EPIDEMIOLOGICAL STUDY OF ROAD TRAFFIC ACCIDENTS IN AN URBAN SETTING IN SOUTH INDIA

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PhD THESIS

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**SREE CHITRA TIRUNAL INSTITUTE FOR
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A THESIS SUBMITTED BY

DR ANAND N

TO

SREE CHITRA TIRUNAL INSTITUTE FOR MEDICAL SCIENCES AND TECHNOLOGY, TRIVANDRUM

IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE AWARD OF

DOCTOR OF PHILOSOPHY

2023

DECLARATION BY THE STUDENT

CERTIFICATE

I, **Dr. Anand N**, hereby do certify that I had personally carried out the work depicted in the thesis entitled, " **Epidemiological Study of Road Traffic Accidents in an Urban Setting in South India**".

No part of the thesis had been submitted for the award of any other degree or diploma prior to this date.

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Date: 15-08-2023

CERTIFICATE BY THE RESEARCH GUIDE

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The thesis entitled, '**Epidemiological Study of Road Traffic Accidents in an Urban Setting in South India**', was carried out under my direct supervision. No part of the thesis was submitted for the award of any degree or diploma prior to this date.

Clearance was obtained from the Institutional Ethics Committee for carrying out the study.

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Signature

Name of the Guide Dr Biju Soman

Date : 21-Aug-2023

APPROVAL OF THESIS

The Thesis entitled

'Epidemiological Study of Road Traffic Accidents in an Urban Setting in South India'

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Post Script :- I thank my parents Shri. Neelakantan and Smt. Vijayalakshmi for the spiritual, emotional and mental succour they provide to me at all times. I most humbly place my head on the feet of Lord almighty, for having protected me through two major road crashes early on in life, helped me not only survive them but also emerge unscathed. Maybe, that is the reason I chose this topic for research, so that even a single life saved by applying this study finding will surely be worth all the effort.

Dr Anand N

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LIST OF ABBREVIATIONS

Sl	Abbreviation	Full Form
1	ADSI	Accidental Deaths and Suicides India
2	AFR	African Region
3	AI	Artificial Intelligence
4	AIDS	Acquired Immune Deficiency Syndrome
5	CDC	Centre for Disease Control
6	DALY	Disability Adjusted Life Years
7	DBSCAN	Density Based Spatial Clustering of Applications with Noise
8	HIC	High Income Countries
9	EMR	Eastern Meditteranean Region
10	EU	European Union
11	FOSS	Free and Open Source Software
12	GDP	Gross Domestic Product
13	GIS	Geographical Information System
14	GNP	Gross National Product
15	GOI	Government of India
16	GPS	Global Positioning System
17	HIV	Human Immunodeficiency Virus
18	ICMR	Indian Council of Medical Research
19	INR	Indian Rupee
20	JAMIE	Joint Action for Injury Monitoring in Europe
21	KNN	Kernel Nearest Neighbours
22	LMIC	Low and Middle Income Countries
23	MORTH	Ministry of Road Transport and Highways
24	MHA	Ministry of Home Affairs
25	ML	Machine Learning
26	MMUCC	Model Minimum Uniform Crash Criteria
27	NCAP	New Car Assessment Programme
28	NCRB	National Crime Records Bureau
29	NGO	Non Governmental Organization
30	NH	National Highway
31	NKDE	Network Kernel Density Estimate
32	OOP	Out of Pocket
33	PWD	Public Works Department
34	RTI	Road Traffic Injuries
35	SDG	Sustainable Development Goals
36	SEAR	South East Asian Region
37	SQ. KM	Square Kilometre
38	SWOV (Dutch)	Stichting Wetenschappelijk Onderzoek Verkeersveiligheid
39	UN	United Nations
40	USDOT	United States Department of Transportation
41	UT	Union Territory
42	WHO	World Health Organization

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Introduction

Road traffic crashes pose a significant public health challenge the world over, especially in developing nations. About 1.3 million persons die from road crashes every year, with millions more sustaining severe injuries and getting disabled for life. As per World Health Organization (WHO) global road safety report 2018, road crashes form the seventh leading cause of deaths worldwide; and are projected to be the third leading cause by the year 2030. They are the leading cause of deaths amongst children and young adults, with more than 90% crash fatalities happening in Low and Middle Income Countries (LMIC). India has one of the most dangerous roads in the world, where nearly 1.5 lakh people are killed annually, and many times more maimed in crashes. The nation loses approximately 3% of its GDP to losses of men and material from road crashes, since most deaths occur in productive age group men of 15-40 years.

The tiny union territory of Puducherry holds the dubious distinction of topping the national charts in rate of accidental deaths resulting from road crashes. National Crime Records Bureau (NCRB) data shows the highest rate of accidental deaths per lakh population from Puducherry (72.8), which is more than twice the national rate of 31.5 deaths per lakh population. Puducherry led 19 States/Union Territories (UTs) which reported higher rates of 'accidental deaths' than the all-India average, which is quite worrying.

In the past, road crash prevention strategies have traditionally revolved around the Haddon's matrix (human/user, road and vehicle). While human behaviour change was the primary focus of such strategies, addressing road and vehicle factors formed additional secondary focus areas. However, deaths from road crashes continued to rise through the years, though the absolute number of crashes plateaued or even reduced marginally. Hence, seized of the critical urgency to proactively address the issue, WHO and United Nations (UN) declared 2011-2020 as the Global decade of action for road safety. This has been extended to the present decade 2021-2030, with an ambitious aim to halve the number of deaths due to road crashes by the year 2030. The revised strategy centred around the safe systems approach, which recognized the high vulnerability of human body to damage, and its fragile nature while encountering the damaging force imparted in a road crash. Further, considering the innate tendency of humans to commit errors, this approach shifted the pivot of preventive strategy to non-human elements such as proper designing of roads and vehicles, to make road travel safer.

There have been considerable knowledge gains so far in this sphere, especially on the risk factors and preventive modalities, although with sub-optimal impact/outcome. The WHO-South East Asian Research Organization (SEARO) framework for research in road safety (2018) flags the several knowledge gaps which exist in terms of both quantity (such as under-reporting, low research proportion) and quality (such as unreliable, inaccurate data).

Further, road safety research is neither operational nor translational, with latest available technology being grossly under-utilized in finding solutions. There exists felt need for a dynamic, robust road crash data system to enable key stakeholders in developing effective solutions. In this context, the term 'Data Systems' refers both to the framework–structure in which data is captured, and the mechanism–function of data processing. It also refers to the environment in which such data flows in different directions. This study is an effort to contribute towards enriching the existing road crash data system in an urban setting in south India.

Justification-Rationale

The study envisions harnessing of latest available technology to fill knowledge gaps. It also aims to address the need for analysing both crash characteristics, individual profiling and elements of crash hotspot cluster mapping under the ambit of a single study. It focusses primarily on objective, cross-linkable data which is vital for preventive strategies. The study looks at creating a data analytical framework using open-source, reproducible solutions, which is essential to develop sustainable models for road safety. The ultimate goal of the study is to empower key stake- holders like traffic police by arming them with robust data for action.

Objectives

The study had three objectives, namely (given along with corresponding methodology) :- (i) To carry out profiling of fatal road crashes in an urban setting in the study setting (Puducherry) by analysing road crash data, (ii) To identify fatal road crash hotspot clusters in this setting by spatio-temporal analysis using open-source software solutions,and (iii) To develop a reproducible operational, stand- alone data management framework for fatal road crash data, using open-source solutions. The ultimate aim being to empower key stakeholders in developing and fine-tuning preventive interventions on road safety, with in-built mechanism for fatal crash spot identification.

Methods

The study setting is Puducherry district, one of four such districts in the Union territory of Puducherry. It is bordered on the east by Bay of Bengal, and surrounded on all other directions by the state of Tamil Nadu. Puducherry is an educational and tourist hub with a total population of 9.5 lakh persons residing within an area of 293 sq km. It is divided into 4 taluks,2 municipalities, 5 communes and 3 census towns for administrative purposes, and is urban in character. The district is served by 4 main roads extending in north, north-west, west and southern directions; and the total road length is 422.77 km.

With a vehicle density of 494 per 1000 population, Puducherry is second only to Goa (555) in terms of vehicle density, many times more than national average of 14 vehicles per 1000 population. Its vehicle density of 106.4 vehicles per km of road is also manifold than the corresponding national figure of 46.3. It has a discontinuous, patchy geographical spread, thus rendering it a cartographer's challenge. The district is divided into four zones (east, west, north and south) from a traffic police perspective.

Data Sources

After obtaining necessary administrative and ethical clearances from appropriate authorities, road crash data for 3 years (2016-18) was accessed from records of traffic police department, Puducherry. This raw data was available as excel files (.xlsx), 12 excel sheets, one for each year-zone subset (03 yrs x 04 zones); personal details anonymized. However, only fatal road crash data was available, that too in different formats for each zone and year, while crash location data was entered only in descriptive terms. Date and time were mentioned in same column in different styles.

This dataset was not suitable for analysis, hence the authorities were approached to rework on the source data and provide standardized datasheets amenable to analysis. Consequently, data on all crashes (both fatal and non-fatal) with crash locations geo-coordinated as per latitude-longitude of crash site was provided by traffic police department. However, this revised dataset was also non-uniform, with different column styles in each sheet, and zones indicated as rows.

Thereafter, a data extraction template was developed to capture all details in a standardized format. This data frame excelsheet consisted of one column for each variable, with unique identifier Id assigned for each study subject/ record. The latitude-longitude details of crash locations were extracted onto two separate columns, and date-time details were extracted onto two separate columns in standardized formats. Thus, a standardized data frame suitable for analysis was extracted from the raw data.

The second data source used for the study was map of administrative boundaries of Puducherry. This was accessed from Survey of India, through spatial resources of Achutha Menon Centre for Health Sciences Studies (AMCHSS). The boundaries file was in the form of shape files (.shp)-polygons.

