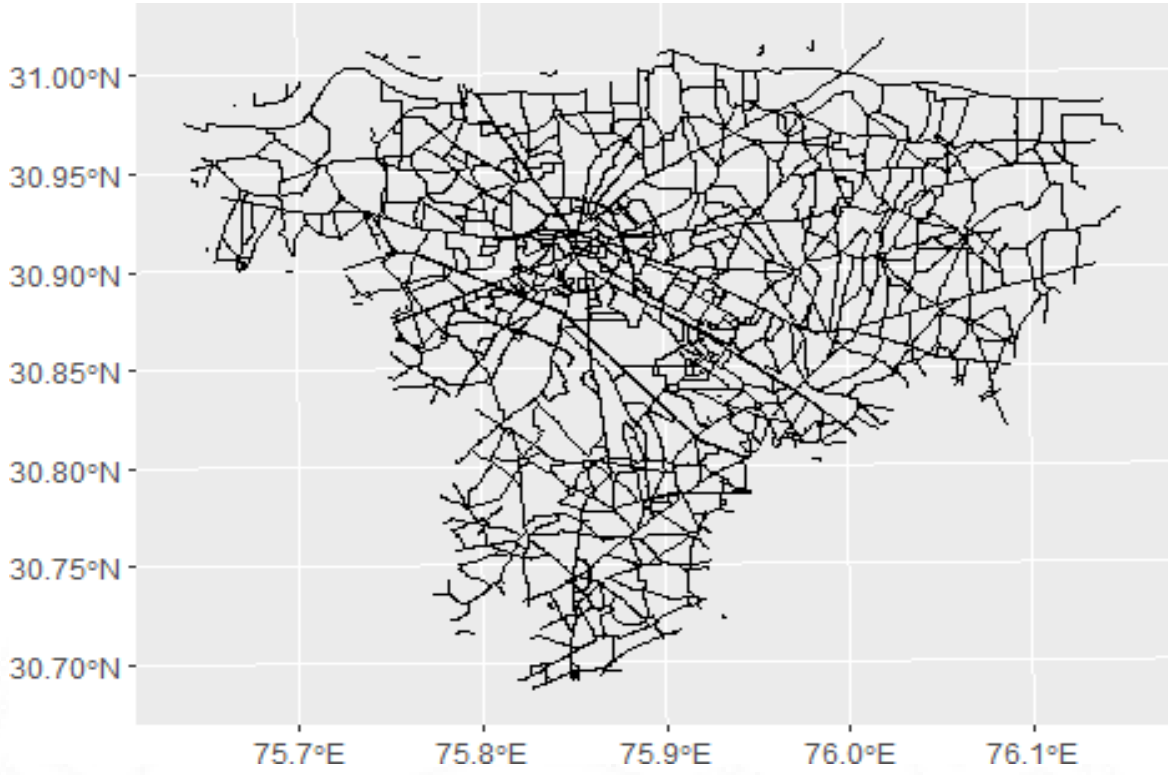
a) **Crash data:** Once the subsample data was exported to R, using latitude and longitude information extracted from the dataset , the accident locations were geocoded using sf package in R and plotted on the using *ggplot* utility. The crash records with locations outside the city limits were excluded to ensure the results accurately reflect the city's internal accident patterns. Some unknown latitude, longitude values were found. Therefore 1154 crashes were plotted and were available for hotspot analysis from 2020-2022 even though total number of crashes recorded were 1310 (Fig 2.6).

Figure 2.6: Crash dataset forms the core of the analysis



b) Road network data: The obtained road network was for the whole Ludhiana district. To prepare the obtained road network data for further analysis in the context of road crashes, unconnected elements which do not contribute to the analysis were removed and the road network was clipped to the city boundary (Fig.2.7). The road dataset provided the context for crash locations as it contains the road network, allowing us to understand the network on which crashes occurred and analyse factors like road type, intersection complexity in relation to crashes. The residential roads not contributing to analysis were removed for the initial analysis but were added later for calculating shortest routes for ambulances and hospitals.

Figure 2.7 Road network ready for analysis



c) **108 Ambulance data:** The obtained ambulance dataset was plotted onto the map using the latitude and longitude information, the boundary shapefile for the city was added and a bounding box was created. All the locations outside the city boundary were removed and the list was finalized as shown in table for further analysis (Table 2.2).

d) **Health facility data:** Like the ambulance dataset the hospital dataset was extracted in the context of the study from the state health facility dataset. A comprehensive list of 76 was extracted but on processing not all were found relevant to the study as there were many maternity and eye-care centres without any emergency room. After a detailed cross-check, using the list from the Civil Surgeon's office and by confirmation via direct calling. The final refined list of 24 hospitals was achieved, which clubs 24/7 Emergency Trauma and multispecialty service offerings (Table 2.3).

Table 1.2 108 Ambulance list

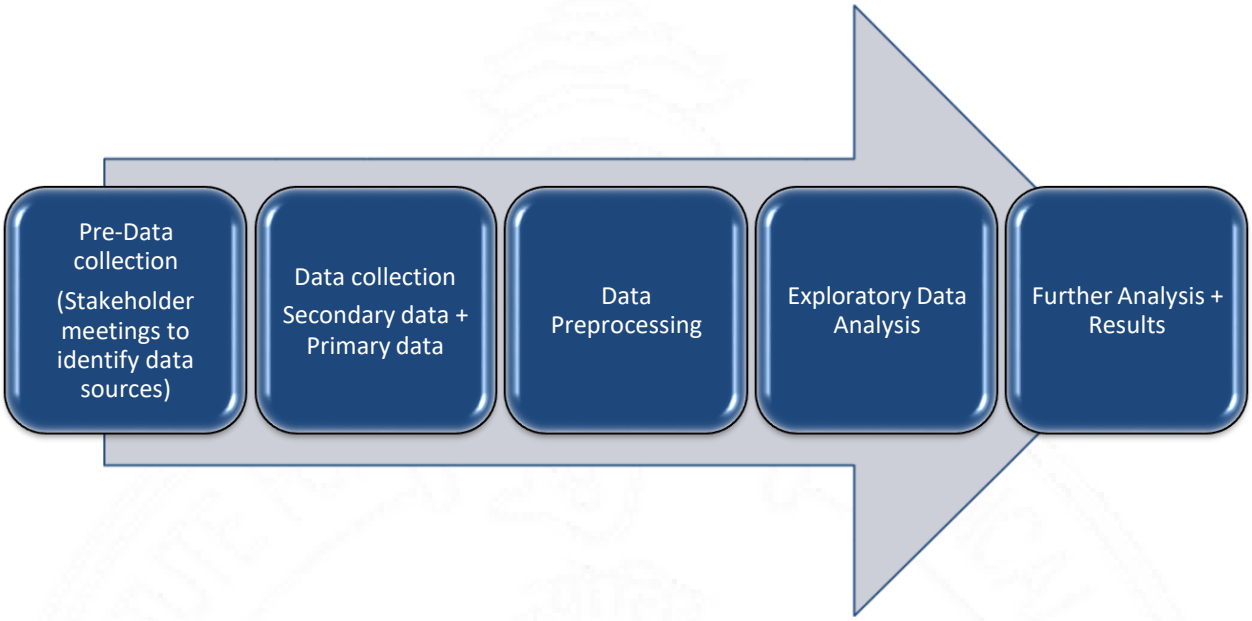
Sr. no.	Locations	Latitude	Longitude
1	Civil Hospital Ludhiana (MH2020TR0881S)	75.85963	30.9066
2	PHC Ladowal (MH2020TR0909S)	75.79252	30.97962
3	RH Katani Kalan (MH2020TR0911S)	76.08116	30.84932
4	CHC Subhash Nagar Ludhiana (MH2020TR1261S)	75.88404	30.93461
5	Khohara Chownk (MP11TRAV7146)	76.00677	30.8699
6	CHC Dehlon (PB02BP9503)	75.8501	30.74415
7	Gurdwara Sahib Vill Thakrwal	75.80629	30.84532
8	Gurudwara Alamgir Sahib (PB2020TR3928C)	75.86215	30.81084
9	Gurudwara Sahib Village Tibba (PB2020TR3938C)	75.94565	30.80469
10	CHC Kumkalan (PB2020TR3940C)	76.06329	30.91464
11	Gurudwara Feruman	75.86695	30.89519
12	CHC Sahnewal (PB65AV5120)	75.97922	30.83939
13	CHC 2	75.88934	30.85898
14	Police Station	75.9024	30.90414
15	Guru Nanak Stadium (T0721CH8122A)	75.84486	30.91079
16	Dhandari Khurd	75.9252	30.86784
17	PHC Hambran (T0921CH0831B)	75.67055	30.93708
18	PHC Ghawaddi (T0921CH0834B)	75.89437	30.78278
19	MCH Vardhman (T0921CH0840B)	75.89086	30.91087

Table2.3 Selected Hospital list

Hospital	Latitude	Longitude	Description	24hr	type
DMC Hero Heart Hospital	30.913675	75.823075	Multispeciality	Yes	pvt
U.P.S.C. Jain Charitable hospital	30.926727	75.864243	Multispeciality	Yes	pvt
Shri Krishna(C)Hospital	30.888328	75.845778	Multispeciality	Yes	pvt
SNS Pahwa Hospital	30.885791	75.859341	Multispeciality	Yes	pvt
Shri Rama Charitable Hospital, Pind Dholewal	30.890999	75.870515	Multispeciality	Yes	pvt
Gurdev Hospital	30.888439	75.791507	Multispeciality	Yes	pvt
Deepak Hospital	30.892577	75.811049	Multispeciality	Yes	pvt
Shri Raghunath Hospital Ludhiana	30.910639	75.833932	Multispeciality	Yes	pvt
SatguruPartapSingh(SPS)Hospital	30.88366	75.88845	Multispeciality	Yes	pvt
Fortis Hospital Mal lRoad	30.90862	75.8404	Multispeciality	Yes	pvt
Prolife Hospitals Ludhiana	30.83696	75.86501	Multispeciality	Yes	pvt
Arora Neuro Centre	30.91235	75.84	Multispeciality	Yes	pvt
E.S.I.C. Model Hospital	30.90188	75.83996	Multispeciality	Yes	pvt
CMC Ludhiana Hospital	30.91097	75.86357	Multispeciality	Yes	pvt
DMC Hospital ludhiana	30.91536	75.82292	Multispeciality	Yes	pvt
DeepHospital	30.88934	75.83726	Multispeciality	Yes	pvt
Civil Hospital	30.90651	75.85961	Multispeciality	Yes	govt
Aykai hospital	30.90748	75.88692	Multispeciality	Yes	pvt
Grewa lHospital	30.8788	75.85899	Multispeciality	Yes	pvt
GK Hospital	30.88164	75.89465	Multispeciality	Yes	pvt
GuruTegBahadurHospitalRoad	30.89245	75.89074	Multispeciality	Yes	pvt
FortisHospitalChandigarhRoad	30.893184	75.935269	Multispeciality	Yes	pvt

e) **Further analysis:** Explained in results.

Figure 2.8 Summary Flowchart for methods followed.



2.4.4 Data Collection: Primary Data

In addition to secondary data, an observation checklist was prepared to collect primary data on the physical characteristics of accident hotspots and coldspots to fulfil the second objective. The checklist was adapted from **Inspection Checklist Guidelines for observing site of accidents developed by KSCTC-National Transportation Planning and Research Centre - NATPAC.** The checklist included the following information:

Data collection tool: Structured ODK-based Observation form*

a) **Road Infrastructure:** Road features and conditions such as-

- Road type (e.g., highway, Major district road, Municipality Road)
- Road surface condition (e.g., potholes, unevenness)
- Roadside conditions (e.g. Paved, narrow etc.)
- Roadside hazards (Guardrail condition, obstructions, ditches etc).

- Road markings and signage (absence, presence of markings, speed limit etc.)
- Lane changes and merges

b) Surrounding Environment:

- Junction complexity (number of lanes, traffic light presence, type of junction)
- Access control
- Visibility at night (streetlights, reflectors)
- Pedestrian infrastructure (crosswalks, sidewalks)

c) Availability of **traffic calming devices** like road studs, rumble strips, speed breakers.

d) Traffic flow and congestion:

- Presence of Heavy Motor Vehicles such as trucks and buses.
- Observable bottlenecks
- Observable violators such as encroachments, crowding, entry from wrong side, irregular pedestrian crossing.

*The complete format of the data collection tool is given in Annexure I

Benefits of Combining Data Sources:

By combining data obtained through secondary and primary data collection, we could gain a richer understanding of road traffic crashes in Punjab:

Secondary data provides quantitative information on accident locations, severity, and potentially contributing factors while data from observations adds qualitative details about the physical environment and suggest modifications.

2.5 Some Operational definitions:

1. Road: Line of communication (travelled way) open to public traffic, primarily for the use of road motor vehicles, using a stabilized base other than rails or air strips.

2. Road Network: All roads in a given area. The road network may be classified according to the surface, e.g.: a) Paved roads; b) Unpaved roads.

3. Road Transport: Any movements of goods and/or passengers using a road vehicle on a given road network.

4. Road Traffic crashes: World Health Organization (WHO) defines a Road Traffic Crash (RTC) as a collision involving at least one vehicle in motion on a public or private road that results in at least one person being injured or killed. Included are collisions between road vehicles; between road vehicles and pedestrians; between road vehicles and animals or fixed obstacles and with one road vehicle alone. Included are collisions between road and rail vehicles. Multivehicle collisions are counted as only one accident provided that any successive collisions happen within a very short time period.

5. Light Goods Vehicle (LGVs): Goods road vehicle with a gross vehicle weight of not more than 3500 kg, designed, exclusively or primarily, to carry goods. Included are vans designed for and used primarily for transport of goods, pick-ups, small lorries, and two- or three-wheeler vehicles with a gross vehicle weight of not more than 3 500 kg.

6. Heavy Goods Vehicle (HGVs): Goods road vehicle with a gross vehicle weight above 3500 kg, designed, exclusively or primarily, to carry goods and passengers. Included are Buses, trucks etc.

7. Hotspot: A specific location along the road network with a **relatively high estimated density of road traffic crashes** compared to its surrounding segments. The study uses Network kernel density estimation, so it will highlight segments with statistically higher likelihood of crashes compared to other segments.

8. Coldspots- A specific location on the road network with low intensity of road crashes compared to surrounding segments.

9. Hospital- A hospital is a geographically fixed facility in which personnel with some acceptable level of training deliver emergency medical care. The distinctions between a clinic, health centre, and hospital are unclear, and the presence or absence of a doctor is not a determining factor in this distinction. A range of facilities from small, basic units up to tertiary care hospitals provides an increasing level of capability for emergency and other care(Kobusingye et al., 2006).

10. The Avg. Site Response Time (SRT) i.e. the time from receiving the call to reaching the site for accepted calls is approx. 10min(Gupta et al., 2009).

11. The Avg. Hospital Response Time (HRT) i.e. the time taken in transferring the victim from the site to the hospital is approx. 30min (Gupta et al., 2009)

2.6 Data storage

All the data related to the study was soft data and was stored in an encrypted format (AES 128-bit advanced encryption) in principal investigator's portable password-protected computer.

2.7 Data analysis

Data were analysed using R software -version 4.3.2.

2.8 Ethical Considerations

The study was reviewed by the Institutional Ethics Committee of Sree Chitra Tirunal Institute for Medical Sciences and Technology, Thiruvananthapuram, Kerala and clearance was given to conduct the study

As the study was a detailed analysis of road accident crashes and primary data collection was done by observation, no participants were approached for data collection. There was absolutely no risk to the study population. No identification markers were included in any study documents. Only the principal investigator has access to collected information. The study will be disseminated through scholarly publications once the thesis is completed and the study findings/ report will be shared with the Punjab Road and traffic research Centre and State health agency, Punjab.

CHAPTER 3

RESULTS

This chapter briefly describes the results of the study in concordance with the study objectives. A total of 1310 road traffic crashes were reported as per the data obtained from Punjab Road Safety and Traffic Research Centre (PRSTRC) from 2020-2022. It delves into a detailed analysis of a road crash dataset, followed by hotspot identification which allows to compare and contrast hotspots and cold-spots which further allows to estimate travel times from ambulance location to hotspot and from hotspot to nearest 24-hour emergency hospital facility. This would help to explore potential factors that contribute to crash occurrences. The ultimate goal is to identify patterns and trends that can inform road safety initiatives.

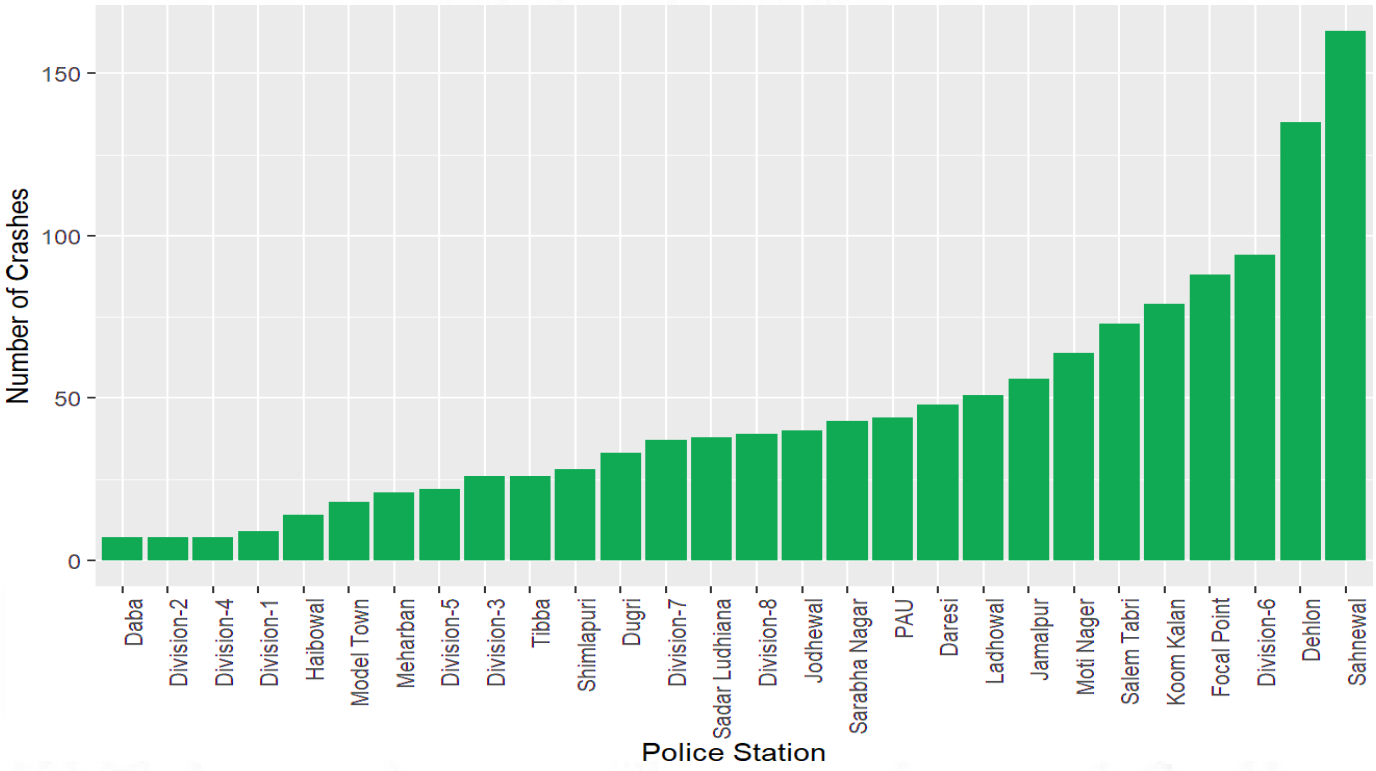
3.1 Exploring Existing Data

3.1.1 Crash distribution by Police stations: Since the data was obtained from FIR reports across Ludhiana CP, distribution across police stations is seen. Sahnewal (12.44%), Dehlon (10.30%), Division-6 (7.17%), Focal point (6.71%) and Koom kalan (6.03%) are the five police stations in which 42.65% (n=559 cases) of the total road crashes reported from the year 2020 to 2022 have been recorded. These critical police stations are on NH-44, NH-5, SH-11. Police station wise distribution of road crash fatalities is shown (Fig.3.1)

3.1.2 Crash distribution by age and sex: A subset of data was looked at for age distribution of victims amongst the reported crashes dataset and fatalities by sex, data was extracted from 581 reports for age of victim and 1310 reports for fatal crashes amongst male and female. The mean age obtained from the reports was 41.5 years ±

13.2 years. Looking at fatal crashes by sex, it was found that out of the 948 reported fatal crashes, around 89.02% (n=844) were male fatalities and 10.9% (n=104) were female fatalities.