The third data source was Puducherry road network map. The initial baseline road network map of Puducherry was accessed from Open Street Map (OSM) as shape files (.shp)-lines. However, this map contained very many segments- features in bits, and hence was too cluttered to make any analysis feasible. Therefore, government sources (Public Works Department) from the study setting were approached to seek clearer road network map; but the same was available only in pdf format for selected roads, hence the issue persisted. Concurrently, the segments road network map was combined into single stretches, and a combined network map was arrived at; still this map also was very dense and not amenable to the crash spot analysis planned.

To resolve this issue, subject experts in geology were consulted, who suggested that the available map extracted from OSM be cleaned/ pruned using certain tools. Consequently, the master network map was re-scrutinized, with each road segment being manually identified, and non-affected/ irrelevant road segments removed manually using QGIS software. Thereafter, dangling, 'orphan' road segments (leading to/from nowhere) with a thresh (threshold) length of 250 m or less were identified and removed using *smoothR* function in R software. Thus, a refined road network map was made available for analysis.

Data Analysis Plan

The first phase of data analysis plan involved description of crash characteristics. Distribution of crashes was analysed as per year of occurrence, traffic zone, injury type (severity) and as per time of day. Details of individuals involved in crashes was then analysed, with respect to injury type (fatal/ grievous/ simple), profile of victim and accused as per age, gender, vehicle and occupancy. R, an open-source, easy-to-reproduce, multi-platform compatible software was used for data analysis. Packages specific to analysis of crash and individual characteristics were applied; including *tidyverse, janitor, lubridate, hms, ggplot* and *gtsummary*.

Phase two of data analysis plan involved spatio-temporal analysis of crash spots using Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm. Clustering is a technique in unsupervised ML which groups data points into clusters based on similarity of information for the datapoints in the dataset. Two commonly used clustering techniques are:- Kernel(K)-Means clustering and DBSCAN. K-means clustering is a partition/ centroid based technique, where the number of clusters need to be pre-determined *a-priori*, and it is not suitable for datasets with many outliers/ noisy datasets.

DBSCAN on the other hand is a density-based algorithm, where no *a-priori* assumptions are needed on number of density clusters. The three pre-requisites to carry out DBSCAN algorithm on a dataset are:- (a) *K- Nearest Neighbours (KNN)*: assumes the similarity between the new case/data and available (old) cases and puts the new case into the category that is most similar to the available categories, (b) *minPts* : minimum number of points (a threshold) clustered together for a region to be considered dense and (c) *Epsilon-eps (ε):* A distance measure that is used to locate the points in the neighbourhood of any point. R packages '*dbscan'*, *'sf'* and '*fpc*' were applied on the dataset to implement DBSCAN algorithm. For study purposes, *minPts* of 30 and *eps* of 0.005 were used to map all crashes, with the corresponding readings for fatal crashes being 05 and 0.02 respectively; for non-fatal crashes, 10 *minPts* and 0.01 *eps* were used.

The third phase of data analysis plan involved application of Network Kernel Density Estimate (NKDE) method on the dataset to estimate crash density. NKDE is one of the latest methods to estimate event density in network spaces, the other being planar KDE. The basic advantage of KDE over DBSCAN is that it is specific to spaces involving road network. While planar KDE analyses density of events (data points) in a planar space using pixels by measuring Euclidean distance, NKDE analyses event density in linear space using lixels (linear pixels) by measuring network distance.

Parameters required for NKDE are Lixel length (length of line on a given network split into lixels according to a chosen resolution) and bandwidth (distance within which the 'influence' of the point lies). Lixel length of 300 m and bandwidth of 500m were used for the study. Among the three subtypes of NKDE namely simple, discontinuous and continuous NKDE, the discontinuous NKDE was used considering the study requirements, objectives and available data. R packages '*spnetwork*', '*tidygraph*' and '*igraphs*' were applied on the dataset while performing NKDE analysis.

Results

A total of 5202 crash records from 2016 to 2018 were analysed for crash and individual characteristics. On an average, data was not available for about 6% of certain variables like age (accused and victim age), vehicle and occupancy.

The year 2016 witnessed maximum number of crashes (1904), with the count decreasing to 1682 crashes in 2017 and further to 1611 crashes in 2018. However, the number of fatal crashes showed a rise, from 157 deaths in 2016 to 164 deaths in 2018. West traffic zone accounted for maximum proportion of crashes (31.4%), while east zone recorded the least proportion (20.8%). More than one-tenth (11.4%)

of all crashes were fatal; nearly two-fifths (38.1%) resulted in grievous injuries to the victims, while 37.6% of crash victims sustained simple injuries. Crash fatality rate was nearly equal in both south (14%) and west (13%) zones. Vehicle damages, with no injury to humans also accounted for a small proportion (3.3%) of all crashes. A bimodal distribution of fatal crashes over time of the day was observed, with peaks being in the morning (8 am-12 noon) and again in the evening (6-10 pm) time. Non- fatal crashes also followed a similar pattern, and on most days of the week. However, the sole exception to this distribution was Sundays, wherein most crashes occurred in late evening and night hours. This bimodal distribution was observed to uniformly involve all types of vehicles, however it was more pronounced and clear in the case of two-wheelers and least in case of three-wheelers.

Median age of crash accused was lower (24 years) compared to the victims (26 years). This difference in median age was wider (7 years) in caseof fatal crashes (median victim age 32 years vs accused age 25 years) as compared to non-fatal crashes (2 years difference; victim age 26 years vs accused age 24 years). Most crash victims (56.2%) belonged to the productive age group of 15-40 years. Under-age driving was observed to be associated with all crashes (1.9%) and fatal ones (2.5%).

Majority of both crash victims (83.2%) and accused (99.6%) were males, with one transgender victim. This applied equally true for fatal crashes as well. Vulnerable road users (pedestrians, bicycles and two- wheelers) bore the brunt of crashes, accounting for more than two-thirds (67.5%) of all crashes and about 69.8% of fatal crashes. An interesting finding was that two-wheelers were also the perpetrators and the victims in both fatal and non-fatal crashes. Vehicle occupancy seemed to play a role in crashes including fatal ones, with drivers being victims in 41% of all crashes and 55% of fatal ones. Two-wheelers were an exception to this observation, with drivers and pillion riders equally being vulnerable to crashes and deaths.

When crash location details were geo-coordinated for hotspot analysis, it was found that five locations out of the total 5202 records were erroneous (wrong entry), which fell outside the study area and even in sea location. Thus, finally 5197 records were taken up for analysis.

DBSCAN analysis of crash spots year-on-year revealed a total of 16 crash clusters in the year 2016, which reduced to 12 clusters in 2017 and increased to 17 clusters in 2018. Crash spots (overall and fatal) were densely clustered along the four main arterial roads extending from the city in four different directions. Half-yearly spot mapping revealed 10 clusters each in the first and second halves of 2016, while the corresponding number of clusters were six and seven clusters in 2017, while 2018 witnessed 11 and 10 clusters respectively.

A noteworthy finding emerging from DBSCAN analysis was that crash clusters tended to evolve in a particular pattern, with smaller patchy clusters of one year coalescing to form a large single cluster in the next year. This further enlarged and elongated in the succeeding year to form a larger, longer cluster. However, no significant inter-zonal differences were discernible between the clusters in the four traffic zones.

Both fatal and non-fatal clusters were near-similar in their distribution, with no significant differences in between. Crash spots in one large cluster located in the central township area of Puducherry were observed to be from all traffic zones. Mapping of crash spots against administrative boundaries map of Puducherry enabled clearer visualization of clusters.

Crash spot analysis using Network KDE method revealed deeper insights into cluster locations and pattern over the three-year study period. The number of clusters on yearly, half-yearly and quarterly basis was nearly the same as found from DBSCAN analysis. Patchy clusters especially in west zone in 2016 coalesced to form a larger cluster in 2017,and expanded in the year 2018. Similarly, medium sized cluster observedin central area in 2016 merged with the adjoining small clusters and formed a large cluster in 2017, and further elongated in 2018.

Clusters and non-clusters showed statistically significant findings in terms of crash time, accused vehicle and traffic zone. Most crashes occurred between 1200h-1800h in both clusters (38%) and non-clusters (33%), with least crashes between 0000h-0600h (6.6% and 8.9% respectively). Two-wheelers were the most common accused vehicle in both clusters (57%) and non-clusters (45%). Non-clusters were spread equally across all four zones (north: 29%, south : 21%, east : 26% and west : 24%). However, crash spot clusters were predominantly located in west (58%) and south (32%) traffic zones.

Discussion

The year-wise and zone-wise figures (total number of crashes and fatalities) reflected in the study are matching those in the report released annually by NCRB, titled 'Accidental Deaths and Suicides in India (ADSI)'. However, deeper data on crash locations within Puducherry, detailed profiling of crashes and crash victims and accused are not available for in-depth and broader analysis.

Epidemiological profiling of crash and individual's characteristics in the study revealed that time distribution of crashes varies from conventional impression. In that maximum crashes (including fatal) do not occur during late night or early morning hours as is commonly believed. Instead, peak hours when persons commute to and from office witnesses most crashes including fatal ones. The significant proportion of underage drivers leading to crashes and fatalities is a cause for concern. Girl children under 15 years of age formed largest sub-set when age-wise data of female victims was analysed.

The finding of overall crash rates plateauing, but fatalities rising may be explained partially by the rising speed of vehicles, and increased vehicle density; however it needs deeper analysis. Clusters (all and fatal) are located along the four arterial roads, thereby indicating need toposition rescue resources on priority along these routes. No major inter- zonal variations emerge, indicating that a common solution can be worked out for implementing across all zones.

It is ironic that pedestrians who do not enter the road at all, end up bearing the brunt of crashes and resulting deaths. Walker safety measures need to be inbuilt while conceptualizing and designing road safety systems, and the focus must not be on the vehicle rider alone. Two- wheeler users formed a unique subset of crash-afflicted individuals, with them being both culprits and also victims (self-driven). Female victims are larger in relation to female accused, indicating that female riders may be safer to their own selves and others on the roads.

Crash spot clusters identified by DBSAN followed a temporal pattern, wherein present-day small patchy clusters coalesce to form singlelarge cluster in future, and expand in width and length subsequently. No significant receding/ disappearing clusters were observed. This may indicate that road safety measures have not been implemented in the locations where they are needed the most, and also that such measures have not been effective in reducing crashes and deaths.

Mapping of crash spot clusters by NKDE validated the findings arrived at by DBSCAN, thus reinforcing the robust nature of 'R' softwareand the two techniques themselves. Discontinuous NKDE is a new concept using latest technology, and its use has hitherto fore been used mainly in non-health sectors like transport, geology etc. The difference inindividual and crash characteristics between clusters and non-clusters is worthy of deeper analysis.

Recommendations-Way Ahead

Formulation of Road safety strategy must take into consideration the epidemiological profile of both victim and accused in crashes. Key stakeholders must employ a standardized template for road crash data processing, with in-built scope for capturing crash location in terms of geo-coordinates. Inter-sectoral coordination amongst various agencies involved in road safety if the need of the hour to achieve optimal outcomes. The planned way ahead is to hand over final master data sheet to Puducherry traffic police authorities, share the 'R' code and entire data flow algorithm with input-coding-output chain, train the stake-holders on data management process, and periodically review and fine-tune the schema.

Strengths

This study proved the utility of cleaning and enriching raw data onto a final refined data frame by developing a data extraction template. Mapping of crash spots precisely in locations in such a cartographer's mess/ nightmare as Puducherry, is an achievement in itself. New technology in the form of NKDE has been used probably for the first time in health care settings in India. Use of density-based (DBSCAN) and network based (NKDE) algorithms on the same dataset, with similar findings goes onto prove the robustness of extracted data, the sources tapped and the process involved.

Generalizability/ feasibility for extrapolation of study process is also validated. The outcomes and resources will prove to be a valuable tool in hands of key stake-holders for dynamic and informed decision-making.

Limitations

The limiting factors of the study were: lack of standardized data form to capture data efficiently *ab-initio;* and lack of data on secondary layers (such as locations of health care establishments, educational institutions, liquor shops etc.,.) to cross-validate the findings. Further, absence of a single nodal agency to approach and access data delayed the process. Non-availability of baseline Road network maps and other data related to road or vehicles impacted the outcome quality. Insufficient hardware systems to handle large sized datasets, heterogenous patchy nature of area topology, non-capturing of deeper wider data on other pertinent variables of crashes and individuals *a-priori* were other constraints. In addition, road network map of interlocked/ interspersed area (Tamil Nadu) was not available for comparison.

1 INTRODUCTION

1.1 The Importance of Roads

Roads are to a nation what blood vessels are to a person. Just like arteries enrich an individual by transporting vital life energy throughout the body, a vibrant road network brings economic development and important social benefits to a country. Increased employment opportunities and better access to health, education and other welfare services accompany wherever roads are opened up. Therefore, roads are considered pivotal to the economic upliftment and prosperity of any country, especially developing ones.

1.2 Road Accidents or Road Crashes

As the road network in a region expands, so do the number of road traffic crashes. Road 'crashes' are no longer called 'accidents' because it has been clearly proven that they are neither 'accidental' nor inevitable. They result from preventable shortcomings on the part of either the road user, the vehicle, the road or a combination of these factors. Road crashes result in deaths or disablements to human beings involved while also causing significant damage to non-human elements like animals or even inanimate materiel. It is noteworthy that unlike other diseases or health issues which affect other species in the animal or plant kingdom, this phenomenon of road crashes and consequent mortality, morbidity etc., is unique to human beings. They are purely a (hu)man-made problem which adversely impacts human beings.

1.3 Road Traffic Injuries (RTIs): Definition

Road Traffic Injuries (RTIs) are at times interchangeably recorded as road traffic crashes, road traffic accidents, or motor vehicle crashes. However, each may slightly differ from the others. The present research defines RTIs according to the World Health Organization (WHO), as the cause of fatalities leading to loss of life during the event time or within a maximum period of 30 days after the crash (WHO, 2018).

1.4 RTIs: The Problem

1.4.1 World

RTIs are a major public health concern worldwide, causing significant mortality, morbidity and damage to the economy. Globally, about 1.35 million people die every year due to road crashes. For children and young adults aged 5 to 29 years, road crash-related injuries constitute the major cause of death (CDC, 2023). Fatalities from road traffic crashes, which form the eighth leading cause of deaths worldwide, are expected to become the fifth leading cause of mortalities by 2030 if present trends continue. In addition to deaths *per se*, the injuries sustained in road accidents can have long-term physical, psychological, and economic consequences for individuals, families, and communities (WHO, 2018).

1.4.2 High Income Countries (HICs) Vs Low and Middle Income Countries (LMICs)

The distribution of road crashes and RTIs worldwide is unevenly skewed against low resource settings, the economically weaker regions. Developing nations shoulder a significant portion of the burden, accounting for 90% of the Disability-Adjusted Life Years (DALYs) lost due to road traffic injuries and 85% of annual fatalities. Low and Middle-Income Countries (LMICs) bear the heaviest burden of all RTIs in the world. Despite having only 60% of the world's registered vehicles, LMICs account for over 90% of all crash fatalities (WHO, 2018). These countries account for 85% of the global annual average of 750,000 RTIs, as compared to 15% in High-Income Countries (HICs). RTIs have caused approximately 1.3 million deaths and 20 to 50 million injuries in LMICs, with the numbers continuing to rise (CDC, 2023). Amongst the LMICs, the African Region (AFR) along with the Eastern Mediterranean Region (EMR) have the highest rate of deaths resulting from road traffic crashes (Mohammed *et al*., 2019).

1.4.3 South East Asian Region (SEAR) including India

South East Asian Region (SEAR) of the WHO accounts for about 25% of all road crash fatalities worldwide and nearly 35% of all injuries sustained in road crashes(WHO, 2018). India, with less than 2% of the world's total road network, witnessed nearly 1.3 lakh deaths and more than 3.4 lakh injuries due to road crashes in 2019. The nation forsakes approximately 3% of its annual GDP to losses of men and materials from road crashes since most deaths occur in the productive age group of men of 15-44 years. Vulnerable road users (pedestrians, motorcyclists and bicyclists) account for more than half of all such deaths, highlighting the paradox of those occupying the least space on the road paying the heaviest price with their lives (Government of India, 2021).

1.4.4 Puducherry

The tiny Union Territory (UT) of Puducherry, located in south coastal India, holds the dubious distinction of topping the national charts in the rate of deaths resulting from road crashes. Puducherry led 19 States/Union Territories which reported higher rates of 'accidental deaths' than the all-India average, which is quite worrying. Data from Government of India-Ministry of Road Transport and Highways (GoI-MoRTH) shows the highest rate of accidental deaths/per lakh population from Puducherry (72.8), which is more than twice the national rate of 31.5 deaths/per lakh population (Sun, 2022).

1.5 Knowledge Gains and Gaps

Multiple prevention strategies and projects for road safety have contributed to a significant reduction of the burden in many HICs (CDC, 2023). As brought out earlier, RTIs are both predictable and preventable. There are extensive knowledge gains in the form of empirical evidence for effective interventions. These include enforcement of legislation on speed control and alcohol consumption, promotion of seatbelt and helmet utilization, and safer design/ use of roads and vehicles (UNECE, 2018; Wali *et al.*, 2017). Unfortunately, most of such research was previously carried out in high-income settings and focused on vehicle occupants rather than vulnerable road users in LMICs, the group that merits maximum research and focus (Heydari *et al*., 2019).

1.6 Road Safety Strategies: Paradigm Shift

1.6.1 Thrust of Road Safety Strategies in the Past

In the past, road crash prevention strategies have traditionally revolved around Haddon's matrix, which analyses the interaction between human/user, road & vehicle at various stages of the crash (pre, during and post-crash). Human behaviour change was the primary focus of such strategies, whereas addressing road and vehicle factors played a secondary role. This approach aimed to prevent ALL road crashes in toto and did not focus on a specific subset of crashes, like fatal or non-fatal ones (Bocage *et al*., 2020). This was based on the presumption that the road user (human) is perfect, and not prone to commit errors; hence all change must emanate only from them. It did not fully take into consideration the human-machine interaction, with respect to ability of human body to absorb the impact of energy.

1.6.2 Sub-optimal Outcomes

However, the gaps in knowledge seem to far surpass the gains, as evident from the sub-optimal outcome of strategies based on research findings. Despite implementing multi-pronged approach measures over many years, deaths from road crashes continued to rise, though the absolute number of crashes plateaued or even reduced marginally (The Lancet, 2022).

1.7 Initiatives for Road Safety

Sensitized to the critical urgent need to proactively stem this rising tide, in the year 2010, the WHO and United Nations (UN) jointly declared 2011-2020 as the Global decade of action for road safety. An ambitious target of bringing down road crash fatalities by half by 2020 was set as Sustainable Development Goal (SDG) number 3.6. A global plan for the

Decade of Action for Road Safety 2011–2020 was developed to guide efforts at national and local levels to reduce the forecasted level of road traffic fatalities around the world. The aim was to strengthen institutional capacity for road safety management and improve the health system for the post-crash response. However, it was realized that more sustained and coordinated efforts from all stakeholders were required to achieve these targets. Hence, the aim of halving deaths due to road crashes by half was extended to the present decade (2021-2030), for achieving by the year 2030. The latest SDG 11.2 aims at improving road safety, among other targets(United Nations Road Safety Collaboration, 2010) (WHO, 2020).