Figure 3.1 Reported Crashes across 28 Police stations over a span of 3 years



3.1.3 Temporal Distribution of Crashes

a) Yearly: Table3.1 shows the number of crashes that occurred over a three-year period, from 2020 to 2022. Looking at the years individually, 2021 had the most crashes (480), followed by 2020 (373) and 2022 (457). However, it's important to note that the percentages don't show a substantial difference between the years (28.47% for 2020, 36.64% for 2021, and 34.89% for 2022).

Table 3.1 Year-wise Crash Distribution

Year	Counts(n)	%
2020	373	28.47
2021	480	36.64
2022	457	34.89

b) Monthly: Table 3.2 Month wise distribution reveals some variation in the reported crashes across the months, but overall, they appear to be somewhat evenly distributed throughout the year. Lowest number of crashes were reported in April (4.73%) , May (5.80%) and June (7.71%). This could be because this is the summer vacation period every year when people leave the city for vacations or do not venture out much due to scorching heat and the national lockdown from March 25, 2020, to May 31, 2020, due to the COVID-19 pandemic could also be another reason, for the reduction in crashes (Fig. 3.2).

Table 3.2 Month-wise Crash distribution

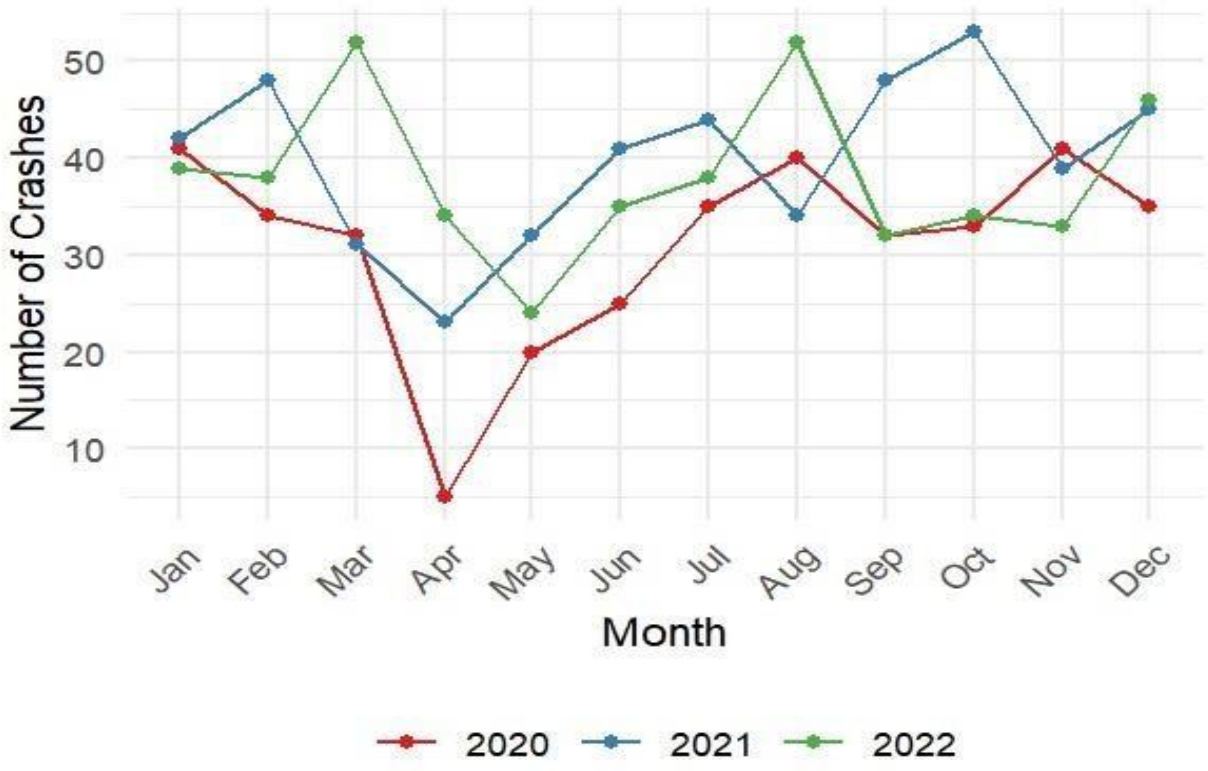
Month	2020	2021	2022	Counts(n)	%
Jan	41	42	39	122	9.31
Feb	34	48	38	120	9.16
Mar	32	31	52	115	8.78
Apr	5	23	34	62	4.73
May	20	32	24	76	5.80
June	25	41	35	101	7.71
July	35	44	38	117	8.93
Aug	40	34	52	126	9.62

Sept	32	48	32	112	8.55
Oct	33	53	34	120	9.16
Nov	42	39	33	114	8.70
Dec	35	45	46	126	9.62
	373	480	457	1310	100

.

Figure 3.2 is a line graph looking at monthly year wise crash distribution. Overall, here also months of April and May experience lesser crashes than other months which progressively rises for months of June and July.

Figure 3.2 Monthly crash counts year-wise



c) Day-wise crash distribution: Looking at crash frequency based on day of the week, it was seen that about (n=402~30.69%) crashes were on the weekends i.e. Saturdays and Sundays. Lowest number of crashes were reported on Tuesdays and overall crashes were distributed evenly on weekdays. (Fig.3.3).

When looked year wise, the pattern observed was varied across the years but 2021 and 2022 still recorded higher frequency of crashes on Sundays. Year 2021 had comparatively higher number of crashes across all days of the week, 2022 had a lower frequency on weekdays as seen in fig 3.4.

Figure 3.3

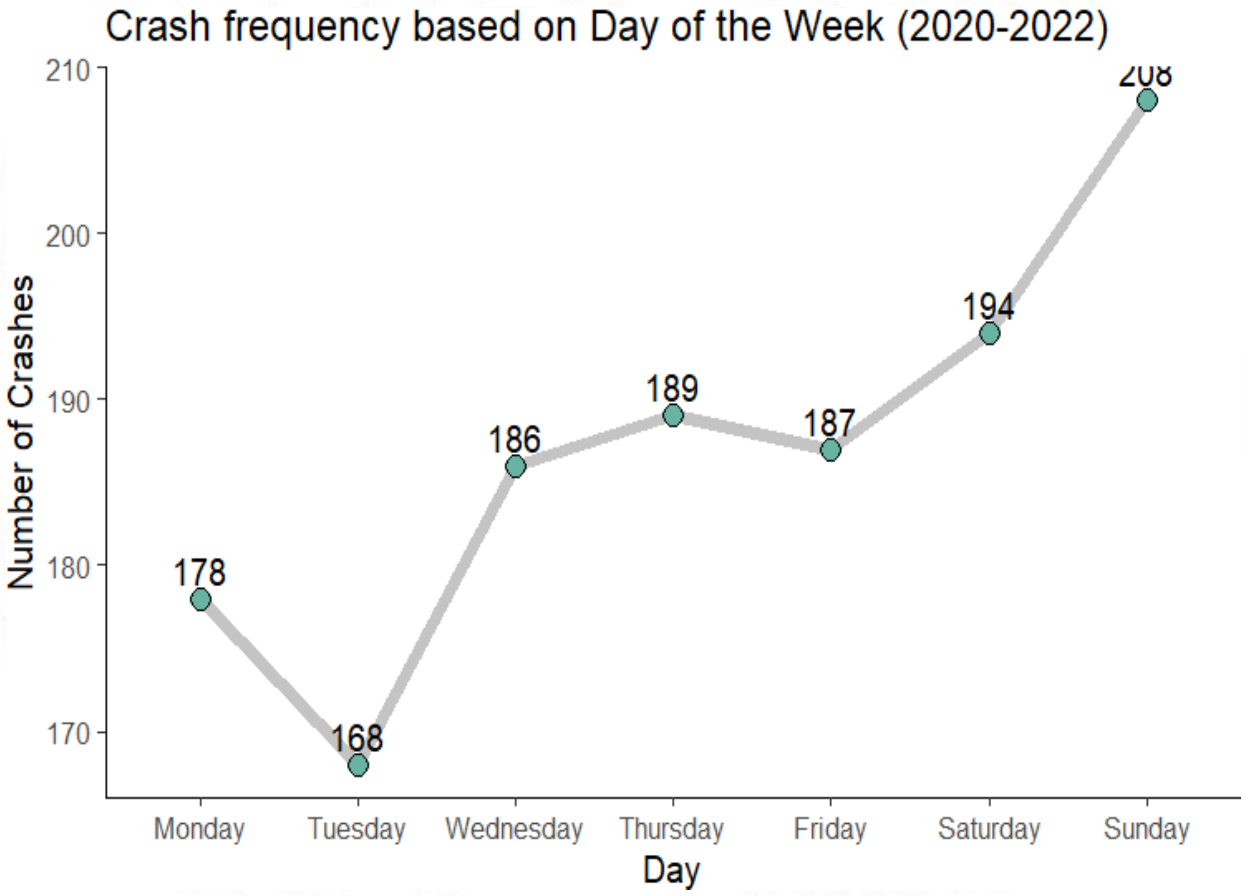
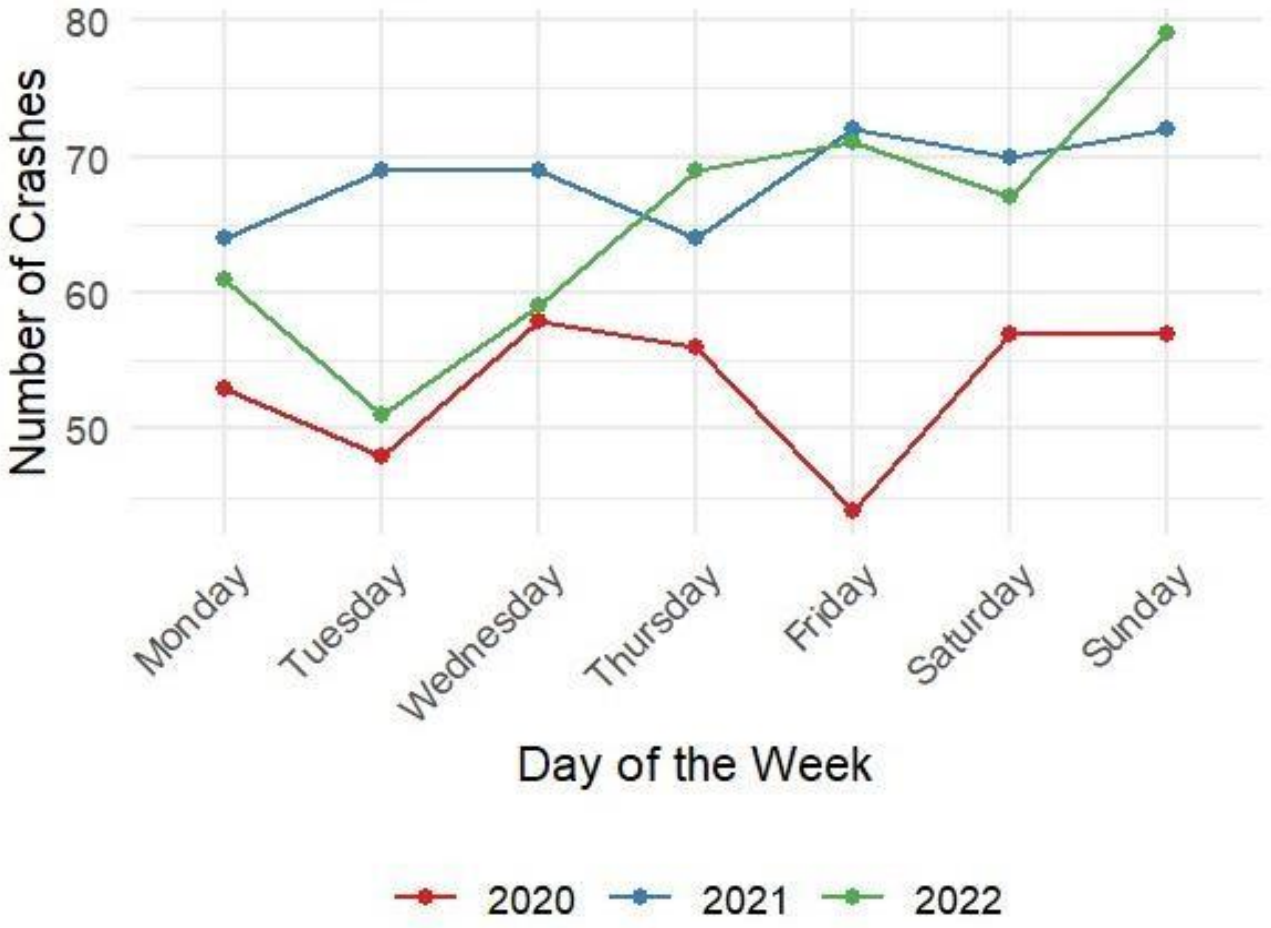


Figure 3.4 Day of the week Crash Frequency for each year



d) Hour-wise crash distribution: Fig3.5 shows distribution of crashes during the day; There are two major peaks in the number of crashes throughout the day. The first peak occurs in the late morning hours, between 7AM and 11 AM with most crashes reported around 8AM. The second and the more pronounced peak occurs in the evening hours, between 6 PM and 10 PM with maximum cases reported around 8PM. Crashes at night-time are much higher than at daytime. This observation mirrors the fact that reduced visibility due to darkness likely plays a role, along with potential safety hazards posed by poorly maintained roads. There were fewer reported crashes post-midnight till

Figure 3.5

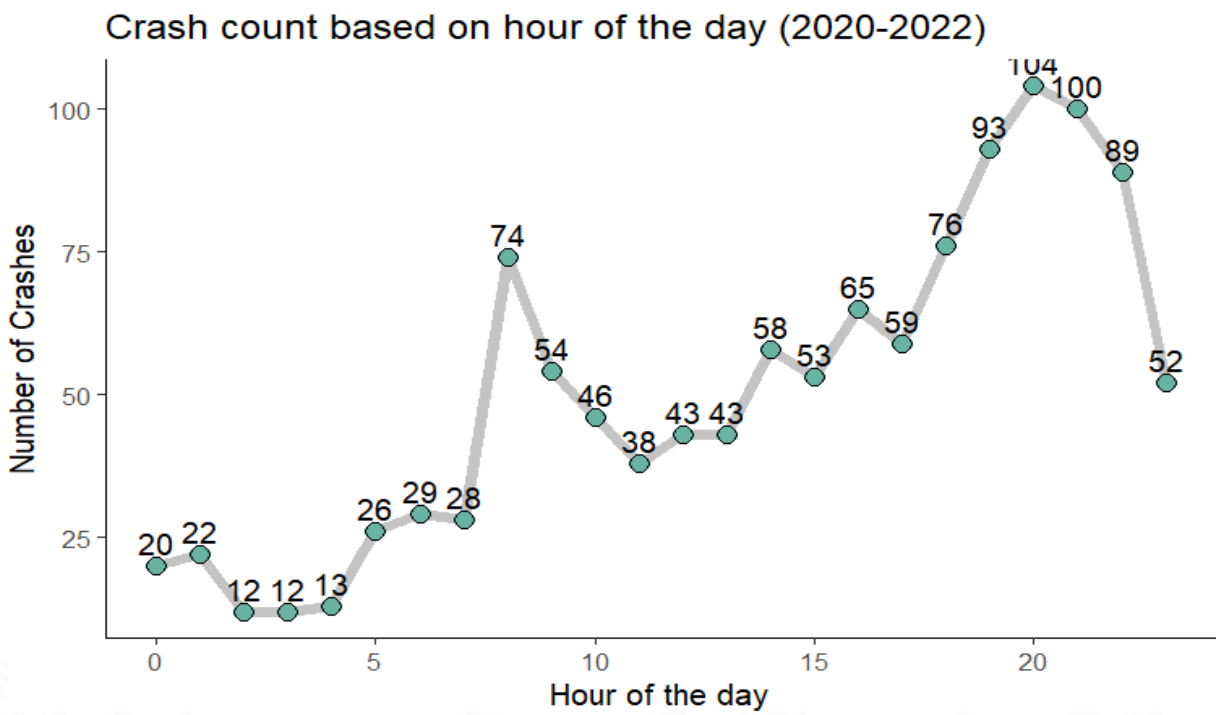
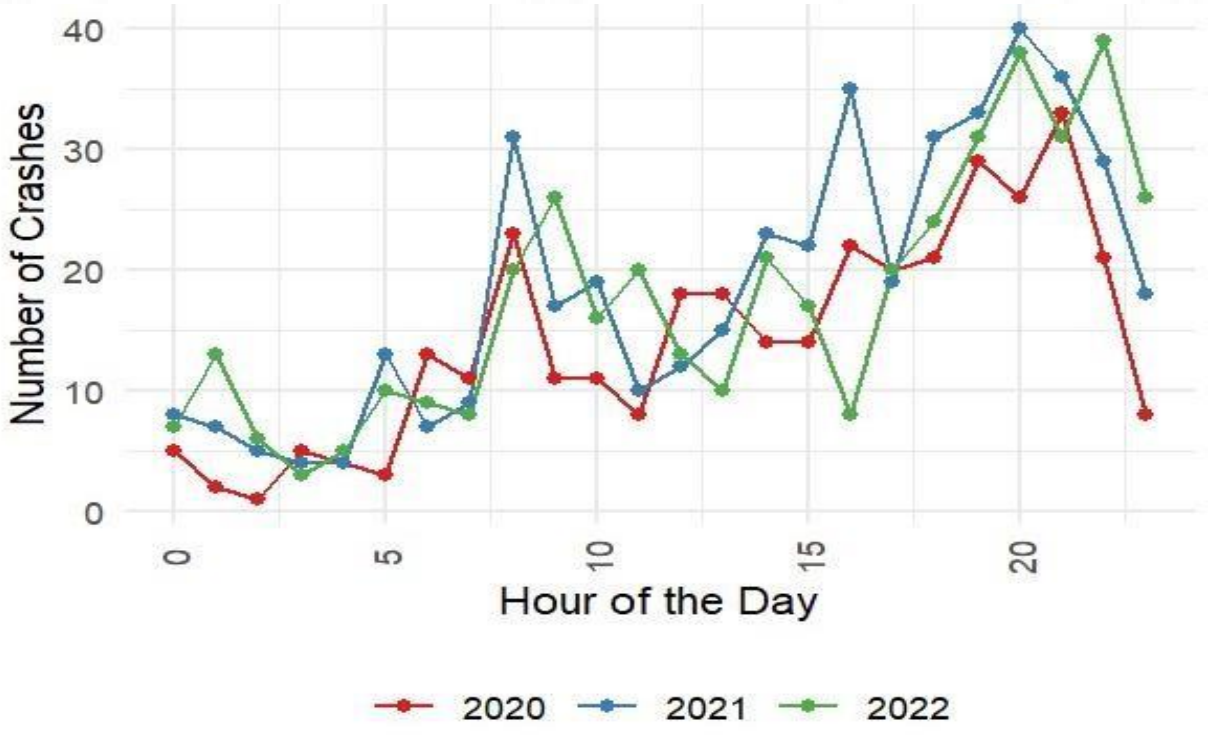


Figure 3.6 Hourly crash counts for each year



early morning. Fig. 3.6 further explores the year wise trend, the rise in crashes around 8am was evident even in the year-wise pattern, the second peak , seen in the evening shifted for 8pm to 9pm , however , it can still be said that evening time experienced more crashes than daytime.