1.8 Safe Systems Approach

1.8.1 Core Concept and Aims

The revised strategy, called the 'Safe Systems Approach', differs from the traditional approach in three cardinal ways. Firstly, it recognizes and accepts the innate propensity of human beings to commit errors while on the road. Secondly, it caters to the high vulnerability and fragile nature of the human body to damage while encountering the destructive force/ energy imparted in a road crash. Thirdly, it does not aim to prevent ALL crashes since that was deemed impractical. However, it targeted maximal prevention of FATAL AND SERIOUS INJURIES in crashes by working on factors predisposing to a higher risk of deaths and serious injuries resulting from collisions. Hence, this approach shifted the pivot of preventive strategy from a predominantly human-centric one to non-human elements, such as adequately designing roads and vehicles to make road travel safer (PIARC, 2011).

1.8.2 Key Thrust Areas

To achieve its stated objective, among other recommendations, the safe systems approach advocated the need for streamlining road safety data by creating an objective data system on road crashes, which will capture data accurately and reliably. The report of the WHO-SEAR on 'Research Framework for road safety in the South-East Asian region' has also reiterated this point for road safety in SEAR countries. This document flags several knowledge gaps in quantity (under-reporting, low research proportion) and quality (unreliable, inaccurate data) of such data presently. It further laments that road safety research is neither operational nor translational, with the latest available technology being grossly under-utilized in finding solutions. Thus, a robust, dynamic road crash data system is essential to enable key stakeholders for developing wholesome and effective solutions for road safety (Alta, 2022) (WHO, 2010) (WHO, 2015).

1.9 Road Safety Data Systems

1.9.1 Data Systems: Definition

In this context, the WHO document on road crash data systems describes the term 'data systems'. It refers to both the framework, namely the structure in which data is captured and the mechanism, namely the function of processing such data. It also considers the environment in which such data flows in different directions. Good quality data which is more expansive, profound and comprehensive, will help in assessing the nature and magnitude of road crash injuries and deaths and their distribution; and will also help identifying the risk factors and priority areas for action. This in turn will help policy makers, planners and implementers devise result-oriented road safety strategies (WHO, 2010).

1.9.2 Recommended Framework

Guidelines on how such data systems must be premised upon, are laid down in the document 'Research framework for road safety in the South-East Asian Region (SEAR)', a strategy report by the WHO-SEAR. It recommends that road crash data systems must capture all fatal crashes, and a significant proportion of those resulting in serious injuries. It further states that accurate information of crash location, vehicle characteristics, road user and road environment must also be collected reliably by these data systems (WHO, 2015).

1.10 Geographical Information System (GIS) in Road Safety Data Systems

Harnessing newer technology, such as Geographical Information System (GIS) is vital in rendering road crash data systems more objective and dynamic. Using GIS is envisaged to be a good starting point in this direction by marking the exact location of a road crash as geo-coordinates (latitude-longitude) and a time function. Such geo-spatially and temporally smart data makes it possible to correctly pinpoint the spots with higher concentration or grouping of crashes. These spots are interchangeably called hotspots or black spots. They can further be grouped into clusters based on their density and distribution. The impact of such hotspot cluster mapping is that it will enable channeling or focusing of limited resources available for preventive measures to the neediest spots. This, in turn, will significantly enhance the probability of successful holistic outcomes (Altaweel M, 2018) (Budzynski *et al*., 2018).

1.11 Justification/ Rationale of Present Study

The present study looked to harness latest available technology, thereby enriching road crash data systems to fill some of the existing knowledge gaps. It recognized the need to objectively analyse both individual and combined elements of road crashes in a single study. Characteristics/ profile of individual persons involved in the crash (both victim and accused), as also grouped mapping of crash spot locations and clusters were to be captured in a single study frame. It further set out to develop an analytical framework using open-source, reproducible solutions, thereby aiming to empower key stakeholders like traffic police to take evidence-based decisions on a dynamic basis; with a robust, inbuilt mechanism for multi-directional data flow.

1.12 Purpose and Significance of the Study

The study planned to create an epidemiological profile of road crashes, with a focus on fatal ones in a predominantly urban setting in South India. Variables related to road crash epidemiology in the given setting over a specified time period (three years) were proposed to be studied. These variables include the total number of road crashes within the timeframe, location and time of the crash, distribution thereof as per age, gender, vehicle type (both of the victim and the accused) and vehicle occupancy. The requisite variables were to be deciphered from the raw data using a data extraction template. Subsequently, spatio-temporal analysis (time-location details of road crashes, especially fatal ones) was to be carried out to identify high-density zones (blackspots) of road crashes, mainly fatal crash spots. These blackspots were to be further grouped into clusters as per density of their distribution. A data management framework, including elements of data extraction and subsequent analysis, was developed to aid in the refinement of road safety data systems. Those high-end analytical frameworks that are presently being used in other disciplines were purposed to be adopted to suit the public health arena, using Free and Open Source Solutions (FOSS) to make upscaling and sustenance possible even in resource-constrained settings.

1.13 Goals-Aims Envisioned by The Study

To summarize, this study is an effort to contribute towards enriching the existing road crash data system in urban Indian settings. It envisioned to develop an epidemiological profile of road crashes (mainly fatal ones) comprehensively, to get a wider perspective of the issue. It also aimed to map the road crash spots into density clusters (groups) in the setting and to analyse the characteristics of related variables in each cluster. Further, it aimed to create a template to extract and standardize available raw data into intelligible, easy-to-analyse formats for arriving at workable seamless solutions.

1.14 Study Objectives

The study had three stated objectives, namely:- (i) To carry out profiling of fatal road crashes in a South Indian setting (Puducherry), (ii) To identify fatal road crash blackspot clusters in this setting, and (iii) To create a reproducible and operational, stand-alone analytical framework for fatal road crash data, using open-source solutions, for aiding in preventive interventions on road safety.

1.15 Scheme of Thesis

The succeeding chapters are structured to travel schematically so as to cover the features of the study. A review of the literature on the topic (focussing on the most recent evidence) will be presented first, followed by the material and methods used for the study. Findings emerging from the study will be presented subsequently, after which the relevant discussion will be given. Salient takeaways will be summarized after that, along with conclusions and recommendations for key stakeholders.

2 REVIEW OF LITERATURE

2.1 Search Strategy Adopted for Literature Review

The literature review for the present study was carried out by search strategy using both electronic and manual sources. Electronic search was done in PubMed, Cochrane library, websites of WHO, CDC, Government of India etc. Manual search was done in libraries of National Institute of Epidemiology, and Achutha Menon Centre for Health Sciences Studies, Sree Chitra Tirunal Institute for Medical Sciences and Technology. Further, detailed discussion was done with experts in the field. The process adopted and resources tapped for literature review are as provided in Fig. 2.1.

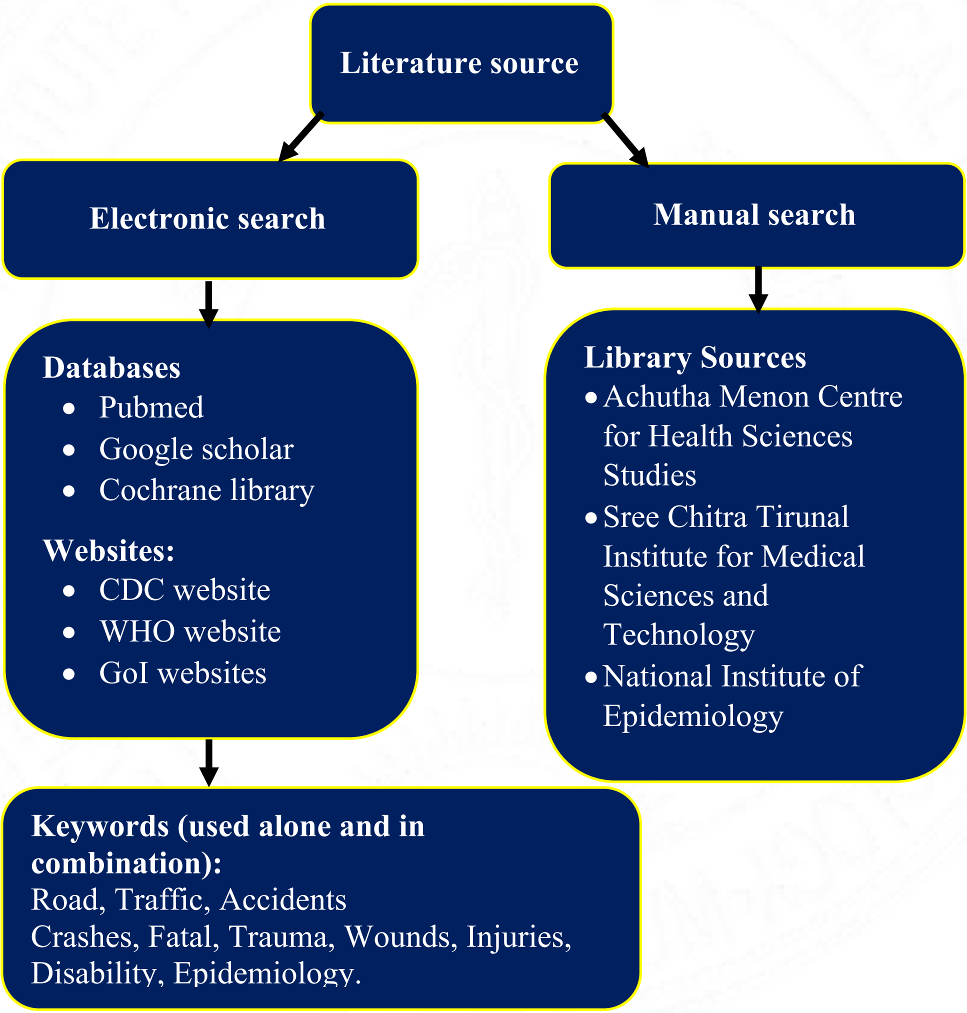


Fig. 2.1. Flowchart Showing Search Strategy Adopted for Literature Review

2.2 *Transportation: A Brief Overview*

2.2.1 Man and Movement

Movement from one place to another has been part and parcel of evolution of mankind since pre-historic times. The early hunter-gatherer used his own feet as self propulsive mode of movement in the form of walking and running. The agriculture-based man who came later on, domesticated animals and used them for transport. Subsequently, machines replaced men and animals as primary modes of transport.