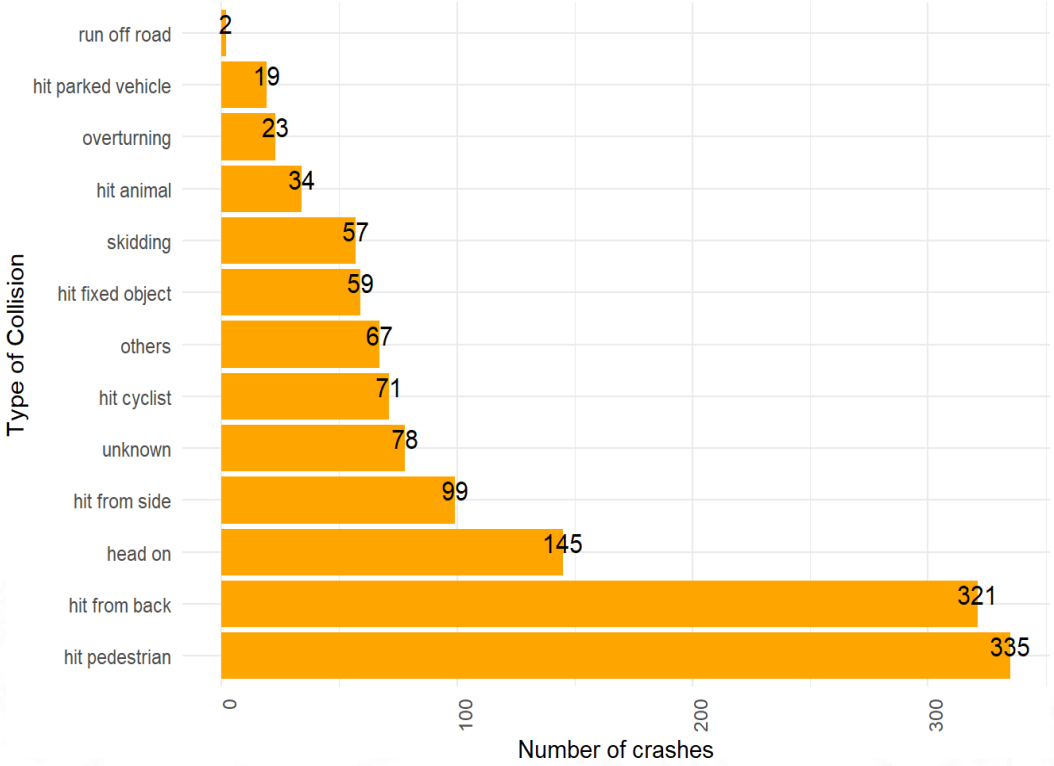
3.1.4 Crash severity and Type of collision: The distribution of crashes was seen for variations in the number of crashes and severity levels. Around 948 (72.4%) of the total reported crashes were fatal, the high number of fatal crashes compared to serious crashes (309~ 23.6%) paints a concerning picture, but it has to kept in mind that a lot of minor crashes do not show up in the official statistics.

Table3.3 Crash severity.

Year	Fatal	Serious	Minor	Total	%
2020	251	106	16	373	28.5
2021	362	106	12	480	36.7
2022	335	97	25	457	34.9
Total	948	309	53	1310	100
%	72.4	23.6	4.0	100	

Furthermore, it is useful to analyse the type of collision in conjunction with crash severity to receive valuable insights into the nature of crashes and potential areas for intervention. Fig3.5 highlights, that "Hit pedestrian" wherein vehicle hits pedestrian is the most frequent (n= 335~ 25.57%) , followed by "Rear end/Hit from back" (n=321~24.50%) and "Head-On"(n=145~11.06%) collisions. "Hit from side " and "Hit Cyclist" crashes are also relatively common. This clearly points on the need for increased safety measures for pedestrians.

Figure 3.7 Frequency of each type of collision



3.1.5 Potential contributing factors to crashes

a) Characteristics of roads – Road category

Table3.4 Distribution of crashes by road category

	Severity				
Road Category	**Fatal**	**Serious**	**Minor**	**Count(n)**	**%**
National Highway	406	125	16	547	41.75
State Highway	96	22	8	126	9.61
Municipality	261	126	22	409	31.22
Others	133	34	6	173	13.2
Unknown	52	2	1	55	4.19

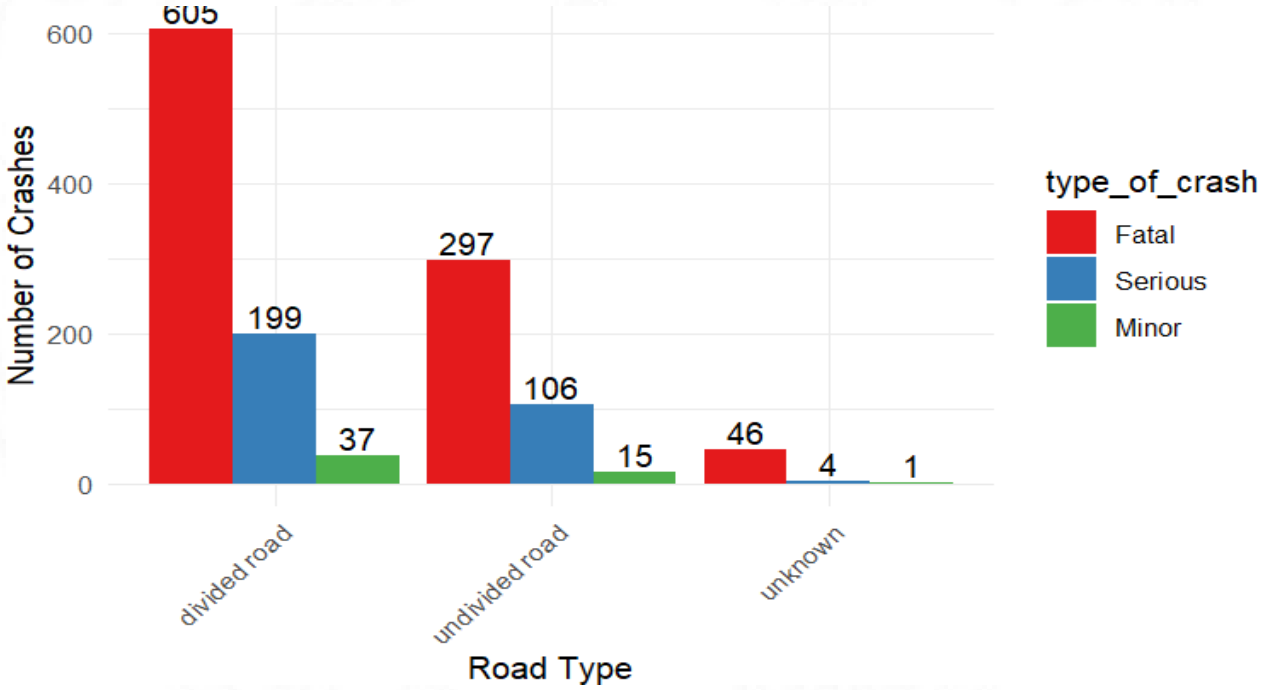
The table presents a breakdown of road crashes by severity and road category. 41.75% of all crashes occurred on National Highways of which 74.22% (n=406)

resulted in fatalities, 125 were reported as serious and 16 were reported as minor crashes. Across various types of roads, a concerning trend emerges: a significant proportion of all crashes resulted in fatalities.

b) Type of road:

When looked at crash severity based on road design i.e. whether the road had a median or not, it was observed that divided roads had higher frequency of crashes among all types of crashes with highest frequency of fatal crashes ~ 46.1% while roads without median constituted 22.6% of all fatal crashes. The frequency of each type of crash by road type is summarised in fig3.8.

Figure 3.8 Frequency of each type of crash by road type



c) Junction type – common junction types reported as crash sites.

Table 3.5 Common junction types reported in crashes.

Junction type	Counts(n=449)	%
T-junction	186	41.43
Four arm intersection	147	32.74
Staggered junction	44	9.80
Y-junction	29	6.46
Others	19	4.23
Roundabout/rotary	12	2.67
Vehicular underpass	11	2.45
Pedestrian underpass	1	0.22

The data also provided an overview of the distribution of crash sites by junction type. 449 crashes (~34.3%) were reported near a junction. Out of those **T-junction** was the most common type of junction where crashes occurred, accounting for approximately 41.43% of all reported crash sites. The cause could be due to their design, or the traffic pattern handled.

Four arm intersection were the second most common type of junction with around 32.74% of crashes. These intersections involve four roads meeting at a point, which present complex scenarios conflict points for drivers, possibly leading to a higher risk of crashes. **Staggered junctions** accounted for 9.80% of reported crash sites while **Y-junctions** constituted 6.46% of reported crashes occurring at these locations. Table3.5 summarizes common junction types where crashes were reported.

d) Type of vehicle:

The type of vehicle involved in crashes influences the likelihood and severity of collisions due to differences in size, mass, manoeuvrability, speed, visibility, and safety features. For understanding these better. It was observed that around 50% of the affected were motorized two wheelers (MTW) riders followed by pedestrians, bicyclists, and rickshaws (35.3%). Together they constituted around 86% of all crash victims. On the other hand, Light Motor vehicles (LMVs) which includes cars, van, jeep, taxi and light commercial vehicles caused 31.2% of the crashes while Heavy Motor vehicles such as trucks, buses caused 26.71% of the crashes. Another category causing around 16% of crashes was single vehicle, wherein even without directly colliding, it caused damage to nearby two wheelers , pedestrians and so on. The matrix (Table 3.7) provides information about collisions involving different types of vehicles and the entities they collided with. Others included animal driven vehicle collisions etc.

Table 3.6 Number of fatalities by affected road user

Affected Road user	**Pedestrian, Bicyclists and Rickshaws**	**Motorized Two wheelers (MTW)**	**Three wheelers**	**Light Motor vehicles (LMVs)**	**Heavy Motor Vehicles (HMVs)**	**Others**	**Total %**
Fatalities	364	486	11	53	24	12	948
%	(38.1)	(51.2)	(1.2)	(5.6)	(2.5)	(1.3)	100

Table 3.6 further informs about the proportion of death among affected road users wherein vulnerable road users constitute 89.1% of the total deaths.

Table 3.7 Collision Matrix

COLLISION INTO → / *COLLISION BY* ↓	**Pedestrian, Bicyclists and Rickshaws**	**Motorized Two wheelers (MTW)**	**Three wheelers**	**Light Motor vehicles (LMV)**	**Heavy Motor Vehicles (HMV)**	**Others**	**Total %**
Motorized Two wheelers	66	49	3	2	4		124 (9.4)
Three wheelers	7	10				1	18 (1.37)
Light Motor vehicles (LMVs)	145	212	9	41	1	2	410 (31.29)
Heavy Motor Vehicles (HMVs)	112	192	4	28	11	3	350 (26.71)
Single vehicles	20	141	5	28	14	1	209 (15.95)
Others *	8	2		1		3	14 (1.06)
Unknown	105	70	2	3	1	4	190 (14.50)
Total	463	676	23	103	31	14	1310
%	(35.34)	(51.60)	(1.75)	(7.86)	(2.36)	(1.06)	(100)

e) Crash Characteristics based on Road User Behaviour and manoeuvrability.

These cases of “Hit and run” where drivers fled the scene of a crash without providing aid to victims or reporting the incident to authorities was around 45.19% of all cases. This statistic is troubling, as timely aid could have saved many victims' lives or

reduced the severity of their injuries. Additionally, speeding, and rough driving contributed to a large proportion of reported crashes. Approximately 44.12% (n=578) of crashes were caused by over speeding, while 20.38% (n=267) were a result of rough driving. Together, these make up a substantial 64.50% of all reported crashes. Other categories (n=373) ~28% included approaching from wrong side, because of an animal, a pothole, a high beam during night, wrong parking etc. Around 7% were reported as unknown.

f) Vehicle used: Reaching the nearest facility

The data provided an insight into how crash victims were transported to medical facilities after an incident, with a focus on the mode of transport. It was found that in around 65% of the cases private vehicles were the most common mode of transport for crash victims meaning in most cases, victims or bystanders rely on their own means to transport victims to medical facilities. This may result in suboptimal or delayed care, especially if the vehicle is not equipped for emergency medical care or patient is not handled appropriately. Only 17.8% used Emergency medical service which is most effective means in transporting and stabilizing victims. A small proportion ~1.8% were transported through a police vehicle. Table 3.8 summarizes this.

Table 3.8 Distribution of Vehicle Types Involved in Road Crashes

Vehicle used	Count(n)	%
Private Vehicle	851	64.9
Emergency Medical Service	233	17.8
Unknown	203	15.5
Police vehicle	23	1.8
Total	1310	100

3.1.6 Factors associated with crash severity.

Variables were cross tabulated with crash severity which was divided into fatal and non-fatal crashes. The findings are detailed below. A p value of less than 0.05 was considered significant.

a) **Category and type of road:** Chi-square test was performed to assess the association between road category and road type with crash severity. Table 3.9 indicates that there is in fact an association between road category (National Highway, state highway, municipality or others which included MDR and ODR) and outcome of crash (Fatal or non-fatal), suggesting that the type of road may influence the severity of crashes.

Table 3.9 Association between Road Category and Crash Severity

Variable	**Crash severity**		χ^2
Road category	**Fatal n=948**	**Non-Fatal n=362**	**p value**
National Highway	406	286	<0.001
State Highway	96	239	
Municipality	261	92	
Others	185	73	

The association was further explored with having a divided or undivided road with outcome of crash (Fatal or non-fatal). Table 3.10 reveals a non-significant p-value which suggests that the chances of a crash being fatal or non-fatal does not appear to be influenced by whether the road is with or without a median.

Table 3.10 Association between Road Type and Crash Severity

Variable	Crash severity		χ^2
Road Type[1]	**Fatal n=902**	**Non-Fatal n=305**	**p value**
With Median	605	199	0.342
Without median	297	106	

Road Type[1]: 51 cases unknown for the variable

b) Affected Road user and crash outcome: The association between type of road user and crash outcome was analysed. Table 3.11 indicates that there is a strong association between the type of affected user (Pedestrian and bicyclists, Motorised Two-wheeler, Others) and crash severity (Fatal or Non-Fatal).

Table3.11 Association between Affected User and Crash Severity

Variable	Crash severity		χ^2
Affected User	**Fatal n=948**	**Non-Fatal n=362**	**p value**
Pedestrian and bicyclists	368	96	<0.001
Motorized Two-wheeler	486	202	
Others	94	64	

c) Hit and Run Incidents and Crash Severity: The results of test of association from table 3.12 suggest that crashes involving Hit and Run incidents are significantly more likely to be fatal compared to those without Hit and Run involvement. This also

highlights the behaviour of the driver and how timely care could have saved the people involved in the crash.

Table 3.12 Association between Hit and Run Incidents and Crash Severity

Variable	Crash severity		χ^2
Hit and Run[1]	**Fatal n=946**	**Non-Fatal n=361**	**p value**
Yes	388	204	<0.001
No	558	157	

Hit and Run[1]:3 values were missing.

d) Transportation to hospital and Crash Severity: When compared with the mode of transport chosen to reach hospital with the crash outcome, it was indicated that ambulance intervention crashes are more likely to be fatal. It's important to note that this table only shows an association, not causation.

Table 3.13 Association between Mode of vehicle and Crash Severity

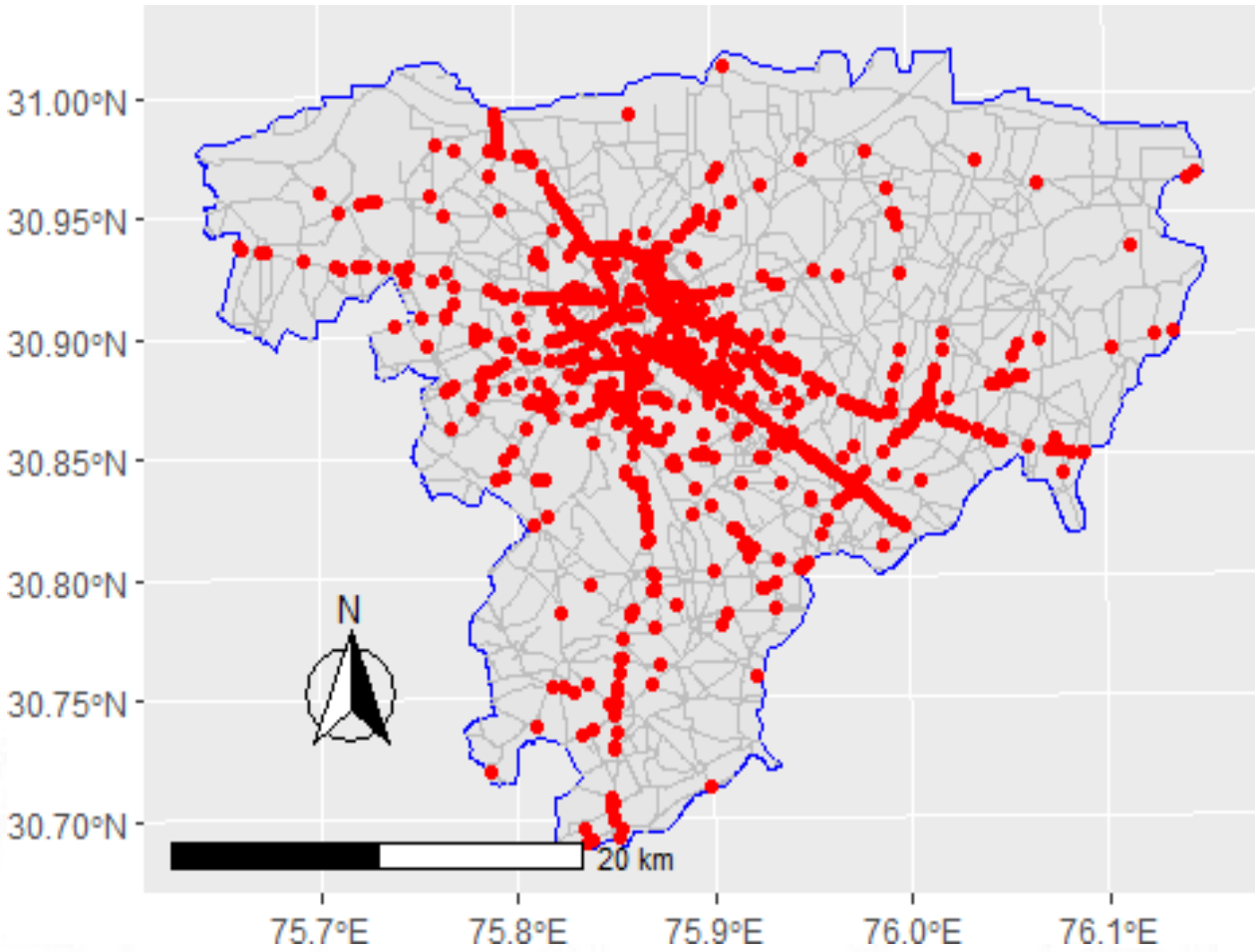
Variable	Crash severity		χ^2
Vehicle Response[1]	**Fatal n=798**	**Non-Fatal n=326**	**p value**
108Ambulance	198	35	<0.001
Others	600	272	

Medical Response[1:]205 values response was unknown.