2.2.2 Travel, Transport and Traffic

At the outset, it will be worthwhile to delineate the terms 'travel', 'transport' and 'traffic' and place them in perspective. Oxford advanced dictionary defines the term 'Transport' as a system for carrying people or goods from one place to another using vehicles, roads etc. 'Travel' is defined as the act of going from one place to another, especially over a long distance. The word 'Traffic' refers to movement of vehicles along a particular route (Wehmeier, 2023).

2.2.3 Ever-Evolving Process of Human Transportation

Change has been the only changeless constant insofar as human transportation history is concerned. Records speak about the earliest horses, oxen and camels domesticated by humans for their transport more than 6000 years back. The first known wheel that revolutionized transport, was invented 5500 years ago. River boats were used as early as 5000 years ago, while the chariots came into use a thousand years later. The previous millennium witnessed unprecedented diversification of transportation facilities, from the first horse-drawn carriage invented in seventeenth century, till the first space shuttle lift-off towards end twentieth century(Twinkl, 2023). Undoubtedly, the pace and scale of human transportation have always been swift and wide.

2.2.4 Types of Transport

There are three primary categories of transport used by humans, namely land, water and air. Most of the transportation modes fit into any one or a combination of these categories, and each of these in turn have witnessed significant changes over time. Air transport consists of different types of aircrafts like airplanes and helicopters. Various types of boats and ships form the mainstay of water transport, while road and rail remain the main modes of land transport. (European Union, 2021).

2.3 Road Transport and its Special Features

2.3.1 Definition of Road

A road can be defined as 'line of communication (travelled way), usually open to public traffic, primarily for the use of road motor vehicles, built using a stabilized base (OECD *et al.*, 2010).

2.3.2 Evolution of Roads over Time

Roads have existed as long as humanity itself. The first roads were the earth tracks created by movement of men and goods from one place to another. These crude earth tracks became more well defined and took a clearer shape with increase in the number of people and goods being transported. The evolution of roads in human life has been parallel to that of all other transportation facilities (Stainton, 2023).

The world over, roads are the most widely used mode for passenger transport, with automobiles occupying the largest share (16,000 bn passenger km), followed by Buses (7,000), Air (2,800), Railways (1,900), and Urban Rail (250). The most widely used modes for freight transport are Sea (40,000 bn ton km), followed by Road (7,000), Railways (6,500), Oil pipelines (2,000) and Inland Navigation (1,500) (European Commission, Directorate-General for Mobility and Transport, EU, 2021).

2.3.3 Special Features of Road Transport

Roads transport is unique in many ways. Even a person with no money to take a vehicle ride, can use the road freely by walking on it as a pedestrian, whereas travel by ship, rail and air mandatorily need a paid ticket. Road travel can thus be considered the most democratic of all modes of transport. Further, roads form the connecting link to other modes of transport, be it by air, water or rail. Reaching any seaport, airport or railway station necessarily involves travel by road from the person's home/ workplace to the boarding point. Thus, it has got a hidden multiplier effect, wherein it is embedded in the program of other transport modes also.

2.3.4 Vital Role of Roads in a Nation's Growth

Among all public assets, roads are considered the most vital infrastructure, since they play an important role in furthering the economic development and growth of a nation. Roads help in facilitating significant social benefits to the population by enabling easier access to employment opportunities, health and educational services. It thus indirectly helps the people in coming out of poverty. Roads also boost the economic stature of an area by unlocking its potential, be it tourist locations or industrial corridors. As the road network expands, more and more areas are opened up, thereby stimulating economic and social development simultaneously (Malkoc G, 2015).

2.3.5 Steep Increase in Road Network and Vehicles

There has been an explosive increase in the road network the world over, more so in developing nations. The length of global roadway network has increased by around 12 million lane kilometres since 2000, with an increase of 35% in the last 10 years alone. China and India have had the highest growth in road network, accounting for more than half of all additions in paved roads in terms of lane-kilometres (Jimenez, 2018). The rise in number of vehicles occupying these roads has been even more exponential. For instance, vehicle density (number of vehicles per 1000 inhabitants) in Africa remained static over a ten year period (1998-2008), whereas China's ratio more than tripled during the same period (Vehicle Technologies Office, 2010). The variety of vehicles entering the road network has also diversified, and the speed of their propulsion has accelerated. This has resulted in tremendous pressure on space available for vehicles to ply on the roads, leading to road crashes and accidents.

2.4 Road Traffic Crashes : Definition and Problem-Load

2.4.1 Road Traffic Crashes: The Definition

As the road network keeps increasing, so does the problem of road traffic crashes. As per the WHO, a Road traffic crash is defined as 'any injury due to crashes originating from, terminating with or involving a vehicle partially or fully on a public road'(WHO, 2018).

2.4.2 World

2.4.2.1 Deaths, Disabilities and Damages to Economy

Around the world, about 1.35 million people perish on roads every year. Road traffic crashes cost the globe approximately 70 million DALYs. Daily, around 3,700 people die worldwide in collisions involving automobiles, buses, motorbikes, bicycles, lorries, or pedestrians. Bicyclists, motorcyclists, and pedestrians account for more than half of all fatalities (WHO, 2018). According to estimates, crash injuries are the seventh most common cause of death in the world across all age categories. Automobile accidents presently claim more lives than those by Acquired Immuno Deficiency Syndrome (AIDS) or Human Immunodeficiency Virus (HIV) combined. For children and young adults aged 5 to 29 years, traffic-related injuries constitute the major cause of death(CDC, 2023). Vulnerable road users such as pedestrians, cyclists, and motorcycle riders account for more than half of all traffic-related fatalities. There are an additional 20 to 50 million people who sustain non-fatal injuries, many of whom go on to develop disabilities (The Lancet, 2022). From 2015 to 2030, it is predicted that both fatal and nonfatal crash injuries will cost the global economy $1.8 trillion.

That amounts to a 0.12% annual levy on the global Gross Domestic Product (GDP) (Chen, Kuhn, Prettner and David E Bloom, 2019).

2.4.2.2 Emergence of RTIs as Major Cause of Mortality and Morbidity

By 2030, it is anticipated that Road Traffic Injuries will rank as the third largest cause of disease and injury worldwide, if current trends continue (WHO, 2021). Although the agony endured by those involved in road accidents—the victims, their families, and their friends—cannot be measured in terms of human misery, these mishaps also have a significant economic impact. Making policy requires an understanding of the macroeconomic impact of traffic accidents and their distribution across world regions and nations.

2.4.2.3 Increasing Impact on Macroeconomic Burden

Around the world, adults aged 15 to 44 years, who are at the height of their economic potential, account for more than half of all traffic fatalities. Additionally, this age group's handicap burden accounts for 60% of all DALYs lost in road traffic accidents.(Peden *et al.*, 2017) These losses have high costs and repercussions. In addition, as males (who account for 73 percent of fatalities) and those between the ages of 15 and 44 are most commonly affected, this burden is causing severe economic hardship because it results in the loss of family breadwinners. Seventy-five percent of all impoverished families who lost a family member in a traffic accident said their standard of living had decreased, and 61 percent said they had to borrow money to pay for expenses as a result of the loss (Silcock, 2003). The macroeconomic burden of road injuries for 166 countries was estimated, wherein the researchers also stated that different nations and areas bear different financial and health burdens caused by traffic accidents (Chen, Kuhn, Prettner and David E Bloom, 2019).

2.4.3 Low and Middle Income Countries (LMIC)

2.4.3.1 Disproportionate Load of RTIs

Despite the fact that low- and middle-income nations have about 60% of the world's vehicles, they account for 93% of all traffic deaths. Most nations lose 3% of their gross domestic product to road accidents (Heydari *et al*., 2019). Compared to high-income countries, low-income countries have a death rate from crashes that is more than three times greater. From 2013 to 2016, there was no decrease in the number of crash fatalities in any low-income nations(WHO, 2021). Developing nations shoulder a significant portion of the burden, accounting for 90% of the Disability Adjusted Life Years (DALYs) lost due to road traffic injuries and 85% of annual fatalities (CDC, 2023).

2.4.3.2 Impact on Already Fragile Economies

Injuries from road crashes cost LMICs a significant amount of money (Peden *et al*., 2004). It is predicted that between 2015 and 2030, fatal and nonfatal collision injuries will cause LMICs to suffer economic losses of almost $834 billion. (Chen, Kuhn, Prettner and David E. Bloom, 2019). Roughly 90% of the 70 million DALYs lost to vehicle accidents worldwide in 2015 happened in low- and middle-income nations. Despite the high DALY load, only 46.4 percent of the world's economic cost is borne by LMICs due to traffic accidents (Heydari *et al.*, 2019). According to the World Bank, the cost of road traffic casualties is between one and two percent of the Gross National Product (GNP) of developing nations, or double the total amount of development aid that these nations have ever received (World Bank, 2018).

2.4.4 India

2.4.4.1 Heavy Load, Major Health Problem

Road accidents and injuries are a major public health concern in India, with a high burden of death and disability. According to the WHO, India has the highest number of road traffic deaths in the world, with an estimated 1.5 million deaths per year. India accounts for over 10% of all crash-related fatalities while having just 1% of the world's vehicles (World Bank, 2015). In India, road accidents resulted in more than 3.4 lakh injuries and nearly 1.3 lakh fatalities in the course of the year 2020 (Government of India, 2021). With the exception of the transition from 2020 to 2021, which saw an increase in road accidents from 3.66 lakhs to 4.04 lakhs, the overall trend of road accidents in India has exhibited a decrease in recent years. Time trend in number of road crashes from 2015-2020 is provided in Fig. 2.2.