3.2 Spatial Distribution of Road Traffic Crashes

The analysis using geocoded crash locations from crash dataset revealed the spatial distribution of RTCs within Ludhiana city limits. By visualizing the data on a map, we were able to identify areas with a higher concentration of crashes, potentially indicating hotspots. Further analysis using Network Kernel Density Estimation pinpointed statistically significant crash clusters within the city's road network. Fig 3.9 shows the pre-processed map which indicates the locations of crashes. The dataset was further explored by combining these datasets based on geospatial identifiers (For instance here, matching crashes to specific roads within the boundary and making observations as part of further analysis. The map (Fig3.9) represents road crashes in Ludhiana City from 2020 to 2022. The red dots indicate the locations of road crashes within the city boundaries during this period. The map shows a concentration of crashes in certain areas, particularly in what happens to be the centralpart of the city where the road network is densest. The scale at the bottom indicates that the map covers an area of approximately 20 kilometres across.

Figure 3.9 Road crashes in Ludhiana city (2020-2022)



Statistical Analysis: Discontinuous Network Kernel density estimation was performed using sfNetwork package. The idea was to non-parametrically estimate the intensity function λ(u) of a spatial process , represented by a set of events e (Road crash in this case), kernel estimation is commonly employed.(Kazmi et al., 2022b; Sandhu et al., 2016; Xiangzhen Li et al., 2012)

In a two-dimensional space, the intensity of the spatial process is only estimated on the network. Its edges are split into lixels (one-dimensional pixels), and the centers of the lixels are used as locations for estimating intensity. At any given location u, the contribution to the local estimated intensity is determined by events within a specified bandwidth (bw).

This contribution is influenced by factors such as the distance between events and u, the event's weight, and the selected kernel function. The distances between events and sampling points are calculated as the shortest path distances on the network instead of Euclidean distances.

The kernel function distributes the mass of events within a circular area centred around each event, with the radius of this circle being the bandwidth (or the standard deviation of

$$K(dist(u,e_i)) = \frac{2k(dist(u,e_i))}{n_{i1}\prod_{i=i}^{j}(n_{ij}-1)},$$

the kernel). The Kernel Density Estimate is calculated using the following formula(Jeremy Gelb, 2021; Xie and Yan, 2008, 2013):

The road network was converted to nodes (points in the network where the line turns, changes) and edges (being the roads between the intersections) (Fig3.10) and the crashes were then plotted on the map and using the lixelise function in sfNetwork the hotspot analysis was done. Using these filtered edges as input for further network analysis that consider edge lengths or network connectivity.

Figure 3.10 Road network for Hotspot analysis

In NKDE, the spatial process is estimated only along the road network. The road network is divided into small segments called "lixels," which are similar to one-dimensional pixels. The centres of these lixels are used as reference points for estimating the intensity of road traffic crashes.

At any given location along the road network, the local estimated intensity of road traffic crashes was determined by considering various factors. These factors included the distance between the location and the crashes, the weight of each crash event, and the selected kernel function, which defines how the contribution of each accident event decreases withdistance from the location. The crashes within a 5m radius were aggregated as 1 for ease of calculation.

In simpler terms, NKDE helped us understand where road crashes occurred more frequently along the road network by analysing the distribution of crashes and their proximity to specific locations(centres of lixels in this case) .

Fig.3.11 visually represents the steps to estimate density of crashes across the road network.

Figure 3.11 Snippet of code for network analysis

```
# Network analysis

lixels <- lixelize_lines(roads_sf_final,500, mindist = 50)
samples <- lines_center(lixels)

densities <- nkde(roads_sf_final,
                  events = accidents_snapped,
                  w = rep(1,nrow(accidents_snapped)),
                  samples = samples,
                  kernel_name = "quartic",
                  bw = 300, div= "bw",
                  method = "discontinuous", digits = 1, tol = 1,
                  grid_shape = c(1,1), max_depth = 8,
                  agg = 5, #we aggregate events within a 5m radius (faster calculation)
                  sparse = TRUE,
                  verbose = FALSE)
```

Explanation :

lixelize_lines(roads_sf_final, 500, mindist = 50): This function was used to divide the lines in road network into smaller segments (lixels) of approximately 500 units in length, with a minimum distance of 50 units between the starting points of these lixels to avoid overlap.

samples <- lines_center(lixels): This function calculated the central points of the lixels created. While **nkde**() function performed the network kernel density estimation.

events = accidents_snapped: The spatial points represented that were snapped to the nearest point on the road network.

w = rep(1, nrow(accidents_snapped)): A vector of weights for crashes, each with equal weight of 1.

kernel_name = "quartic": A quartic kernel function is a common choice used for the density estimation.

bw = 300: The bandwidth for the kernel was 300, it determined the smoothness of the density estimate.

method = "discontinuous": The method used for the estimation, which in this case is discontinuous.

digits = 1, tol = 1: Kept precision of the calculation

grid_shape = c(1,1): The shape of the grid used for the estimation, which here is a single cell.

max_depth = 8: A parameter that controlled the depth of the calculation or recursion in the algorithm. And **agg = 5**: Aggregation distance, meant that events within a 5-meter radius were aggregated for faster calculation.

samples$density <- densities:

The resulting density estimates from the *nkde* function were added to the samples object as a new column named density.

samples$density <- samples$density * 1000:

The density values were multiplied by 1000, to convert the units from per square meter to per square kilometre.

Figure 3.12 Crash density by km from 2020-22 within a radius of 300m

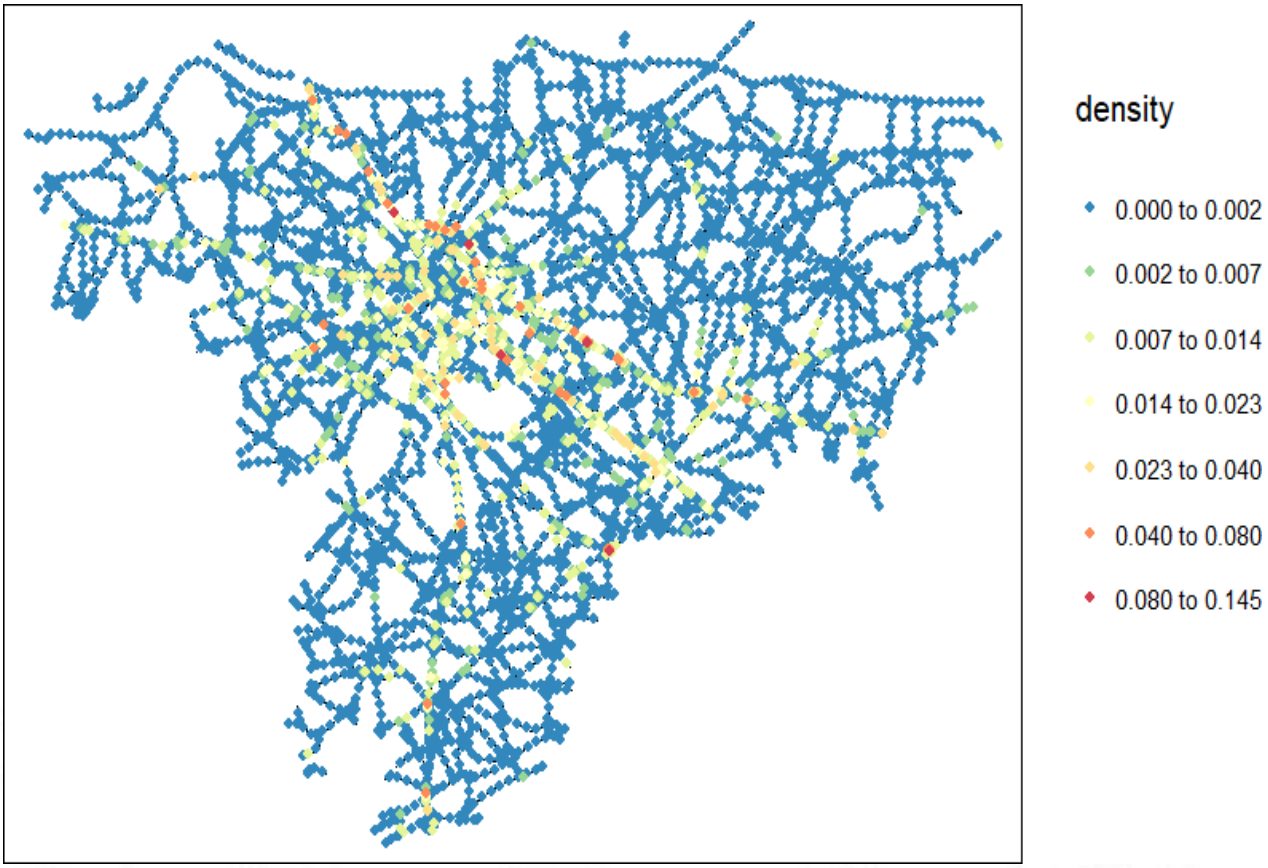


Fig 3.12 represents the estimated density of crashes across the road network and the findings are similar to the expected concentration of hotspots within the centre of the city where the road network is densest. Areas with higher density values (0.080-0.145) highlighted in red indicate locations with a higher concentration of crashes. These were referred to as "hotspots" for further analysis. There were 29 hotspots identified within the city boundary after road network analysis.

3.3 Characteristics of Crash Hotspots

The primary data collection through observations at hotspots and cold spots aimed to understand the environmental factors potentially contributing to crash occurrences. A total of 15 hotspots and 15 coldspots were investigated. The data was collected using the

structured checklist and was categorized and analysed to identify potential problems in road infrastructure, surrounding environment, traffic flow characteristics, and presence of traffic calming measures.

a) **Road Infrastructure:** The condition of road surface condition (potholes, unevenness), roadside hazards (missing guardrails, obstructions), and adequacy of road markings and signage (speed limits, lane markings).

b) **Surrounding Environment:** The complexity of junctions (number of lanes, traffic light presence), pedestrian infrastructure (crosswalks, sidewalks), and nighttime visibility (street lighting).

c) **Traffic Flow and Congestion:** Presence of Heavy Goods Vehicles (HGVs), observable bottlenecks, and traffic violations like encroachments, speeding, and improper pedestrian crossings.

d) **Traffic calming measures:** The presence of rumble strips, road studs , delineators, traffic lights and cameras.

Figure 3.13- 3.18 give a glimpse of observations.

Detailed list of observations is attached in Annexure II

Figure 3.13 Observations at hotspots

Hotspot Visit Findings

Spot	Site Address	Photo	Observations
1	Tibba bridge , near Sidhwan canal 		• Canal level crossing near the National Highway 5 joining to another road parallel to NH5. • There were no road markings , street lights around. • The barrier along the road over the canal was very low and even open at the end. • Many cyclists, pedestrians used this crossing but there are many HGVs also. • There was no police or traffic signal present.

Figure 3.14 Observations at Coldspots

Cold spot Visit Findings

Spot	Site Address	Photo	Observations
1	Sixty-nine ml , South City Road canal level crossing 	 	• The road runs along the Sidhwan canal and is one of the very recently constructed roads and was very smooth with paved kerb and shoulder. The road markings and signages were adequate. • There were canal level crossings that were clearly marked and has police check posts and police was present. • The traffic is not much except near some intersection like the one moving to Sunview enclave • Some trucks were observed in the area • There were street lights

Figure 3.15 Observed problems highlighted in red

Figure 3.16 Observed safety measures highlighted in yellow

Figure 3.17 Observed potholes and road condition highlighted in red

Figure 3.18 Adequate lighting and signals highlighted in yellow

Empirical Observations:

9 out of 15 hotspots were on national highways, 4 of the 9 being service roads, 5 of the 15 hotspots were open spaces around highways.

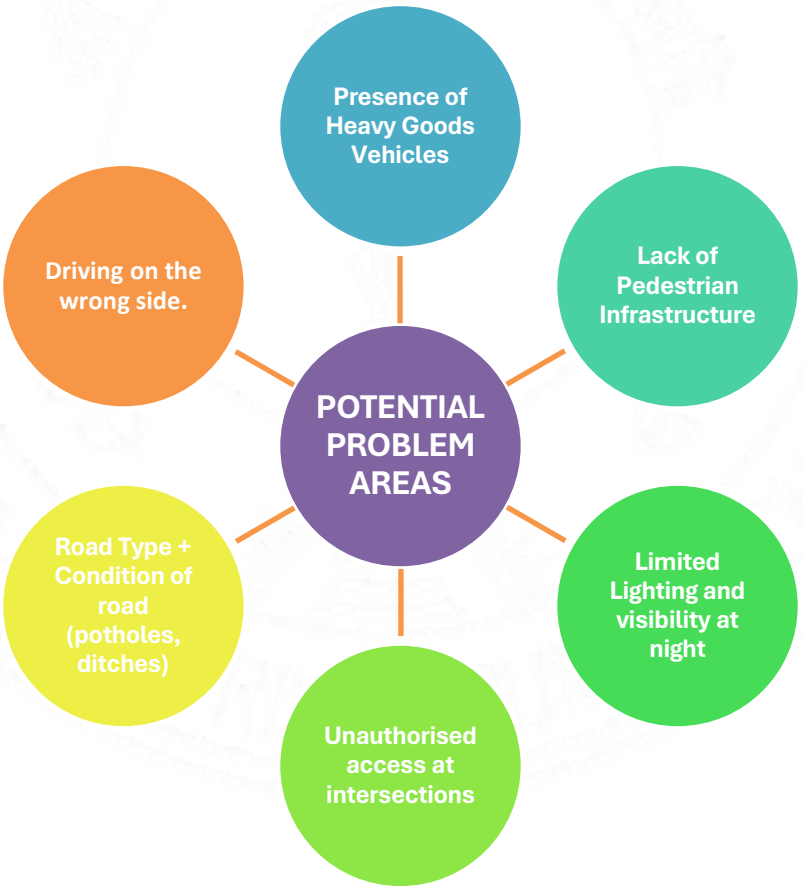
None of the hotspots had a roundabout junction type, 4 had four-armed junctions, while 3 cold-spots had a round-about.

Traffic signals were non-operational at most of the hotspots (1 working traffic signal) and cold spots (4 working traffic signals), and police control was also seen at only a few places. There were cameras installed at most of the places (19 out of 30 spots).

13 out of 15 Hotspots were in areas where high number of Heavy motor vehicles were observed.

Traffic calming measures such as road studs, rumble strips, delineators and streetlights made driving easier and visibility better at night.

Figure 3.19 Potential Problem Areas in Road Safety Infrastructures



Driving on the wrong side, unauthorised accessing of national highways by cyclists and pedestrians whilst absence of pedestrian infrastructure such as sidewalks, crosswalks and footbridges was a common sight on both hotspots and cold spots.

Figure 3.19 summarises the common findings.

3.4 Mapping of Ambulances and Health Facility

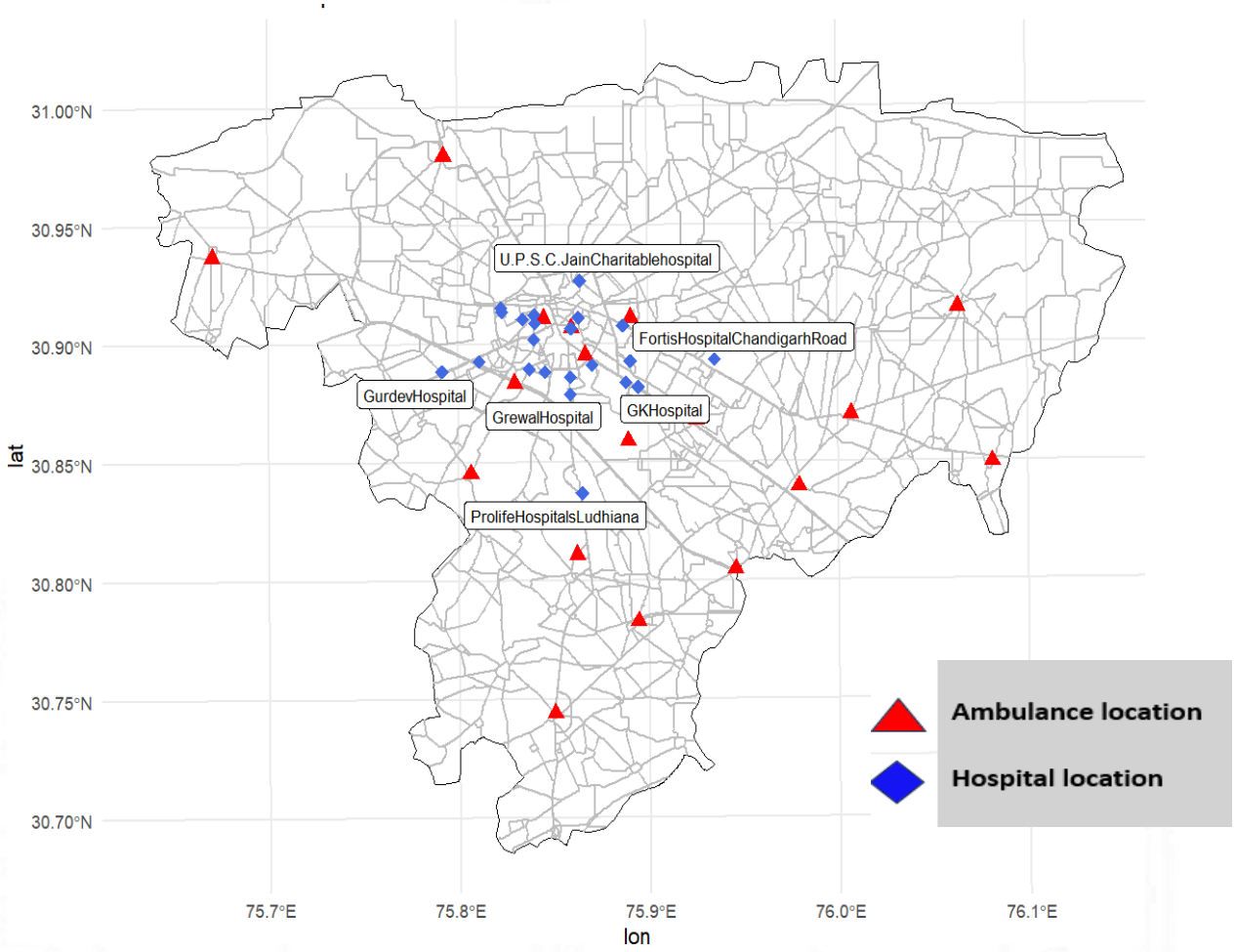
The mapping of ambulances and health facilities using Geographic Information Systems (GIS) has yielded valuable insights into the spatial distribution and accessibility of emergency medical services within the study area. Through meticulous data collection and analysis, the following finding emerged:

1.Spatial Distribution: The distribution of ambulances and health facilities across the region was depicted on a choropleth map to get a comprehensive overview of the geographic coverage of emergency medical services, highlighting areas with high concentrations of facilities as well as underserved regions. The list used to plot the map has been shared as pre-processed dataset in methods.

It can be seen that ambulances are distributed at various points throughout the city, however the hospitals providing 24 hr emergency care are clustered near the city centre. This might make accessibility difficult for farther off hotspots. To investigate this further, travel time and distances were estimated as described in the next section.

Figure 3.20 is a choropleth map showing distribution of ambulances and selected hospitals within the city.

Figure 3.20 Distribution of Ambulances and selected 24hr Hospitals in Ludhiana



3.5 Estimating Travel time and distances.

The purpose of this section is to analyse the availability of emergency medical services and potential response times to road traffic crashes at identified hotspots. The distances between crash sites and ambulance stops can provide information about the performance of emergency response systems as well as chances to improve access to medical assistance in the case of a traffic crash.

3.5.1 Results: Ambulance Availability at Crash Hotspots

Table 3.14 Ambulance Locations and Distances from Crash Hotspots

No.	(Line ID)	Ambulance location	Distance (km)
1	169	Gurudwara Sahib Village Tibba (PB2020TR3938C)	3.8
2	481	CHC Dehlon (PB02BP9503)	6.4
3	612	Gurudwara Feruman	5.1
4	1207	Police Station	5.8
5	1361	Guru Nanak Stadium (T0721CH8122A)	2.5
6	1415	CHC1	4.5
7	1714	Gurudwara Sahib Village Tibba (PB2020TR3938C)	3.9
8	2841	Police Station	4.2
9	3449	Police Station	2.5
10	3573	CHC Subhash Nagar Ludhiana (MH2020TR1261S)	4.5
11	3731	CHC Dehlon (PB02BP9503)	14.9
12	4255	Gurudwara Sahib Village Tibba (PB2020TR3938C)	3.9
13	4310	Police Station	5.9
14	4314	Dhandari Khurd	5.3
15	4618	Khohara Chownk (MP11TRAV7146)	5.2
16	4625	Khohara Chownk (MP11TRAV7146)	6.3
17	5171	PHC Ladowal (MH2020TR0909S)	9.8
18	5172	PHC Ladowal (MH2020TR0909S)	9.4
19	5190	CHC Subhash Nagar Ludhiana (MH2020TR1261S)	4.7
20	5198	Gurudwara Feruman	8.3
21	5253	CHC Subhash Nagar Ludhiana (MH2020TR1261S)	3.3
22	5300	Gurudwara Sahib Village Tibba (PB2020TR3938C)	3.9
23	5350	CHC Subhash Nagar Ludhiana (MH2020TR1261S)	6.2
24	5351	CHC Subhash Nagar Ludhiana (MH2020TR1261S)	6.2
25	5369	Gurudwara Feruman	4.6
26	5398	MCH Vardhman (T0921CH0840B)	3.1
27	5426	CHC1	4.8
28	5440	Dhandari Khurd	4.7
29	5864	CHC Subhash Nagar Ludhiana (MH2020TR1261S)	6.4

This analysis examined the proximity of ambulances to potential crash hotspots using the OSRM package (function: osrm:route) in R which is an online data source which used the road network to estimate distances .The data included 29 hotspot locations and their distances from the nearest ambulance.

Key Findings:

The nearest ambulance location was found to be 2.5 kilometers away from a hotspot (Guru Nanak Stadium, Line ID 5).

Several hotspots had ambulances within a 4-kilometer radius (e.g., Gurudwara Sahib Village Tibba, Police Station).

The farthest ambulance was 14.9 kilometers away from a hotspot (CHC Dehlon, Line ID 11).

Observations:

The analysis highlighted a variability in ambulance proximity to crash hotspots. While most hotspots had ambulances within a close range, hotspots near the city periphery had longer travel time due to larger distances.

3.5.2 Travel time from Ambulance Halt point to Hotspot

Travel Time Calculation:

Similar to distance time estimation, using R and the *purrr* and *dplyr* packages to the travel times from multiple ambulance locations to crash hotspots was determined using a travel time matrix and then the ambulance with the minimum travel time was determined for each hotspot location.

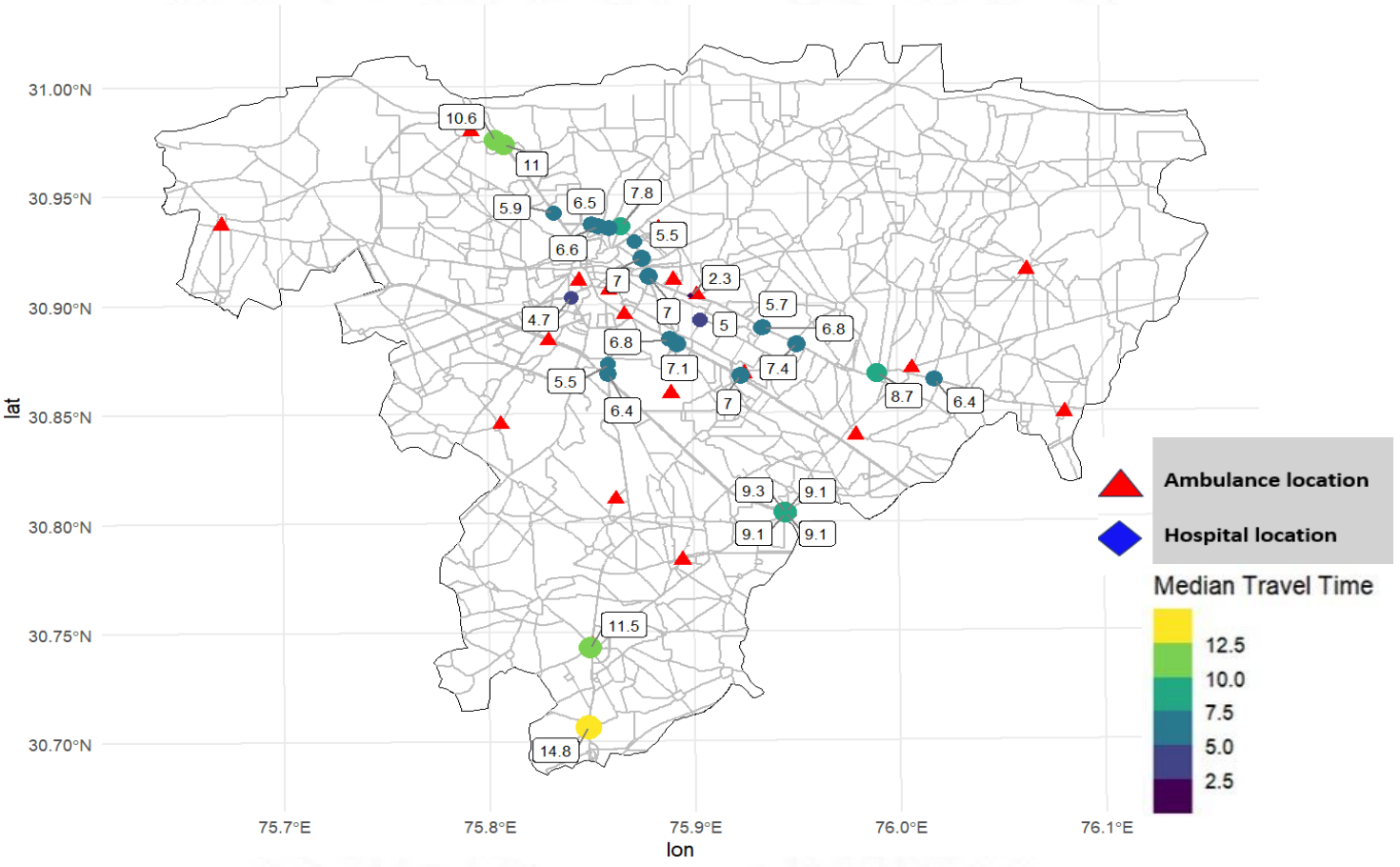
Here is a snippet of the function used:

travel_time <- osrm::osrmTable(loc = merged_df) which calls the **osrmTable** function from the osrm package, passing the merged_df (ambulance and hotspot) as the location parameter loc. This function calculates the travel time matrix between the ambulance location and each crash location.

Using the information generated through travel time matrix a plot was created using

ggplot2 which displayed median travel time in minutes. Warmer colors represent longer travel times, while cooler colors represent shorter travel times. It is clearly visible that for the hotspots around the city boundaries, the ambulance is taking more time to reach. The longest time being 14.8 mins, near the periphery while within the city centre it takes around 6-8 mins to reach the crash hotspot. The Avg. Site Response Time (SRT) i.e. the time from receiving the call to reaching the site for accepted calls is approx. 10min. The calculated durations fall within this range as depicted in figure 3.21.

Figure 3.21 Travel time – Ambulance halt point to Hotspot location

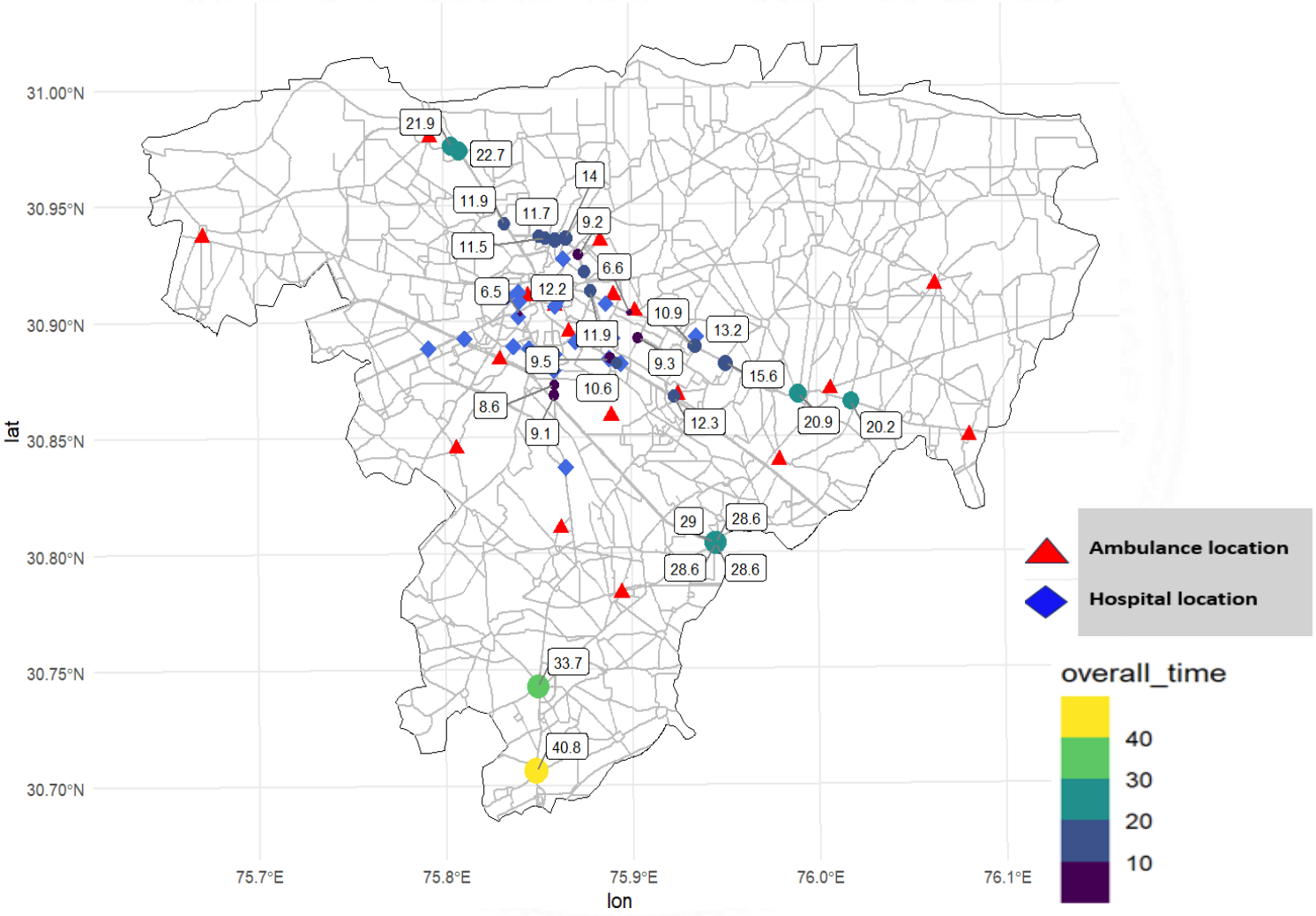


3.5.3 Overall Travel time from Ambulance Halt point to Hospital

Similar to ambulance time estimation here the total travel time from ambulance halt point to crash location and to nearby 24 hr trauma centre was done. A travel time matrix was created which then identified the hospital with the minimum travel time for each hotspot.

The travel time matrix formed for overall time estimated from each hospital, the travel times to all crash hotspots. The results were combined into a new data frame with each column representing a hospital and then further minimum time was calculated.

Figure 3.22 Overall travel time – To nearest 24hr ER



Using the information generated through travel time matrix a plot was created using ggplot which displayed median travel time in minutes. Warmer colours represent longer travel times, while cooler colours represent shorter travel times. It is clearly visible that for the hotspots around the city boundaries, the overall time was more time to reach. The longest time being 40.8 mins, near the city centre it takes around 10-15 mins to reach the crash hotspot.

The Avg. Hospital Response Time (HRT) i.e. the time taken in transferring the victim from the site to the hospital is approx. 30min, and hospital response time mostly falls within the defined range. The response time to various hospitals has been depicted in figure 3.22.

CHAPTER-4

DISCUSSION AND CONCLUSION

The study investigated road crashes in Ludhiana city from 2020-2022. A total of 1310 crashes were reported and 948 of them were fatal. Crash attributes were analysed using digitized police data obtained from PRSTRC for the years 2020-2022. This data included information such as the crash date, location, vehicle type, outcome, collision type, and more. Geospatial analysis was used to identify crash hotspots. Furthermore, the distribution of ambulances and hospitals was investigated, and average site and hospital response times were calculated.

The city ranks 2nd in a study among 53 cities in India with average fatality rate of 21.4 per 100,000 population which is almost twice the national average (Tiwari et al., 2023). There is an urgent need to improve road safety and reduce social cost of crashes.

Most road fatalities (72%) occurred on National and State Highways, which collectively account for only 5.93% of Punjab's total road length. The crash data across various police stations within Ludhiana CP provide valuable insights into the geographical concentration of crashes. The police stations with highest number of reported crashes (Sahnewal, Dehlon, Division 6) were towards the south-east part of the city along major highways such as NH-44, NH-5, and SH-11. This suggests potential correlation between high traffic volume corridors and increased crash rates. This observation was in concordance to (Asija et.al , 2023.) report assessing road safety for Ludhiana city for year 2019-2021.

Most crash victims were male. This trend, which is seen internationally, with females comprising a minority share of road deaths is notably pronounced in India, where the proportion of female fatalities is among the lowest globally. Indian data highlights that only

around 6 percent of motor vehicle license holders are female, indicating a disproportionately lower presence of women in road traffic and hence lower risk of fatality(*Statista*, 2020).

Looking at the type of collision, a high number of hit pedestrian, rear-end and head-on collisions were observed. This is in concordance to the report by (Tiwari et al., 2023) where rear-end collisions were high on all types of highways. One of the reasons behind this could poor visibility at night as inferred from the observations.

The high incidence of head-on crashes~ 11.6% can be attributed to the observation that even on roads with medians, tractors and other vehicles preferred to exit from roadside access points in the incorrect direction, since the cut in the median was too far away in some cases.

Other observations were also in concordance with studies done in similar scenarios- (Kaur Dhanoa et al., 2019),(Haque et al., 2022),(Basu et al., 2020). The association between higher number of fatalities on national highways could also be established from these studies.

According to the results of the current study, Vulnerable Road users (VRUs) such as pedestrians, bicyclists and motorists constituted 89.1% of the fatalities while car occupants were roughly 6%. The findings are similar to a detailed study of police reports of road deaths that was conducted in nine Tier-I and Tier-II studies by for the 2008-2011 period by (Tiwari et al., 2023). The proportion of vulnerable road users among all road deaths in these cities range between 84% and 93% compared while Car occupants constituted between 2% and 7% of all road deaths(Tiwari et al., 2022),(Mohan, 2004),(Singh and Dhattarwal, 2004). Even though the study indicates strong correlation between pedestrian involvement and fatality, there may be underreporting of pedestrian injuries overall.

Most instances (64.5%) were reported to be caused by overspeeding or rough driving. This is a problem because most sections of the IPC (listed in methods) require that the "cause" of the crash be documented as "fault of the road user," which could imply that most instances were simply recoded as instances of "human error," leaving no room to determine the other causes. However, the data, when coupled with on-site observations, show a significant incidence of over speeding and rough driving (Dash et al., 2020; Gopalakrishnan, 2012; Shafabakhsh et al., 2017).

The distribution of traffic crashes by time of day indicated that there were more crashes at night than during the day. Peak crash times from 6 to 9 p.m. have been recorded in analysis of road deaths in 27 districts of Chhattisgarh and11 districts of Haryana by (Mohan et al., 2016; Tiwari et al., 2023) which is similar to this study. The peak at nighttime is indicative of poor visibility and higher incidence of driving at higher speeds due to lower vehicular traffic. It can also be the influence of alcohol in some cases which could be inferred from observations and studies (Alharbi et al., 2022; Besharati et al., 2016; Pal et al., 2019)

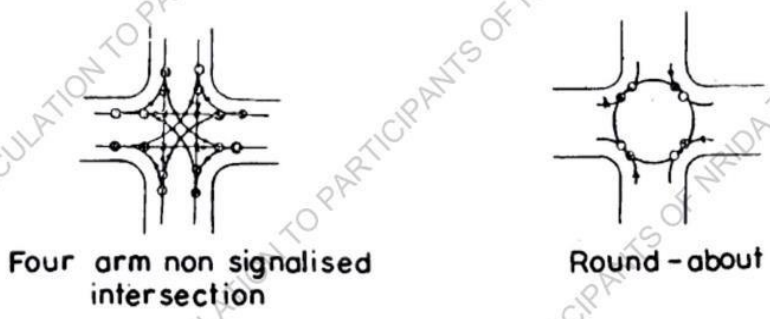
The percentage of road fatalities per category of road user in 17 Indian cities was analysed by (Banerjee et al., 2023, 2024; Mohan et al., 2016).The analysis used case-level road mortality data recorded from police crash data. In these cities, collisions involving trucks, cars, and buses account for the greatest percentage of fatalities across all road user groups, particularly those that are more vulnerable. These finding could be related to the results observed from the collision matrix in current study where 58% of the collisions were caused due to light motor vehicles such as cars, vans etc. followed by trucks and buses. Because pedestrians have to share the road space with MTWs due to lack of proper facilities on these cities' arterial routes, it is possible that there are more crashes involving MTWs and VRUs fatalities with MTWs as the impacting vehicle ~9%. The most interesting finding is high

proportion of single vehicle collisions in Chhattisgarh cities similar to the finding in Ludhiana city ~15%.

using the pre-structured check list to conduct an inspection of the hotspots and coldspots, it was found that there was a clear lack of functioning traffic signals at most sites. However, most spots did have a camera installed, the working of which cannot be commented upon. The hotspots had high presence of trucks and buses and a clear lack of street lighting and pedestrian infrastructure. The lack of lighting caused glare while driving. The coldspots had lesser traffic of buses and trucks, there were traffic calming measures like rumble strips, delineators and road studs observed at more places. Another

observation is the presence of roundabouts at intersections; The hotspots did not have any roundabouts but had 4-armed junctions. Literature suggests that roundabouts are the safest kind of junctions due to lower number of conflict points as shown below (Briz-Redón et al., 2019).