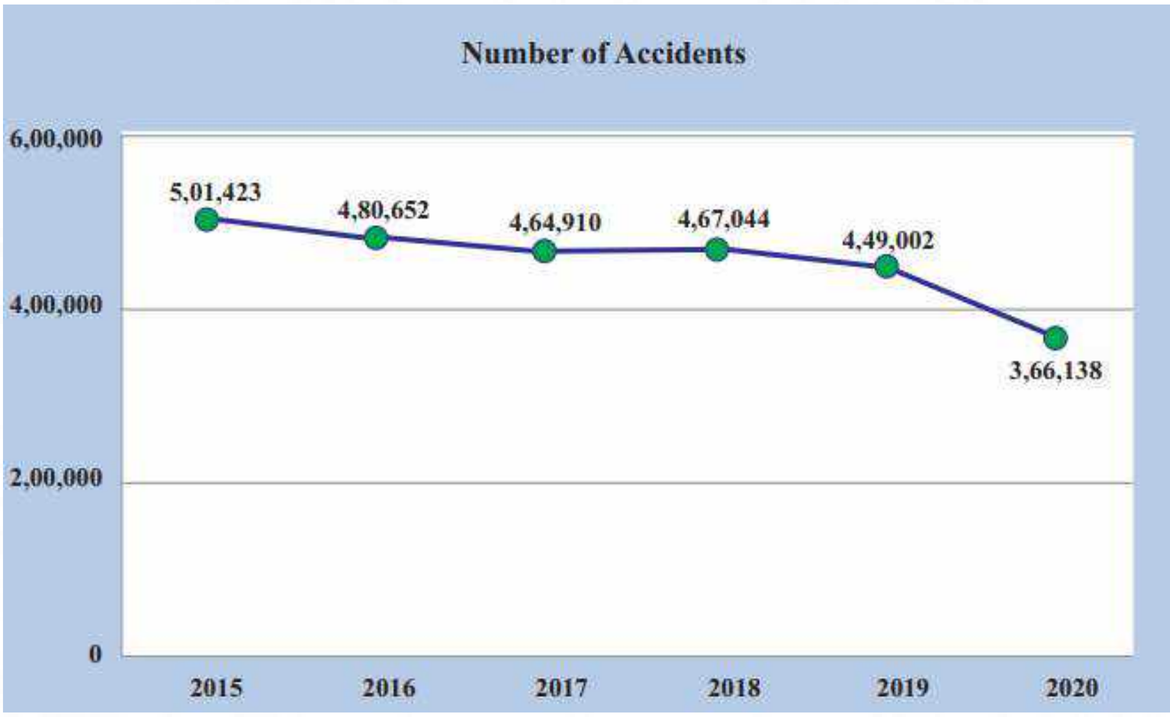


Fig. 2.2. Time Trend in number of Road crashes in India: 2015 to 2020 (Source: Government of India, 2021)

2.4.4.2 Higher Death Rates

In comparison to the worldwide average, India had higher age-standardized fatality rates for road injuries among motorcyclists (4.9 deaths [3.9-5.4] per 100,000 people) and cyclists (1.2 deaths [0.9-1.4] per 100,000 people). In India, road accidents were the second-leading cause of death for both sexes in this age range for males (15–39 years old) in 2017.

(Dandona *et al*., 2020). Reports on 'Accidental Deaths and Suicides in India (ADSI)' issued by National Crime Records Bureau (NCRB) indicate that the number of fatalities per 100 crashes, a measure of the severity of traffic accidents, went up from 33.7 in 2019 to 36.0 in 2020. Despite some minor changes, the long-term trend has been rising since 2000. It emphasizes the necessity of better trauma care and traffic slowing strategies that were intended to lessen crash impact characteristics. (National Crime Records Bureau, 2021).

2.4.4.3 Distribution as per Age, Gender and Vehicle

According to Dandona R *et al.*'s report of Global Burden of Disease 1990-2017 published in The Lancet Public Health in 2020, there were 2,18,876 road injury-related deaths (95% CI: 2,01,734 to 2,31,141) in India in 2017. The age-standardized death rate for road injuries was 17.2 deaths (15.7 to 18.1) per 100,000 people, with males experiencing a higher death rate (25·7 deaths [23·5 to 27·4] per 1,00,000) than females (8.5 deaths [95% CI: 7.2 to 9.1] per 1,00,000) in 2017. From 1990 to 2017, there were 58.7% more road fatalities in India (from 43.6 to 74.7 per lakh population) than there were in 1990, however the age-standardized fatality rate fell by 9.2% (0.6 to 1.8).(Dandona *et al*., 2020). A total of 76729 pedestrians (35%) and 67524 motorcyclists (30%), 57802 motor vehicle occupants (26%) and 15324 cyclists (70%) were responsible for all fatalities on roads in 2017 (Dandona *et al*., 2020).

2.4.4.4 Distribution as per Road Type and State/ Union territory

In 2019, 30.6% of all accidents and 35.7% of fatalities occurred on national highways; in 2020, these percentages rose to 31.8% and 36.4%, respectively. (Government of India, 2021). In 2017, the age-standardized death rate for traffic accidents varied between states by up to 26 times. The percentage change in the age-standardized death rate for traffic accidents from 1990 to 2017 varied greatly amongst the states, from a decrease of 38.2% (22.3 to 51.7) in Delhi to an increase of 17.0% (0.6 to 34.7) in Odisha. As per predictions, no state in India or all of India would meet the SDG 2020 objective in 2020 or even in 2030 if the trends predicted up to 2017 were to hold (Dandona *et al*., 2020). Distribution of road crashes in India in the year 2021, as per state/ union territory is as provided in Fig. 2.3.

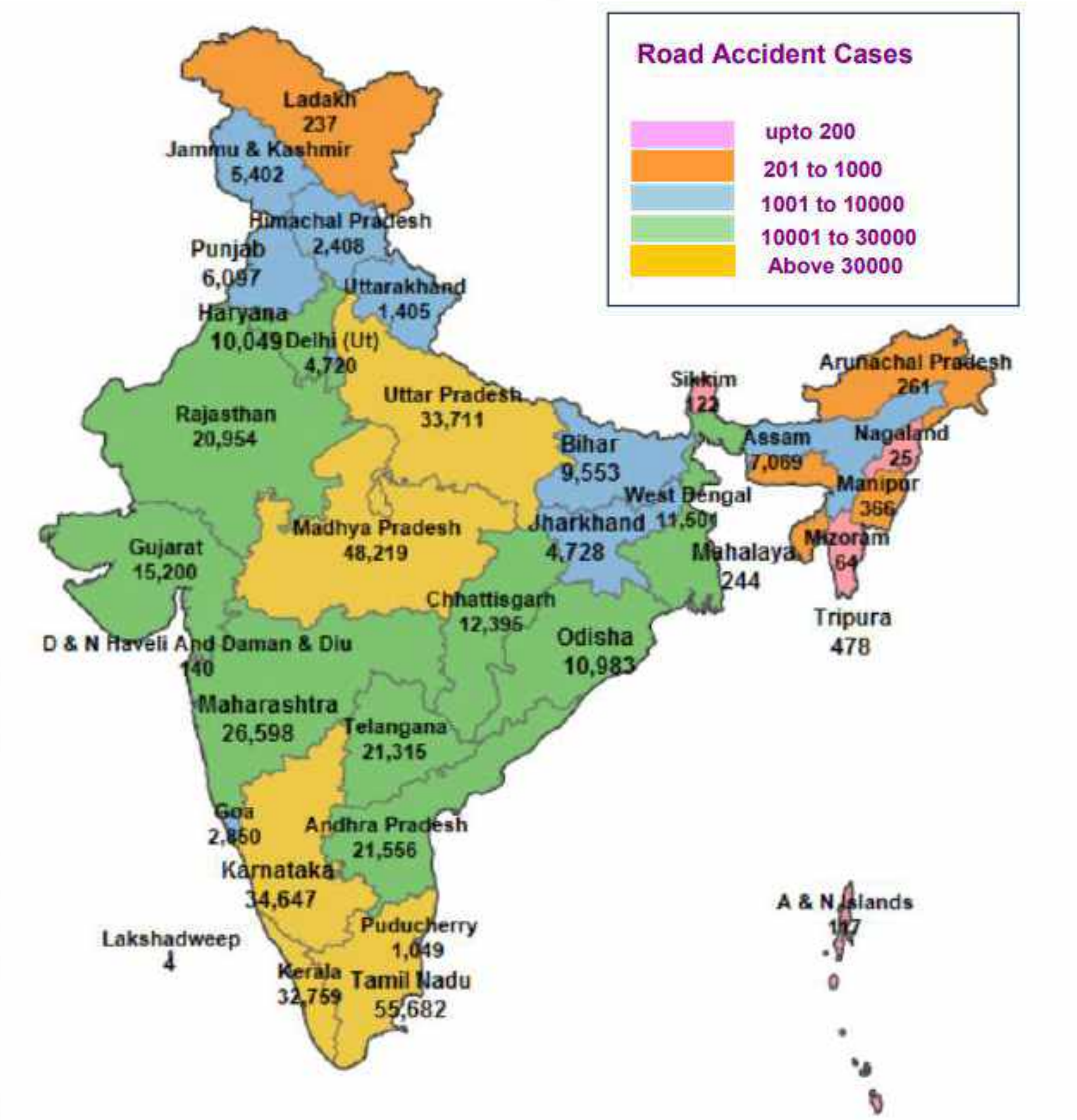


Fig. 2.3. State/UT-wise Distribution of Road Crashes in India during 2021 (Source: National Crime Records Bureau, 2021)

2.4.4.5 Increased Medicare Seeking and Out-Of-Pocket Expenditure

In an analysis of the National Sample Survey 2017–18, Ram B *et al.* found that 2.6 out of 1000 individuals reported episodes of unintentional injuries requiring inpatient care, representing 10.7% of the nation's overall ill population and 88.54% of the injured population. Similar to inpatient care, the prevalence of outpatient care has been reported at 0.8 people per

1,000 people in the country, or 1.1 percent of the total number of sick and injured people there. Additionally, the mean monthly Out of Pocket (OOP) costs for the population impacted by unintentional accidents have been calculated as Indian Rupee INR 2672.5 (US$ 41.1) for inpatient care and INR 3041.6 (US$ 47.1) for outpatient care, respectively (Ram and Thakur, 2022).