Figure 4.1 Roundabouts safer due to lesser number of conflict points



Another interesting finding is the identification of hotspots near service roads on highways, where there is mixing of high and low speed traffic. Even though, service roads are meant to offer more safety on highways, the practice of driving on the wrong side, unauthorised accessing of national highways by cyclists and pedestrians whilst absence of pedestrian

infrastructure such as sidewalks, crosswalks and footbridges could have increased number of crashes.

Furthermore, it was interesting to determine trajectory of crashes over the years using google photos from 2022 as the observations were recent but the hotspots were determined using previous year data, therefore some hotspots were newly modified or constructed and some mentioned risk factors were eliminated. An additional noteworthy finding was that there was a high overall vehicle density in every hotspot. If the study had access to a real-time vehicle density, the trends would have been intriguing to analyse.

It was noted intersections housed the majority of the hotspots found in the current investigation . (Ahmadi et al., 2017; Briz-Redón et al., 2019) who had also determined the effective factors and evaluated their significance in intersection crashes, this was consistent with their findings. The optimal method for gathering, storing, and presenting geographic data about traffic crashes was determined by (Amiri et al., 2021; Haque et al., 2022; Xie and Yan, 2008, 2013). Geographic Information Systems (GIS) facilitated the utilization of existing resources and assist in identifying variables that are not detected using standard statistical methods, allowing for the making of trustworthy decisions. Additionally, application of GIS fosters greater cooperation among all participants in the event and offers a combined language to explain the information (Mohammed et al., 2019, 2023).

For many geospatial research studies, especially those on healthcare accessibility, travel time estimation is essential. The approach to ascertain the accessibility of healthcare facilities in the current study was chosen using study by (Fu et al., 2023), which offers a comparative analysis of six approaches for driving time estimation on geospatial big data in the USA. OSRM (Open Street Route Map) was chosen as it is open source, affordable and accurate. The response time and travel time were found well within the ideal limits but it has to be kept in mind that the that the study was done within city limits where

accessibility is generally better and whether the victim receives timely care once he or she reaches the facility is also something we cannot comment upon. (Misra et al., 2023) reported that even though 91% of hospitals had in-house ambulances, most hospitals lacked the presence of general doctors (practitioners), specialists, and nursing staff dedicated to emergency departments (EDs) in relation to the average patient footfall, although having sufficient total numbers of essential human resources. So, it will be noteworthy to dwell into that further. Furthermore, healthcare accessibility via ambulances were adequate (30 to 60 mins) within the study area (urban Ludhiana) but the usage of ambulance is limited to just 17% and even then, around 85% of the times, it is to carry a dead body.

Pre-hospital care is being provided by the state government regulated ambulances in many states including Punjab by Emergency Management and Research Institute with a common toll-free number 108. The command centre, however, is neither located or operated by the government or emergency departments. The 108 ambulance services do not send any pre-hospital notifications to the emergency departments. Thus, pre-hospital EMS in India is rudimentary and requires modernization and integration with hospitals at the state and national levels. India likewise lacks a universal toll-free number, and there are multiple numbers that connect to ambulance services for various emergency situations.

There is a myth around emergency medical care that not much can be done in lower- and middle-income countries since EMS is inherently expensive needs to change.

Even though emergency medical care cannot be equated to ambulances and transport alone, it can definitely be made more efficient. This would be both simple and effective.

Strengths

1 **Comprehensive Data Analysis:** The study analyses road traffic crashes in Ludhiana city, considering geospatial distribution, crash characteristics and collision types. This comprehensive method provides a thorough awareness of the region's road safety status.

2 **Integration of GIS Technology:** Using newer sources of data such as road network to the crash dataset and further estimation of time required for ambulance to reach the spot and then to the hospital allows the research to effectively evaluate spatial data and identify crucial areas for action. GIS allows for the visualization and comprehension of complicated data, improving the quality and dependability of the results.

3 **Evidence-Based Recommendations:** The study's recommendations are based on an analysis of empirical data, ensuring that initiatives are guided by evidence rather than conjecture. This increases the chances of successful adoption and efficacy in resolving road safety concerns.

4 **Actionable findings**: One of the study's main strengths is its capacity to produce actionable data that can drive practical measures to improve road safety in Ludhiana. By conducting a thorough analysis of road traffic crashes and identifying crucial areas for intervention, the study provides policymakers and stakeholders with actionable information that can be converted into

effective programs.

Limitations

1 **Data source concerns:** International literature(Abay, 2015) reveals that injury and non-fatal crash from Police sourced data might suffer from reporting and numerous other biases, such as relative under-reporting for pedestrian and bicycle injuries, night-time crashes, hit-and-run cases, and crashes on rural roads. However, in this study the investigator has used the data in a pragmatic way to delineate the cluster locations and time requirements.

2 Dataset was from the year 2020-2022 which was correlated with the latest road network, ambulance, and hospital locations so, there could be some mismatch.

3 Information on age and sex of the people involved in the crashes were lacking in the PRSTRC data. However, the investigator has painstakingly extracted that from a subset of data using the publicly available FIR reports, to reduce the potential errors in analysis.

Conclusions

Crash hotspot identification by incorporating the openly available road network and use of free and open-source resources, add value to the routine traffic records. This can help implementors and decision makers alike.

A preliminary analysis of the hotspots around the city limits revealed many correctable factors like lack of traffic enforcers or other traffic calming measures during peak traffic hours that could be adding to crash cases.

Study is useful in pointing out present situation of crashes in the city and the healthcare accessibility, by way of estimating the time required to bring the casualties to hospital. However, more efforts should be brought in for optimal use of the 108 Ambulance services for moving casualties.

This 2020-2022 study on road traffic crashes in Ludhiana city sheds light on the geographical distribution, causes, and features of crashes in the region. Despite efforts to address road safety concerns, the high fatality rate and crash frequency emphasize the critical need for comprehensive interventions.

In a nutshell, the findings emphasize the necessity of improving road infrastructure, strengthening traffic management, boosting emergency response systems, and increasing road safety education. By implementing these recommendations, policymakers and stakeholders can help to reduce the social and economic costs of road traffic crashes while also increasing the general safety and well-being of the Ludhiana population. Furthermore,

the study highlights the need of using GIS technology and data-driven methodologies to guide evidence-based decision-making and promote targeted interventions.

Recommendations

- Spatial analysis of routine traffic data helps in delineating crash prone locations within the city, facilitating potential targeted interventions. This could include interventions to ameliorate the risk elements found in the crash-prone locations in the study, like installing traffic calming features such as rumble strips, delineators, chevron boards etc. Additionally, improving lighting at night and pedestrian infrastructure such as crosswalks and footpaths to protect vulnerable road users can be useful.
- Understanding dynamics of crashes such as peak times of can be useful for effective enforcement. More traffic enforcers can be deployed during peak hours, to restrict risky behaviours such as driving on the wrong side or unauthorized access onto highways. Optimizing traffic signal usage during peak hours can further enhance traffic flow and reduce congestion, thereby minimizing the chances of crashes.
- The study showcase use of Geographic Information Systems (GIS) for road safety and the value addition of traffic data by combined analysis with publicly available road network data. This helps in estimating the travel time for managing the accident victims, using free and open-source resources.
- Lastly, the apparently low utilization of ambulance services in the study area, despite the positioning of 108 ambulances near accident prone areas, suggests a gap in public awareness on traffic crash management. Launching targeted awareness efforts to educate the public about the availability and importance of emergency ambulance services, such as the 108-ambulances using various platforms can be useful.

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Annexure I: ODK Observation Checklist

Spatiotemporal Analysis of Road Traffic Crashes to minimize response time in Ludhiana City , Punjab Observation Checklist - Black Spots vs. Regular Roads

Lankmark :

Location

- ◯ Hotspot
- ◯ Cold-spot

Road type:

- ☐ Expressway
- ☐ National Highway
- ☐ State Highway
- ☐ Others, specify in Notes

Speed Limit specified :

- ☐ <40
- ☐ 40-60
- ☐ 60-80
- ☐ <80
- ☐ Not available

Checking on all that is observed and is applicable , if the whole section is not applicable, check on NA, Any additional findings are added as notes.

Feature/condition

Road feature, select one

- ◯ Unpaved
- ◯ Paved-Straight
- ◯ Paved-Curved

Annexure I: ODK Observation Checklist

Road Conditions, if paved :

- [ ] Presence of Potholes (Visible cracks or depressions in the road surface)
- [ ] Uneven Patches (Visible variations in road level)
- [ ] Cracking (Types of visible cracks, e.g., alligator cracks, longitudinal cracks)
- [ ] Edge Drop-Offs (Visible abrupt changes in road level)
- [ ] Smooth Surface Texture

Others (specify here in notes):

Shoulder and Roadside Conditions

- [ ] Absence of Paved Shoulders (Clear lack of paved shoulder)
- [ ] Narrow Shoulders (Width of shoulders less than standard)
- [ ] Vegetation Encroachment (Visible overgrowth onto road)
- [ ] Presence of Roadside Barriers (Concrete or metal barriers alongside the road)
- [ ] Obstacles on Shoulders (Visible obstacles such as debris or parked vehicles)
- [ ] NA

Others (specify here in notes):

Alignment deficiencies

Is there a presence of tight curves with a low curve radius that may pose a risk to road safety?

- ◯ Yes
- ◯ No

Are there appropriate warning signs or road markings to alert drivers to upcoming curves and alignment changes?

- ◯ Yes
- ◯ No

Others (specify here in notes)/NA:

Roadside Hazards:

- [ ] Guardrail Condition (Observable presence condition of guardrails)- Good
- [ ] Guardrail Condition (Observable presence condition of guardrails)- Bad
- [ ] Presence of Utility Poles (Observable presence of utility poles)
- [ ] Ditch Condition (Observable condition of roadside ditches)
- [ ] Obstructions on Roadside (Observable roadside obstructions)
- [ ] Overhanging Trees or Vegetation (Visible overhanging trees or vegetation)
- [ ] NA

Annexure I: ODK Observation Checklist

Others (specify here in notes):

Road Markings and Signage:

- [ ] Absence of Road Markings (Lack of painted lane markings)
- [ ] Faded Lane Markings (Visibility and condition of lane markings)
- [ ] Crosswalks, if Present and if present, are they maintained well - Condition (Presence and condition of pedestrian crosswalks)
- [ ] Visibility of Stop and Yield Signs (Clearly visible)
- [ ] Visibility of Stop and Yield Signs (obstructed signs)
- [ ] Adequacy of Directional Signage (Clarity and visibility of directional signs)
- [ ] NA

Others (specify here in notes):

Lane Changes and Merges:

- [ ] Number of Lanes (Single)
- [ ] Number of Lanes(Multiple)

Visible signs or road markings indicating the absence of a median or central reservation on undivided roads.

- ◯ Yes
- ◯ No

Others (specify here in notes):

Speed Breakers:

- [ ] Speed breakers painted with high-visibility markings to ensure they are visible from a distance to drivers
- [ ] Proper road signs indicating the presence of upcoming speed breakers
- [ ] NA

Others (specify here in notes):

Speed Calming devices: Speed Speed Calming devices:humps/bumps

- ◯ Yes
- ◯ No

Speed Calming devices: Rumble strips

- ◯ Yes
- ◯ No

Annexure I: ODK Observation Checklist

Speed Calming devices: Cat's eye/Road studs

- ◯ Yes
- ◯ No

Speed calming mechanisms:

- ☐ Are speed calming devices painted with high-visibility markings to ensure they are visible from a distance to drivers
- ☐ Are there proper road signs indicating the presence of upcoming speed breakers
- ☐ NA

Others (specify here in notes):

_____

Access Control

Clear road signs indicating the presence of access points and the need to yield to oncoming traffic?

- ◯ Yes
- ◯ No

Barriers or physical measures visible to prevent unsafe or unauthorized access onto the road?

- ◯ Yes
- ◯ No

Is there evidence of traffic calming measures, such as speed humps or road narrowing, near access points to slow down vehicles?

- ◯ Yes
- ◯ No

Designated pedestrian crossings or sidewalks visible near access points for pedestrian safety?

- ◯ Yes
- ◯ No

Proper road lighting and visibility observable at access points, especially during nighttime?

- ◯ Yes
- ◯ No

Others (specify here in notes):

_____

Annexure I: ODK Observation Checklist

Lighting and Visibility:

Type of street light

- ◯ LED Street light
- ◯ FL Lamps
- ◯ Sodium vapor lamps
- ◯ Mini high mast
- ◯ High mast
- ◯ Others

Functionality of Street Lights

- ◯ Yes
- ◯ No

Visibility Distance During Nighttime

- ◯ Yes
- ◯ No

Glare from Oncoming Vehicles

- ◯ Yes
- ◯ No

Adequacy of Lighting at Intersections

- ◯ Yes
- ◯ No

Others (specify here in notes):

_____

Traffic / enforcement

Traffic Flow and Congestion

- ☐ Traffic Density (Heavy Observable traffic congestion)
- ☐ Traffic Density (Light/Moderate Observable traffic congestion)
- ☐ Long Queue Lengths at Intersections (Length of vehicle queues at intersections)
- ☐ Presence of Bottlenecks (Causing Observable traffic bottlenecks, because of the design of the road or badly timed traffic lights, or sharp curves)

Others (specify here in notes):

_____

Annexure I: ODK Observation Checklist

Intersection Control:

- [ ] Functionality of Traffic Signals (Working)
- [ ] Functionality of Traffic Signals (non-working traffic signals)
- [ ] Presence of Pedestrian Signals (Visible pedestrian signalization)
- [ ] Stop Bar Positioning (Correct positioning of stop bars)
- [ ] Right-of-Way Compliance (Observations of vehicles yielding correctly)
- [ ] Left-Turn Arrow Signals (Presence and functionality of left-turn arrow signals
- [ ] NA

Others (specify here in notes):

Junction Geometry:

- [ ] Intersection Layout (T-intersection)
- [ ] Intersection Layout (Roundabout)
- [ ] Presence of Dedicated Turning Lanes
- [ ] Turn Prohibitions or Restrictions
- [ ] Sight Distance at Intersections
- [ ] NA

Others (specify here in notes):

Traffic Signalization and Timing:

- [ ] Presence of Traffic Lights
- [ ] Properly functioning Traffic lights
- [ ] Adequacy of signal timings
- [ ] Observations of signal violations or confusion
- [ ] NA

Others (specify here in notes):

Traffic Enforcement:

- [ ] Traffic Police Presence and Visibility
- [ ] Operating Speed Cameras
- [ ] Operating Red Light Cameras
- [ ] Enforcement of Traffic Rules at Intersections
- [ ] NA

Annexure I: ODK Observation Checklist

Others (specify here in notes):

_____

Type of Surrounding Establishments and Safety Measures:

- ☐ Schools and Educational Institutions: Safety around schools is paramount to protect children who may be walking or cycling to school. Looking for speed limits and speed breakers are essential in these areas.
- ☐ Hospitals and Healthcare Facilities: Hospitals need smooth traffic flow for ambulances and emergency vehicles. Observing for clear signage and well-marked drop-off zones and noting anomalies, if any
- ☐ Markets and Shopping Centers: High pedestrian traffic areas require careful traffic management to prevent accidents.Congested shopping spaces and streetside markets can add to accidents.
- ☐ Residential Areas: Traffic safety is vital in residential neighborhoods, especially where there are children playing or people walking pets. Speed limits, speed bumps, and traffic calming measures are to be observed , noting anomalies if any.
- ☐ Workplaces and Office Buildings: Large office complexes need well-designed parking and traffic flow systems to avoid congestion and accidents.Observing for coordination in these areas.
- ☐ Public Transportation Hubs: Bus stops, train stations, and transit centers need safe pedestrian access, designated pick-up/drop-off zones, and traffic signals for efficient and safe transit.
- ☐ Event Venues and stadiums : During events, traffic can become congested. Well-organized parking, traffic management, and clear signage are essential, observing any anomalies.
- ☐ Tourist Attractions: Popular tourist destinations often experience heavy traffic. Proper traffic management and parking facilities are crucial for both residents and visitors.
- ☐ Construction Sites: Road safety measures are essential around construction sites to protect workers and minimize traffic disruptions.
- ☐ Railway Crossings: Safety at railway crossings is critical to prevent accidents with trains. Clear signage, barriers, and flashing lights are necessary.
- ☐ Industrial Areas: Industrial zones need safe entry and exit points to avoid traffic bottlenecks and accidents.Many Heavy Goods Vehicles may be moving around,
- ☐ Parks and Recreation Areas: Safety in and around parks and recreational areas, including parking facilities and designated pedestrian zones, is vital.
- ☐ Rescue and Emergency Services: Areas around fire stations, police stations, and emergency response centers require clear access for emergency vehicles.
- ☐ Places of worship: Safety around entry and exit points around places of worship is important for avoiding unnecessary congestion
- ☐ Others, specify in Notes

Others (specify here in notes):

_____

Annexure I: ODK Observation Checklist

Presence of Work Zones/Construction Zones:

- [ ] proper advance warning signs indicating the upcoming work zone
- [ ] the work zone have a clearly defined layout with cones, barrels, or barriers
- [ ] lane shifts and detours are clearly marked with proper signage and there is adequate separation between the work area and the traffic lanes
- [ ] construction equipment and materials stored away from traffic lanes
- [ ] the areas are well lit
- [ ] NA

Others (specify here in notes):

Heavy Goods Vehicles (HGVs):

- [ ] High Number of HGVs
- [ ] To avoid risks Related to Right-Turning Trucks' Blind Spots, Any specified speed limits for trucks
- [ ] NA

Others (specify here in notes):

Pedestrian Infrastructure, if applicable

- [ ] Footpath
- [ ] Foot Bridge
- [ ] Zebra Crossing

Others (specify here in notes):

Surface drains- Existence

- ◯ Yes
- ◯ No

Condition :

- ◯ Functional
- ◯ Non-functional

Others (specify here in notes):

Annexure I: ODK Observation Checklist

Other observable violations / factors

Parking violations

- ◯ Present
- ◯ Not Present

Dumping materials on road

- ◯ Present
- ◯ Not Present

Irregular pedestrian crossing

- ◯ Present
- ◯ Not Present

Vegetation issues

- ◯ Present
- ◯ Not Present

Presence of ongoing road work

- ◯ Present
- ◯ Not Present

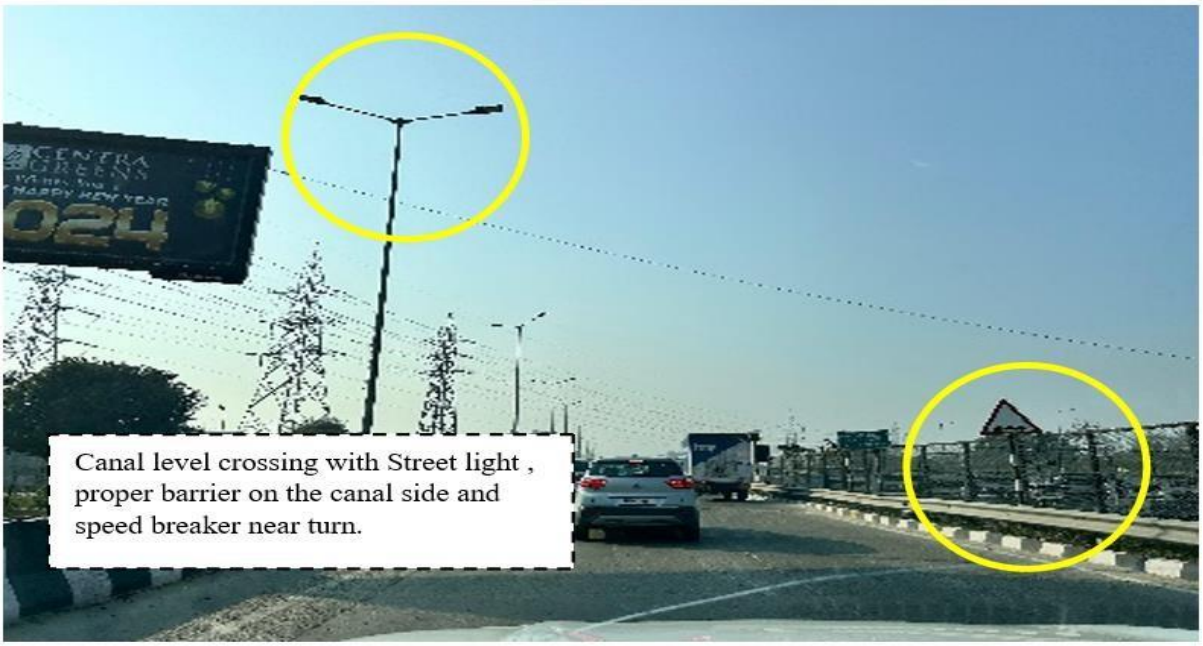
Crowding

- ◯ Present
- ◯ Not Present

Encroachment(Shops, Vendors, Building, Billboard, Others)

- ◯ Present
- ◯ Not Present

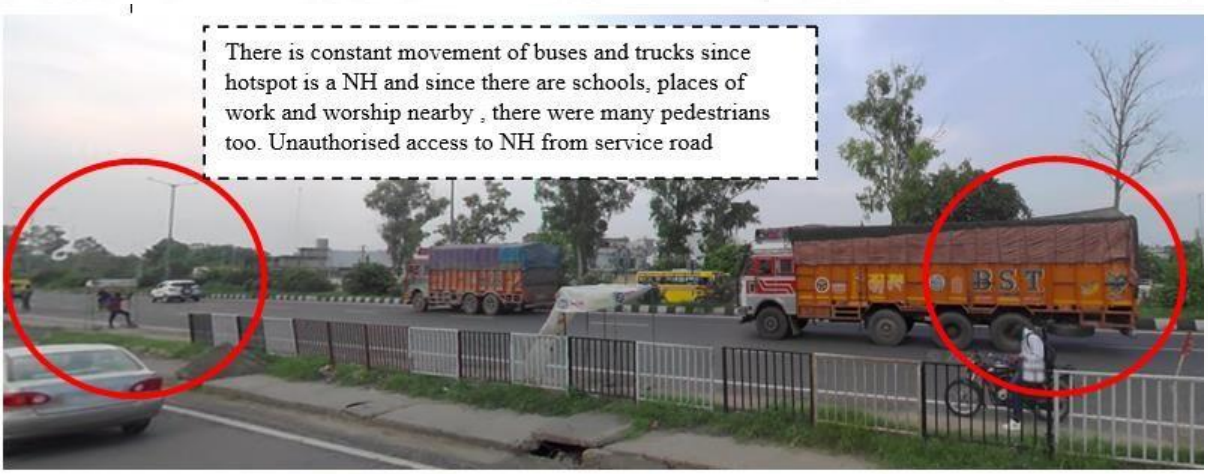
Comparisons- Pictures (Hotspots and Cold-spots)- Annexure II



Comparisons- Pictures (Hotspots and Cold-spots)- Annexure II

Comparisons- Pictures (Hotspots and Cold-spots)- Annexure II

Irregular pedestrian crossing near hotspots which is near a national highway, even though barrier has been built, people can regularly be seen crossing. There was no footbridge or pedestrian underpass nearby.



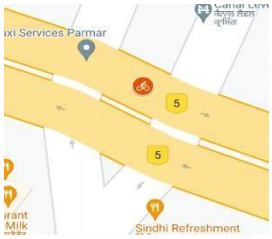
There is constant movement of buses and trucks since hotspot is a NH and since there are schools, places of work and worship nearby , there were many pedestrians too. Unauthorised access to NH from service road

Comparisons- Pictures (Hotspots and Cold-spots)- Annexure II

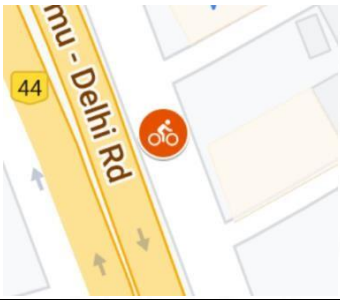
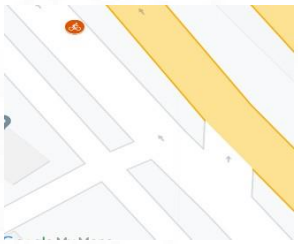
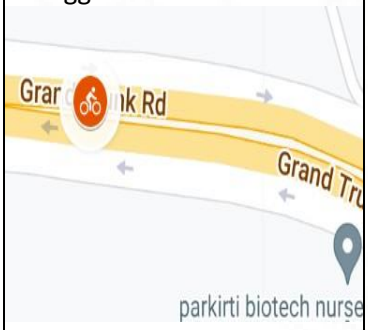
Comparisons- Pictures (Hotspots and Cold-spots)- Annexure II

Comparisons- Pictures (Hotspots and Cold-spots)- Annexure II

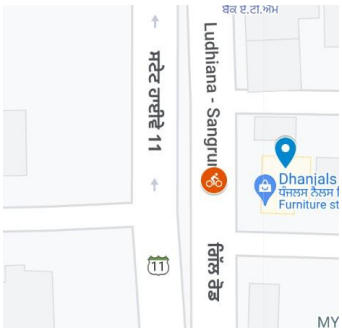
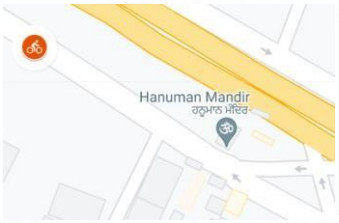
Hotspot Visit Findings- Annexure II

Spot	Site Address	Photo	Observations
1	Tibba bridge , near Sidhwan canal 		• Canal level crossing near the National Highway 5 joining to another road parallel to NH5. • There were no road markings , street lights around. • The barrier along the road over the canal was very low and even open at the end. • Many cyclists, pedestrians used this crossing but there are many HGVs also. • There was no police or traffic signal present.
1	Red moon restaurant, NH5 Canal level crossing 		• The identified hotspot is near a canal level crossing and has few restaurants and a liquor shop nearby and on the day of visit the fog was dense making visibility worse. • There were no traffic signals, traffic calming measures, pedestrian infrastructure observed or street lights nearby. • Since it's a highway spot where smaller roads join there are HGVs like trucks as well as two wheelers .
2	SH11, Milan resort 		• There are many shops and cars by the roadside , there was Dehlon police station nearby. Curved stretch of narrow road joining to a wider road. The area has a signboard marking as “Accident prone area.” • There are 2 access points nearby but access control was poor no traffic lights, physical divider, pedestrian infrastructure observed. • Formation of ruts, cracks, and potholes. HGVs (trucks and buses)
3	Bharat Nagar road , near Park Plaza	**Same road in 2022 (acc. To google photo**  **Now** 	• The area was under construction back in 2022, now the road and flyover is newly constructed. • Traffic is more orderly and stream-lined. • There was adequate lighting and parking space nearby. • There were heavy motor vehicles in the area.

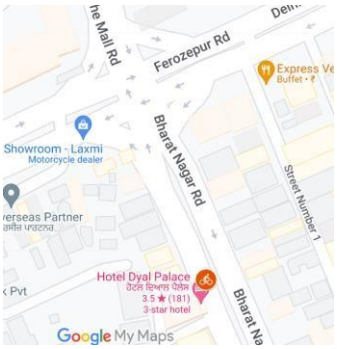
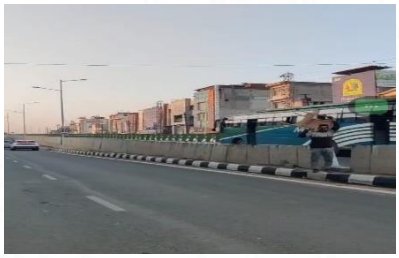
Hotspot Visit Findings- Annexure II

4	NH 44 near Kailash nagar chowk 	 	• This is near the point on the highway where NH comes down and meets with the service roads, there are guardrails to prevent access to the highway but still there was irregular pedestrian movement observed . • Local traffic through the unauthorized access on NH, unauthorized median opening, and inappropriate crossing of road . • NH does have a large number of HGVs .
5	New Subhash Nagar ,near Alliance motors 		• The road is a service road parallel to the NH44 , where the NH 44 flyover comes down and joins the service road . Road has unpaved shoulder areas where trucks and vehicles from dealerships are parked on one side and there are concrete rocks to prevent access to highway on the other side followed by railings. • Local traffic enters via unauthorized access on NH, pedestrian sidewalks filled with garbage.
6	Saroop nagar, near Greenland sr sec school 		• It's a service road running parallel to Jammu Delhi GT Road ,NH44 . Highway here has a controlled access and is well separated from the NH by railings but not so well separated with the collector road which is partly paved • Though the traffic at the time of observation wasn't much, there is constant movement of buses and trucks and since there are schools, places of work and worship nearby , there were many pedestrians too. • Few pedestrians were seen climbing the railing to cross the road.
7	Hardy's world , NH44 Phagguwal 	 	• The hotspot location is near Hardy's world which is an amusement park on the road going into the city. • Few uneven patches and ditches with no divider between NH and service road, overgrown vegetation in the middle. • Tractors were seen approaching from wrong side. • There were many HGVs and buses observed. The line markings were faded at some places and there was no pedestrian infrastructure observed. • The area was an open area with no street lights in sight, the spot was visited during day , so it's assumed the visibility will be limited at night.

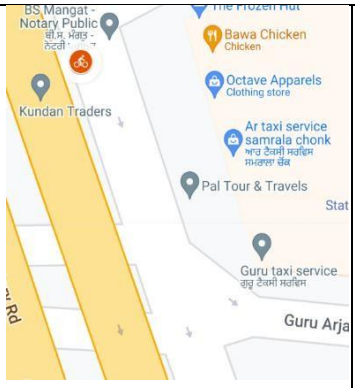
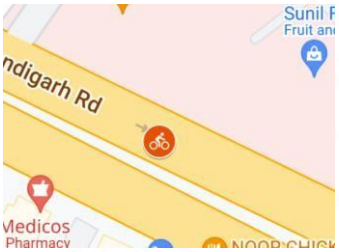
Hotspot Visit Findings- Annexure II

8	Dhanjals nails (furniture store) , Gill Road , Shimlapuri AKA Ludhiana-Sangrur Road 		• Wide road with irregular patches, utility poles, and power grid create hazards. • Parked vehicles, boards, vendors, and garbage on the roadside obstruct visibility and flow. • There are irregular pedestrian and cyclists' crossings at various access points and there is a petrol pump nearby , hence many vehicles come from the wrong side to get petrol at the station. • Crowded area with slow traffic, traffic signals, and police control, but violations of red lights and honking persist. HGVs entry prohibited. • Intersection Layout: 4-armed intersection with a dedicated turning lane in one lane only, lacking uniformity.
9	SPS Hospitals , Dholewal chowk 	 	• The observed road runs parallel to NH 44, near Sherpur Chowk, which serves as a bus stand. It is adjacent to SPS Hospital, a tertiary care center. • Traffic: The road experiences heavy traffic due to buses and trucks going to Delhi, as well as vehicles accessing NH 44. There are frequent traffic jams, with vehicles often parked along the unpaved shoulder riddled with ditches filled with debris. • Street lights are functional, but there is no pedestrian signalization. • Directional signage is adequate, but the stop sign is obstructed. There is a U-turn indicated, and the road appears to be one-way with no divider. • Security guards enforce traffic near the hospital, but police personnel are not observed. There are cameras for surveillance, but no traffic lights. • The area is congested, with various access roads from residential areas. There is a mix of establishments including a liquor shop, a temple, car showrooms, and industries. Additionally, there is a footbridge near the Indo-Canadian bus stop. • The area is frequented by public transport users, cyclists, and pedestrians, including laborers commuting to nearby factories.

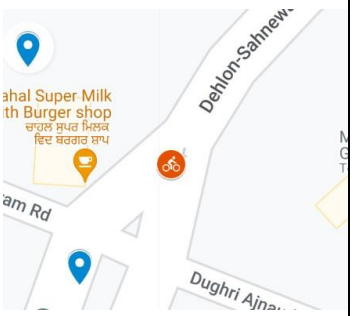
Hotspot Visit Findings- Annexure II

10	Barista lavaza expresso bar , Model Town Rd, Bharat Nagar, Sita Nagar, Ludhiana, Punjab 141001 	**Same road in 2022 (acc. To google photos)**  **Now** 	• The road is near a newly constructed flyover is lined with furniture stores, leading to narrow roadways with many parked vehicles alongside. But proper traffic enforcement is observed in the hotspot • Clear road markings are present to guide commuters through the area. • Crosswalk is present at the junction. However, shops occupy the footpath for advertising purposes. Irregular pedestrian crossing observed • Few PRTC buses are seen, but other heavy goods vehicles (HGVs) are not prevalent inthe area. • **Additional Observations (2022)**: A caution board indicating reduced carriageway due to construction work was present. However, the work zone was not well-marked, with fallen cones and missing tin sheets. Street lighting near the construction zone was insufficient, raising safety concerns at night.
11	NH5 , Chandigarh Road, sector 32A ,near Hotel Mohini resorts 	 	• The road was in decent condition with a well-defined shoulder, but pedestrians faced difficulties due to makeshift shops operating on the footpath as makeshift clothes and shoe shops operated on the footpath, hindering pedestrian movement. • All signboards were in place, and road markings, including crosswalks, were well-painted and visible. However, no stop or yield signs were found. • Traffic lights at the intersection were not functioning, and solar-powered blinkers in the divider area were also non-operational. There were no police personnel or traffic police observed during the observation. • A hotel, shopping area, and liquor shop were present around the intersection, contributing to the area's commercial activity.
12	Gurdwara Nanaksar, underpass near Guru Arjan dev road, Samrala chowk		• The road runs parallel to Biscuit Factory-GT Road (NH44) and features shops, including car rental, repair, and sales establishments, as well as a large gurdwara. • There are no road markings, guardrails, or signage indicating stopping and yielding. Utility poles are abundant, some placed too closely together. The walking pavement near the underpass is hazardous due to holes and garbage accumulation.

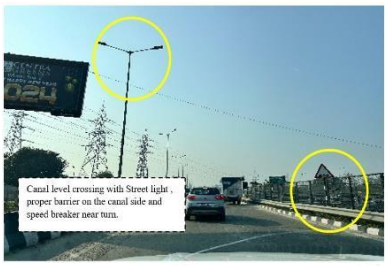
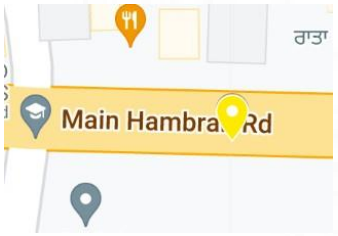
Hotspot Visit Findings- Annexure II

			• The area experiences heavy traffic, with many parked cars and trucks. The road leads to Guru Arjan Dev Road and Samrala Chowk, forming a crowded junction. The malfunctioning traffic lights exacerbate confusion and chaos. • There are no police personnel present, and the lack of speed limits specific to trucks poses safety concerns. Additionally, the drain is filled with garbage, suggesting non-functionality and potential environmental hazards.
13	Fortis hospital, Chandigarh Road 	Hole in the footpath, people walk on shoulder 	• Road condition was generally smooth, but obstacles present such as vehicles driving on the wrong side and shops encroaching on footpaths. • Near the hospital, traffic cones were present, indicating ongoing construction, possibly related to waterworks. Pedestrian sidewalks were partially under construction. • Left turn arrow signals were observed, but traffic lights were absent. • Inconsistent, with some vehicles following the right of way to overtake, but many others driving on the wrong side. • Enforcement measures: No official presence or visible cameras. • Mentioned speed limit of 50.
14	Ludhiana-sangrur Road , Lehran , Punjab 	 	• Road had numerous potholes and patches, posing a risk to two-wheelers. • Narrow paved shoulder used by pedestrian traffic, for vehicle parking, and wrong-way driving. • Surrounding environment: Many shops and overhanging trees along the road, with utility poles and advertising boards causing obstructions. • Sign boards indicating median gaps and directions, but faded markings and no crosswalks for pedestrians. • Road safety features: Reflective and rumble strips visible, but some street lights not functioning. • Lack of traffic police presence, no pedestrian signalization. • No traffic lights in the observed area, intersection located 700m away, with unmanned traffic flow and no police presence.

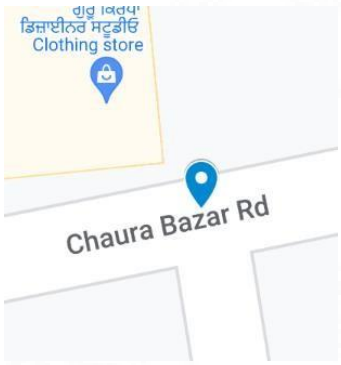
Hotspot Visit Findings- Annexure II

15	Sant Baba Nidhan Singh Ji Market, Verka Deir Dehlon Road and Garg property dealer 		• One side with unpaved shoulder, opposite side with paved marketplace area. • Lack of road markings and designated lanes. Absence of crosswalks and speed breakers, leading to unrestricted crossing. • Presence of trucks, construction equipment, and vendors. • Intersecting unpaved village roads causing traffic confusion. • No visible traffic lights, stop bars, or signage. • Unmanned traffic control leading to confusion. • Limited queuing, potential disorderliness due to unmanned management. • Presence of "GIVE WAY" board but lacking other warnings. • Few surveillance cameras, mainly near canal level crossing. • Lack of pedestrian infrastructure, posing safety hazards.