2.4.4.6 Main Determinants

According to a report by the NCRB, Ministry of Home Affairs, Government of India, the majority of road accidents in India are the result of human error, with the most frequent causes being over-speeding, reckless driving and drunken driving. (National Crime Records Bureau, 2021). According to an NCRB report of 2016, hit-and-run accidents also contributed significantly to a considerable part of road accident fatalities in India. (National Crime Records Bureau, 2016).

2.4.4.7 Summary of Evidence: RTIs in India

According to the latest NCRB report , majority of road accident casualties in India were discovered to be young males, and national highways had the greatest number of collisions (National Crime Records Bureau, 2021). According to a different study by the Indian Council of Medical Research in 2016, the bulk of road accident fatalities in India, were brought on by head injuries. The majority of victims in traffic accidents were discovered to be walkers, motorcyclists, and cyclists, and the survey also revealed that urban regions saw the greatest number of collisions. The majority of road accident casualties were men, according to the survey, and accidents were most common in the states of Tamil Nadu, Maharashtra, and Karnataka. (National Crime Records Bureau, 2016).

According to other research, low-and middle-income groups in India bear a disproportionately heavy burden of road accidents and injuries, with a higher burden among rural populations and in low- and middle-income regions (Sharma *et al.*, 2020).

2.4.4.8 Rising Death Rates: A Cause of Concern

Road Crash fatality rate (number of deaths per 100 crashes) is a workable, ready-to-interpret indicator, and can be considered as a corollary of Case fatality rate which is used in clinical settings. It gives an idea of the severity of crashes by taking resultant deaths as numerator function. The constantly rising trend of road crash fatality rates in India over the past two decades is as provided in Fig. 2.4, and is a cause of concern.

Fig. 2.4. Road Crash Fatality Rates in India over the Years : 2000-2020
(Source: National Crime Records Bureau, 2021)

2.4.5 South India

2.4.5.1 Rising Share of RTIs in Deaths and Disability Profile

Road traffic injuries and deaths are a significant public health concern in South India. A review of literature on the topic reveals that the burden of road traffic injuries and deaths in South India is high, with a significant number of deaths and disabilities resulting from these injuries. One study published in the Journal of Trauma Management and Outcomes in 2017 found that the rate of road traffic injuries in South India was higher than the national average, with Tamil

Nadu having the highest rate of road traffic deaths among all states in India (Inbaraj *et al*., 2017). Compared to other parts of India, Southern India has a higher incidence of road accidents on national roads, particularly Tamil Nadu, which has seen the highest rate of such incidents since 2016. In Tamil Nadu, traffic accidents were responsible for more than 15,000 fatalities annually in 2014. In Tamil Nadu itself, there were 10,000 fewer traffic fatalities in 2019—a decrease of more than 25%.(World Bank, 2021). The state with the most road accidents in 2020 was also Tamil Nadu, with 45,484 incidents (12.4%). (Government of India, 2021).

2.4.5.2 Most Affected are Productive Age Group Males

A study published in the Indian Journal of Community Medicine in 2017 (Rajkumar *et al*., 2017) found that road traffic injuries were the leading cause of death among young adults in South India, accounting for nearly one-third of all deaths among this age group. This finding has been confirmed by other studies and reports also.

2.4.5.3 Disproportionate Damage on Vulnerable Communities

A study published in the International Journal of Injury Control and Safety Promotion in 2018 found that the burden of road traffic injuries and deaths in South India was disproportionately borne by low-income and marginalized communities. The study found that individuals from low-income backgrounds were more likely to be involved in road traffic accidents and that they were also more likely to suffer severe injuries and death as a result.

2.4.5.4 Main Risk Factors

The 2017 study by Rajkumar *et al*., also found that a majority of road traffic injuries in South India were caused by two-wheeler accidents and that a large proportion of these accidents occurred due to reckless and negligent driving. (Rajkumar *et al*., 2017).

2.4.6 Puducherry

In the year 2020 alone, around 969 accidents occurred on the roads of Puducherry, an Indian union territory in south coastal India adjoining Tamil Nadu. (Sun, 2022). Every year, traffic inconsistencies are a major cause of fatalities, injuries, and property loss. Vehicle over speeding was the primary cause of fatal road accidents in 2020. (Puducherry Traffic Police Department, 2021; Sun, 2022). According to the National Crime Records Bureau (NCRB) under MHA's most recent data, Puducherry has the highest rate of unintentional deaths in the country. Puducherry was at the top of the list of 19 States and Union Territories that reported more "accidental deaths" than the national average.(National Crime Records Bureau, 2021).

2.5 Epidemiology of Road Crashes

2.5.1 Contributing Factors-Determinants

The epidemiological aspects of road crashes with respect to problem load and distribution are fairly known. Major determinants/ contributing factors to collisions, fatalities, and severe injuries include driving at excessive speeds, while impaired by alcohol or drugs, while fatigued or sleepy, when visibility is impaired, or when none of the occupants of the vehicle are wearing protective gear. In general, the most vulnerable and active road users in developing nations are walkers, cyclists, moped and motorcycle drivers. The majority of persons who regularly walk, ride bicycles, mopeds, or motorcycles are poor, highlighting the higher risk experienced by those with less privilege. (Nantulya, 2002). Motorized two- and three-wheelers (like motorized rickshaws), for instance, will account for the predicted increase in the number of motor vehicles in Asia. (Mohan and Tiwari., 2006).

2.5.2 Preventability Aspects: Crashes Not Accidents

Road traffic injuries are predictable and avoidable, but reliable statistics are necessary to comprehend how road safety initiatives and technologies from industrialized nations where they have been successfully implemented can be properly exported. Policymakers and the general public are lacking in their understanding of the effects of traffic accidents. Comprehensive road safety programs must be incorporated into national planning in developing nations. that estimated the macroeconomic burden of road injuries for 166 countries. Additionally, they stated that different nations and areas bear different financial and health burdens caused by traffic accidents (World Bank, 2018).

2.6 Preventive Strategies So Far

2.6.1 Past Efforts

In the year 2007, global efforts to improve post-crash care, including trauma and emergency care services, gained major momentum when a World Health Assembly adopted a resolution that called on governments and the WHO to increase their efforts to improve care for victims of injuries and other medical emergencies.(WHO., 2011). It also called on the WHO to raise awareness about affordable ways in which trauma and emergency care services can be strengthened, especially through universally applicable means, such as improvements in organization and planning. (WHO., 2011). Other studies from LMICs have highlighted a similar need and opportunities to improve care for injured patients.(Hyder and Razzak., 2013). Documented case studies have shown that improvements can be made even in the poorest and most difficult settings (Mock *et al*., 2004). For instance, giving tranexamic acid to patients who are actively bleeding during the acute care phase could stop thousands of fatalities from occurring before they should. (Ker *et al*., 2012). Therefore, implementing treatments based on the evaluation of risk variables along with appropriate post-crash care procedures has the potential to save and improve the lives of RTI victims and take the Decade of Action for road safety closer to its goal. (United Nations Road Safety Collaboration., 2010). By 2030, the UN General Assembly hopes to have cut the number of people killed and injured in traffic accidents in half worldwide.

2.6.2 The Haddon's Matrix

2.6.2.1 Application of Haddon's Matrix in Prevention of RTIs

The Haddon's matrix significantly aided in the decline of RTIs and altered our understanding of the multifaceted nature of their causes and risk factors. (Haddon., 1968; Haddon., 1973). With a focus on the precrash, crash, and post-crash phases, the matrix provides a framework for integrating the traditional epidemiological triangle of host, vector, and environment. This method makes it easier to analyse prospective interventions that range from primary prevention to rehabilitation. (Haddon., 1973) The matrix has received widespread use in both HICs and LMICs to help with a comprehensive understanding of the epidemiology and risk factors; and also to make it easier to prioritise the best preventative and therapeutic treatments (Brice *et al*., 2011; Chorba., 1991; Short., 2013).

2.6.2.2 Pre-Crash Risk Factors

Risk variables that increase the likelihood that someone may be involved in a crash are referred to as pre-crash risk factors. At the personal level, these include speeding, operating a vehicle while intoxicated, operating a vehicle while distracted, operating a vehicle while inexperienced or under the influence of substances, and using drugs. At the vehicle level, these include faulty braking systems, poor lighting, and poor vehicle maintenance. At the environmental level, these include both physical and socioeconomic factors (Herbert *et al*., 2011).

2.6.2.3 Crash Risk Factors

Risk variables during the collision phase mostly influence the results in terms of the seriousness of injuries and fatalities. Individual risk factors include not using child restraints, helmets, or seatbelts. Vehicles lacking occupant restraints, collision protection, or adequate braking increased the danger of injury, death, and serious disability. Poorly constructed and maintained roads, poor visibility, and a lack of crash-protective roadside objects also put vehicle users in danger on an environmental level. Even though not wearing a seatbelt, a helmet, or a child restraint considerably increases the risk of RTIs and fatalities among passengers in a vehicle, many LMICs do not have required standards, and even if they do, enforcement and compliance are frequently weak(Peden *et al.*, 2017).

2.6.2.4 Post-Crash Risk Factors

A comprehensive road safety policy must focus on improving post-crash care for injured people in order to reduce fatalities and improve outcomes, even if preventing traffic accidents is always preferable. The high burden of RTI-related deaths and disabilities is mostly a result of the lack of suitable and adequate post-crash care in many LMICs (Khorasani *et al.*, 2009; Miranda *et al.*, 2013; Paravar *et al.*, 2013; Solagberu *et al.*, 2014).