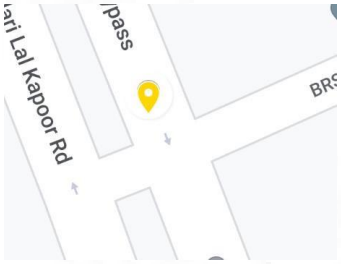
Cold spot Visit Findings -Annexure II

Spot	Site Address	Photo	Observations
1	Sixty-nine ml , South City Road canal level crossing 	 	• The road runs along the Sidhwan canal and is one of the very recently constructed roads and was very smooth with paved kerb and shoulder. The road markings and signages were adequate. • There were canal level crossings that were clearly marked and has police check posts and police was present. • The traffic is not much except near some intersection like the one moving to Sunview enclave • Some trucks were observed in the area
2	CP Residence, Civil Lines, Ludhiana, Punjab 		• The road was near a roundabout , with faded road marking but had proper road signage such as “GIVE WAY”, pedestrian crossing nearby, there were footpath and sidewalks observed. • Though there were few roadside obstructions, the traffic was light and the traffic lights were functional. There was a camera installed near the intersection. • Police presence was observed , the street lights were functional and the surrounding areas were residential areas . • Traffic calming measures such as cat eye studs and delineators were in place
3	GK Dairy, main Hambran road, Ludhiana 		• The road was in a good condition, the coldspot identified was near an intersection. Back in 2022, there was construction going here and the shoulder area had lush green trees , and the divider did not have any reflectors installed. • The shoulders had few vehicles parked here and there and a few vendors • There were many utility poles observed by the roadside, there were no ditches but few vehicles could be seen parked by the roadside • Rumble strips were observed with reflective

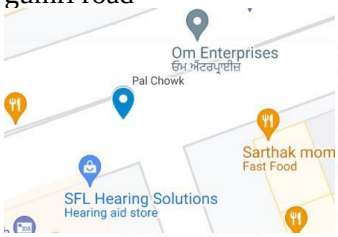
Cold spot Visit Findings -Annexure II

			studs and dividers had delinators. • No traffic lights were observed near the area • Parked Vehicles: Several vehicles were parked along the road shoulders, along with vendors occupying roadside spaces, creating potential obstructions and distractions for drivers. • Traffic Light Absence: No traffic lights were observed near the area, potentially leading to confusion or misunderstandings among road users, especially at intersections, and increasing the risk of intersection-related accidents. •
3	Guru kripa fashion plaza , Chaura bazar road 	 	• Traffic Composition: Chaura Bazar road is predominantly frequented by pedestrians, two-wheelers (such as Activa scooters, motorcycles, and bicycles), and three-wheelers (e-rickshaws, rickshaws), with few four-wheelers. Slow traffic • The road surface is mostly smooth with occasional cracks, but there are no free shoulder areas due to the presence of small shops, parked vehicles, and pedestrians occupying the roadside. • Due to limited space, there are no signboards, crosswalks, or traffic control signs, leading to chaotic traffic flow and potentially unsafe conditions for pedestrians. • Utility poles and roadside ditches are still present, further limiting available space and posing potential hazards. • Lighting and Visibility: Despite the crowded nature of the area, the presence of numerous shops and street lights ensures good visibility, especially at night. • Given its location within a main road, no police personnel are observed, and heavy goods vehicles (HGVs) are unable to pass through the area. Lack of Pedestrian Infrastructure: There are no footpaths, bridges, or designated pedestrian crossings, exacerbating safety concerns for pedestrians navigating the bustling area.

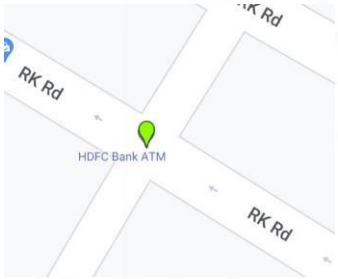
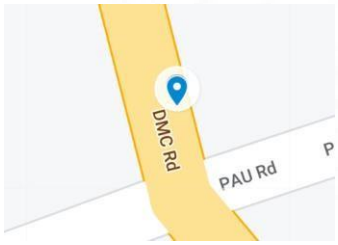
Cold spot Visit Findings -Annexure II

4	Ishmeet Singh chowk, Nehru Nagar , Ludhiana 		• Proximity to Railway Crossing and School: The road is situated near a railway crossing and a school, leading to heavy traffic flow, especially during school hours and when the railway gate opens or closes. Parked vehicles and trees line the roadside. • Signage alerts drivers about the upcoming railway crossing, and reflector strips on the stop bar aid visibility, especially at night. However, traffic congestion occurs quickly when the crossing is closed due to an approaching train. • There was a sign telling about the upcoming railway phatak/ crossing. The stopbar was equipped with reflector strips to help road users at night • Roundabout Layout: The road features a small roundabout with a dedicated turning lane. Horns are prohibited in the area, likely to reduce noise pollution and ensure safety. • Absence of Heavy Trucks: There are no heavy trucks observed in the area • There were sidewalks or crosswalks for pedestrians.
5	BRS Bypass road near NG hospital 	 	• Road Condition: The roads in the area are in good condition, with vehicles often parked on the sides and some scattered garbage in certain areas. There are numerous trees lining both sides of the road. • Traffic Signage: At the junction, there is a stop sign and a "give way" sign with a blinker, indicating traffic regulations. Rumble strips with road studs enhance visibility, contributing to safer driving conditions. • Traffic Flow: Despite moderate traffic, the traffic was observed to be moving smoothly at the time of observation, suggesting efficient traffic management. • Non-functional Traffic Lights: Although traffic lights are present, they were not functioning. However, the stop sign and yielding sign were adequately positioned to regulate traffic flow. • Intersection Configuration: The intersection is a T-type, with dedicated turning lanes and clear visibility from a distance, facilitating

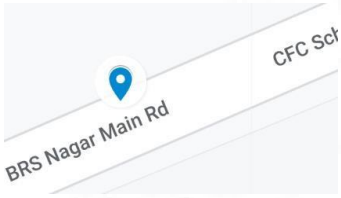
Cold spot Visit Findings -Annexure II

			6safe navigation for drivers. • Enforcement and Surveillance: No police or cameras were observed at the location, indicating a lack of enforcement of traffic rules. A blinker was present, but there was no active enforcement of regulations. • Pedestrian Infrastructure: Footpaths were observed at some places, but they were utilized by vendors to sell goods, potentially hindering pedestrian movement and safety.
6	Pal hospital, near mint gumri road 	 	• Road Condition: The road is mostly smooth with occasional cracking observed at some places. • The sides of the road are densely packed with shops, eateries, and parked vehicles, creating congestion and limited space for pedestrians and traffic movement. • Signage and Markings: Speed signboards and clear road markings are present, enhancing safety and guidance for drivers. • Parking Situation: Parking space was limited, with vehicles mostly parked along the sides of the road. • Crosswalks are clearly visible, but no dedicated footpaths are observed. • Traffic Control: Despite non-functional traffic lights, traffic flow is relatively smooth. • Cameras are installed to monitor traffic movement. • Lighting and Reflectivity: Adequate lighting, reflector rumble strips, studs, and reflective signboards enhance visibility, particularly at night. • Vehicle Composition: No heavy motor vehicles are observed, contributing to smoother traffic flow in the area.
7	Model town extension road, near canal level crossing 		• Road Connectivity: The road joins Pakhowal road, a major road, at the intersection near the cold spot, with a pass connecting directly to Sarabha Nagar, which was constructed recently. Surrounding areas are residential areas. • Alignment and Guardrails: No alignment deficiencies are observed, and guardrails are present and in good condition, contributing

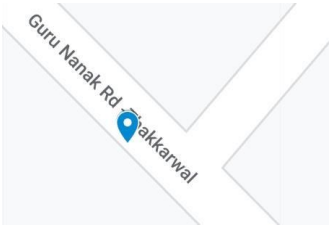
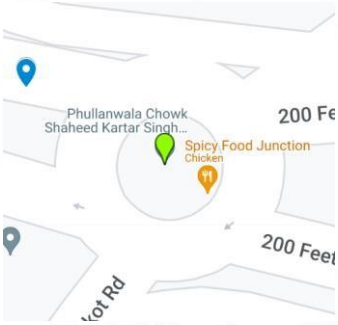
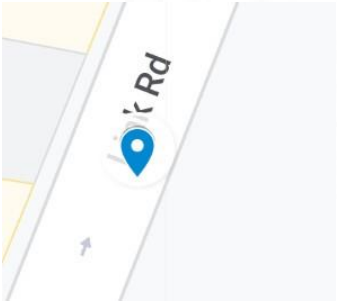
Cold spot Visit Findings -Annexure II

			to road safety. • Past Construction: Two years ago, construction activities in the area led to dustiness and congestion, but the road is currently smooth. However, trees, vendors, and parked cars remain potential obstructions. • There were no crosswalks or road markings observed, this potentially affects pedestrian safety and traffic organization. • HGVs are observed taking Pakhowal road via this route.
8	RK Road , Cheema chowk , Transport nagar, industrial area 	 	• Road Divider and Surroundings: The road divider has trees, while the opposite side features multiple utility poles, a power grid, and a transmission tower. Debris such as waste and large metal panels are visible on the roadside, possibly posing hazards to road safety. • Absence of Road Markings: Despite being wide, the road lacks markings or signages, with pedestrians and cyclists traveling on the wrong side. • Minimal Traffic and Speed Control: The road has minimal traffic and no speed breakers or speed calming measures. • No police are observed in the area, suggesting minimal enforcement of traffic regulations. • Industrial Area Nearby: The area, known as Transport Nagar, is surrounded by industries, resulting in the presence of trucks and commercial vehicles in the vicinity.
9	Sagar homeopathic pharmacy, near DMC road 	 	• Road Condition: The road is smooth with minimal cracking, but incidents of wrong-side driving were observed. • Shoulder and Surroundings: Well-defined shoulders with shops along the road, trees, parked vehicles, and occasional advertising boards. Poles and trees are scattered throughout the area, with some fallen tree branches and stray dogs observed. • Traffic Control Measures: Road markings indicate a crosswalk, and signs warn of upcoming speed breakers. Delineators near road dividers are in place . • Intersection Characteristics: The hotspot

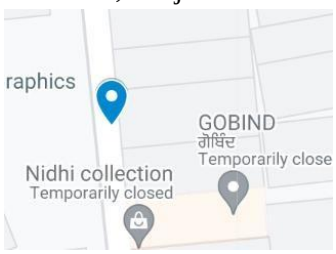
Cold spot Visit Findings -Annexure II

			intersection features two lanes merging into one, with adequate lighting and some traffic chaos, despite the absence of traffic lights. • Traffic Regulation Equipment: Blinkers and cameras are present near the area, but no functioning traffic lights are observed. The junction is a 4-armed plus-shaped junction. • Traffic Flow: Traffic moves without heavy motor vehicles or pedestrians, with some chaos at the intersection and slow-moving traffic. Overall, movement is being maintained despite the absence of traffic lights.
10	CFC Public school, BRS Nagar main road 		• The road is situated in one of the main locations in the city and is mostly smooth, with shops and parked cars lining the sides. • Presence of Parked Vehicles and Vendors: Parked vehicles and food vendors are observed along the road, potentially contributing to traffic congestion and limited space for pedestrians. • Although road markings are slightly faded, road studs are present to enhance visibility at night. Adequate lighting is observed along the road. • Traffic Flow: Traffic is minimal and moves smoothly, indicating efficient traffic management and low congestion. • Intersection Characteristics: A zebra crossing is observed at the intersection, which is a 4-armed intersection. However, no traffic lights are found in the area. • Residential Area and Absence of Heavy Vehicles: The area is predominantly residential, and no heavy goods vehicles (HGVs) are observed, contributing to quieter traffic conditions. • Pedestrian Safety Measures: The presence of a zebra crossing with rumble strips enhances pedestrian safety at the intersection.

Cold spot Visit Findings -Annexure II

11	Guru Nanak road , thakkerwal, near rosette villa 		• Road Condition and Surroundings: The road exhibits some cracks with no shoulder area , only an unpaved side area occupied by utility poles, shops, and parked vehicles. Additionally, vegetation encroaches onto a small section of the road. • Visibility of Road Markings: Road markings are visible, but there are no crosswalks or traffic signs such as stop or yield signs. • Unmarked Speed Breaker: Although there are no signs indicating a speed breaker, one is present on the road, but it lacks proper painting for visibility. • Absence of Pedestrian Sidewalks. • Lack of Traffic Control Measures: There are no traffic lights or traffic police nearby, with the nearest functioning traffic light located at Phullanwal Chowk. • Despite the observation being at night, no trucks are observed, suggesting limited truck movement in the area.
12	BRS Bypass Phullanwal chowk, near Shaheed kartar Singh sarabha memorial, Ludhiana 		• The road was smooth and in pretty good conditiom. • There was heavy traffic observed . • There were traffic calming measures such as delineators , road studs but there was lack of pedestrian infrastructure. • The junction nearby was a roundabout with adequate street lighting. • There were sign boards but a few were obstructed with posters.
13	2924, Link Rd, Transport Nagar, Industrial Area- A, Ludhiana, Punjab 141008 		• This coldspot is near SPS hospitals. • There was a working traffic signal at the junction . • HMVs were present but overall traffic was low at time of observation. • Visibility of Road Markings: Road markings are visible, but there are no crosswalks or sidewalks.

Cold spot Visit Findings -Annexure II

14	Barista lavaza expresso bar , Model Town Rd, Bharat Nagar, Sita Nagar, Ludhiana, Punjab 141001 		• The road was under construction back in 2022 and closed for a long time. • Presently the road is in good condition with proper road markings and shoulder area. • It has street-lighting and chevron boards here and there. • There was irregular pedestrian crossing observed/ • No HMVs observed near the area, the traffic was moderate during time of observation. • The police was manning the junction but the traffic signal was non operational.

Annexure III: Permission letter IEC

श्री चित्रा तिरुनाल आयुर्विज्ञान और प्रौद्योगिकी संस्थान, त्रिवेन्द्रम
तिरुवनन्तपुरम - ६९५०११, केरल, इंडिया
SREE CHITRA TIRUNAL INSTITUTE FOR MEDICAL SCIENCES AND TECHNOLOGY, TRIVANDRUM
Thiruvananthapuram - 695 011, Kerala, India
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Grams : Chitramet, Phone : +91-471-2443152, Fax : +91-471-2550728 / 2446433, E-mail : sct@sctimst.ac.in, Website : www.sctimst.ac.in

Institutional Ethics Committee

CDSCO Registration No: ECR/189/Inst/KL/2013/RR-21
DHR Registration No:EC/NEW/INST/2022/2775

SCT/IEC/2171/DECEMBER/2023 12.01.2024

Dr. Ishika Arora
MPH Student, AMCHSS
SCTIMST, Thiruvananathapuram

Dear Dr. Ishika Arora,

The Institutional Ethics Committee held on 30th December, 2023, reviewed and discussed your application to conduct the study titled "**SPATIOTEMPORAL ANALYSIS OF ROAD TRAFFIC CRASHES TO MINIMIZE RESPONSE TIME IN LUDHIANACITY, PUNJAB" (IEC /2171) "**

Principal Investigator	Dr. Ishika Arora, MPH Student, AMCHSS, SCTIMST
Co-Principal Investigator(s)	Dr. Biju Soman, Professor & Head, AMCHSS. SCTIMST
Duration of the study	6 months – 12 months

The following members of the Ethics Committee were present at the meeting held on 30th December, 2023

SL. No.	Member Name	Highest Degree	Gender	Scientific /Non Scientific	Affiliation with Institution(s)
1.	Smt. Sathi Nair	MA (English Literature)	Female	Lay Person	No
2.	Dr. Kala Kesavan P	MBBS,MD	Female	Basic Medical Scientist	No
3.	Adv. Priya Kaimal	LLM, MBL	Female	Legal Expert	No
4.	Dr. P. Manickam	BSMS, MSc (Epid).,PhD	Male	Health Science Expert/ Social Scientist	No
5.	Dr. Christina George	MD Psychiatry	Female	Clinician	No
6.	Dr. Narayanan Namboodiri. K K	MBBS,MD,DM	Male	Clinician	Yes
7.	Dr. Biju Soman	MBBS,MD, DPH, MSc, DLSHTM	Male	Basic Medical Scientist	Yes

1

Annexure III: Permission letter IEC

SCT/IEC/2171/DECEMBER-2023

The following documents were reviewed:

Original submission

1. *Checklist Form*
2. *Covering letter addressed to the Chairman, IEC, SCTIMST dated 01.12.2023*
3. *Responses/Amendments made based on the Reviewer's comments*
4. *IEC Application Form*
5. *Research Proposal*
6. *Observation Checklist*
7. *CV of Principal Investigator and Co-PI*
8. *Declaration Form*
9. *Permission to use Dataset- Received from Punjab Road Safety and Traffic centre.*
10. *SRC Recommendation Letter*

Revised submission

1. *Checklist Form*
2. *Covering letter addressed to the Chairman, IEC, SCTIMST dated 11.01.2024*
3. *Copy of IEC Recommendation letter dated 09.01.2024*
4. *Responses/Amendments made based on the Reviewer's comments*
5. *IEC Application Form*
6. *Research Proposal*
7. *Observation Checklist*
8. *CV of Principal Investigator and Co-PI*
9. *Declaration Form*
10. *Permission to use Dataset- Received from Punjab Road Safety and Traffic centre.*

IEC Decision
The IEC approved the conduct of the study in the present form.

Remarks:
The Institutional Ethics Committee expects to be informed about the progress of the study, any SAE occurring in the course of the study, any changes in the protocol and patient information/informed consent and asks to be provided a copy of the final report.

There was no member of the study team / Guide who participated in voting / decision making process. The ethics committee is organized and operated according to the requirements of Good Clinical Practice and the requirements of the Indian Council of Medical Research (ICMR).

Sincerely,

Dr. G. Srinivas
Member Secretary, IEC

MEMBER SECRETARY
INSTITUTIONAL ETHICS COMMITTEE (IEC)
SCTIMST, THIRUVANANTHAPURAM

SREE CHITRA TIRUNAL INSTITUTE FOR MEDICAL SCIENCES & TECHNOLOGY
INSTITUTIONAL ETHICS COMMITTEE (IEC)
SCTIMST
THIRUVANANTHAPURAM

2

Annexure IV: Permission letter

Gmail

Ishika Arora <isshikaarora@gmail.com>

Ludhiana Data and Shape Files

1 message

Punjab Road Safety & Traffic Research Centre <prstrc22@gmail.com> Tue, Sep 5, 2023 at 10:12 PM
To: dr.ishika@sctimst.ac.in, isshikaarora@gmail.com

Dear Ishika

This is with reference to your letter dated August 25, 2023, regarding the request to use and reproduce material for a dissertation from the Ludhiana Road Safety Assessment Report. You are hereby authorized to do so, and please find attached herewith the soft copies of the shapefile available with us for your reference related to your project domain area.

If you have any further questions or need additional assistance, please feel free to reach out to us.

KInd Regards,

Navdeep Asija
Director, PRSTRC

Ludhiana Commissionerate Police.zip
100K

Annexure-V

DrillBit

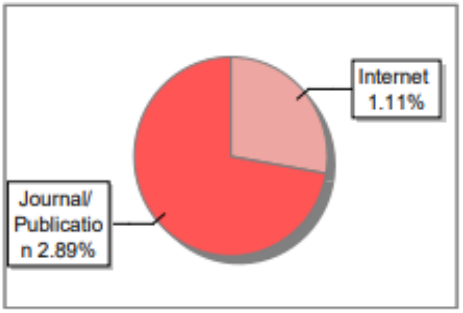
The Report is Generated by DrillBit Plagiarism Detection Software

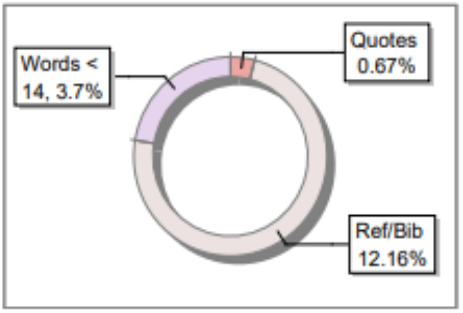
Submission Information

Author Name	ISHIKA ARORA (DR)
Title	SPATIOTEMPORAL ANALYSIS OF ROAD TRAFFIC CRASHES TO MINIMIZE RESPONSE TIME IN LUDHIANA CITY, PUNJAB
Paper/Submission ID	1714007
Submitted by	bijusoman@sctimst.ac.in
Submission Date	2024-04-29 13:02:13
Total Pages	106
Document type	Dissertation

Result Information

Similarity **4 %**





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