2.6.3 Guiding Principles and Knowledge Gains from Past Preventive Strategies

2.6.3.1 Effectiveness of Focussed Action Plans

Because collision risk is mostly foreseeable, it is possible to adopt many effective or promising countermeasures, making it possible to avert the majority of traffic fatalities and serious injuries. RTIs respond well to focused treatments that stop the damage from happening, lessen the degree of the injury that is already there, and lessen the consequences.

2.6.3.2 Core Principles Guiding Road Safety Programmes

Despite the lack of a comprehensive road safety plan, the following guiding principles for interventions are widely accepted. These include: Reducing risk exposure by stabilising motorization levels, offering substitute transportation options, and enhancing land-use planning procedures. Reducing risk factors that are directly responsible for crashes, such as speeding, driving while intoxicated, operating dangerous vehicles on hazardous roads (with insufficient safety measures for the volume of traffic present), and failing to effectively enforce road safety regulations. Lessening the severity of injuries by requiring and enforcing the usage of seat belts, child restraints, and helmets, as well as by enhancing vehicle design and road infrastructure to safeguard all road users. Improving post-accident outcomes by taking appropriate, life-saving action at the crash scene and using rehabilitative services.

2.6.4 Shortcomings in Past Preventive Strategies

Preventive strategies discussed so far were based on knowledge gains of the past, rooted firmly around the Haddon's Matrix. In this Matrix, the human being/road user were the primary focus, while the Road factor/Vehicle factor/System were part of secondary focus. It aimed to prevent ALL accidents in toto, with action plans placing much emphasis on the human factor and not looking at the entire system as a whole. Also, humans are prone to err, and their bodies are fragile by nature, facts which the past systems have not taken into account. Further, although human-centric behavioural countermeasures continue to be useful tools for enhancing safety, these tactics frequently take a long time before the advantages can be seen. Whereas, engineering countermeasures can change the physical surroundings of the transportation system to quickly and effectively improve mobility and safety (Bliss and Breen, 2012), (WHO, 2021; Corben *et al*., 2022; Langford and Oxley, 2006; Shi *et al*., 2023). Road safety strategies emanating from Haddon's matrix at core have given sub-optimal results in the past, and the current scenario of road traffic accidents with resultant deaths/injuries has remained consistent in the past decades. This highlights the importance of finding a newer approach to tackle the problem.

2.7 Lacunae/ Gaps in Knowledge

2.7.1 Gains and Gaps : The Knowledge Picture in Road Safety Arena

The gains in our knowledge/ understanding of road crashes, based on evidences were not enough; and there were huge knowledge gaps. Based on research carried out *hitherto fore*, a fair body of scientific evidence does exist on the epidemiological aspects of road crashes. These include the frequency/load of the problem (world-wide, country-wise and region/state/province-wise). Adequate knowledge is also available on distribution of road crashes with respect to many variables such as victim age, victim gender, vehicle type (both of the victim and the accused), season-time of crash, class of road etc. Further, a good amount of evidence is available on the determinants/ risk factors leading to road crashes and deaths thereof, such as non-wearing of helmets(two-wheelers), over-speeding, non-wearing of seat belts (four-wheelers), not adhering to traffic rules of the road, drunken driving etc. The positive impact brought onto road safety (in the form of reduction of road crashes and attendant deaths) through implementation of preventive modalities (like strict enforcement of helmet wearing and seatbelt wearing rules, hefty fines-penalties for drunken driving and over speeding, continuing traffic education at all levels of community, especially in younger age group) are also well documented and backed by scientific evidence. However, as mentioned earlier, the net resultant outcome of such control-prevention strategies has been sub-optimal, with lesser reduction in crashes compared to the investments made in the sphere, be it in terms of knowledge, infrastructure and manpower-efforts. On the contrary, in many settings, road crashes and resultant deaths have continued to be on the rise, in spite of such targeted interventions. The knowledge gains and their resultant impact on road safety are offset significantly by the existing knowledge gaps in the field.

2.7.2 Evaluating The Efficacy of Interventions

The World Report on Road Traffic Injury Prevention, which discusses effective and potential interventions for preventing traffic injuries, continues to be a seminal work. (Peden *et al*., 2004). Randomized Control Trials, the gold standard for evaluating the efficacy of interventions, are infrequently used to evaluate road safety initiatives due to the resources needed for such studies and the ethical concerns associated with randomising life-saving therapies. As a result, research using case-control or before-and-after data are crucial for proving the effectiveness of interventions, yet even these are mainly concentrated in HICs. In recent years, tactics that had positive outcomes in HICs have been adapted for application in

LMICs as road safety initiatives. Some interventions concentrate on lowering or eliminating exposure to risk factors among vulnerable road users. These include promoting alternate modes of transportation (Duduta *et al*., 2011), building dedicated lanes for motorcycles (Peden *et al*., 2004; Radin *et al*., 2000), improving visibility for pedestrians and cyclists (Radin *et al*., 1996; Radin *et al*., 2000), and supervising kids walking to school. (Muchaka and Behrens., 2012; Muda and Ali., 2006). Other initiatives target the five main behavioural risk factors for RTIs by establishing blood alcohol limits (Bishai *et al*., 2008; Garcell *et al*., 2008), establishing or lowering speed restrictions (Andrade *et al*., 2008), and mandating the use of seatbelts for drivers and passengers as well as helmets for motorcyclists and cyclists. (Espitia-Hardeman *et al*., 2008; Ichikawa *et al*., 2003; Law *et al*., 2005; Passmore *et al*., 2010; Soori *et al*., 2009; Stevenson *et al*., 2008).

2.7.3 **HMICs Vs LMICs : Wide Gap**

2.7.3.1 Effective Interventions in HICs

The four additional intervention types have been demonstrated to be effective in HICs but have not yet been examined in LMICs (or the outcomes of research have not yet been reported in the peer-reviewed literature) are:- (i) Establishing and implementing lower blood alcohol levels for inexperienced drivers, (ii) Establishing and enforcing the use of suitable child restraints, (iii) Lowering speed restrictions near places with a lot of foot traffic, like schools and hospitals; and (iv) Putting in place graduated driver licencing programmes for novice drivers.

2.7.3.2 Challenges in Implementing Interventions in LMICs

However, there are difficulties when tailoring interventions to the LMIC environment. The "efficacy" that is really realised frequently depends on a range of variables, such as the legislative process and enduring beliefs, norms, and habits. Additionally, research and implementation capabilities (as well as access to financing and prices) play crucial roles in the effectiveness element when attempting to identify and measure the interventions in LMICs. (Perel *et al*., 2007). Not only must there be a high level of enforcement, but also a high level of public perception of enforcement, in order to promote a culture of safe driving behaviour governed by law. (WHO., 2013)

2.7.3.3 Successful Initiatives in LMICs

Despite the fact that few studies were carried out in LMICs, available research are testimony to the following successful outcomes: (i) Setting and enforcing speed restrictions in accordance with the intended tasks of the roads can reduce RTIs by up to 34%. (WHO, 2013), (ii) Alcohol-related RTIs can be considerably decreased by establishing statutory blood alcohol limits of 0.05 grammes per decilitre (g/dl) and implementing random breath testing (Elvik *et al*., 2009; Shults *et al*., 2001). Despite improvements in alcohol-related driving penalties around the world, LMICs are less likely than HICs to embrace the policies. (WHO., 2013) (iii) Though LMICs are less likely to adopt the practises, introducing and mandating the usage of motorcycle helmets can cut the risk of mortality by 40% and the risk of major head injuries by more than 70%. (Liu *et al*., 2008). (iv) The risk of fatal injuries can be decreased by up to 50% for front seat occupants and up to 75% for rear seat occupants by mandating and enforcing the usage of seatbelts. (Zhu M *et al*., 2007) Although the majority of nations require seatbelt use, the legislation frequently excludes passengers in the back seat. (World Health Organization., 2013) Requiring children to utilise child safety seats can cut the risk of a fatal collision for them by as much as 80%. (Zaza *et al*., 2001) LMICs don't always have these laws, though. For instance, only one out of ten countries in South-East Asia have laws requiring child restraints. (World Health Organization., 2015) According to research, using seatbelts (Chisholm *et al*., 2012), motorcycle helmets ,observance of traffic codes (Bishai and Hyder., 2006) can be very cost-effective in avoiding RTIs in LMICs.

2.7.3.4 Reliable Evidence of Optimal Outcomes in LMICs

A systematic review of 15 randomised controlled trials on the effectiveness of safety education programmes revealed that there is a lack of high-quality evidence of the effectiveness of education in LMICs, but some individuals have attested to the beneficial effects of strategies that combine education with legislation and enforcement. (Duperrex *et al*., 2002)

2.8 Newer Initiatives

Along with the aforesaid core ideas, political commitment and will are crucial in lessening the burden of RTIs. In order to reduce the impact of RTIs, the WHO and UN jointly declared the decade 2011-2020 as the Decade of Action for Road Safety 2011-2020, which has further been extended to 2021-2030 as the second decade of action for road safety (WHO, 2010b) (WHO, 2020).

2.9 Safe Systems Approach

2.9.1 Background

The newer 'Safe Systems Approach' advocated by WHO-UN as part of 'Global Plan for the Decade of Action for Road Safety 2011-2020' takes into account people's vulnerability to serious injuries in road traffic crashes, while recognizing that systems and processes must be designed to be forgiving of human error. Adjusting the environment to the abilities and limitations of the human being, a concept derived from cognitive ergonomics, has been applied earlier in aviation and all types of transport other than road traffic, resulting in a widespread safety culture. This concept is being applied in the sphere of road safety too. (WHO, 2010b) (WHO, 2020)

2.9.2 Origin

The Safe System concept was initially developed in Sweden and the Netherlands. The Swedish government's "Vision Zero" plan was approved by parliament in 1997. According to the ruling, "the design, operation, and use of the transport system shall be coordinated such that no one is killed or gravely harmed." The cornerstones of Sweden's implementation of a Safe System have been this imperative and the understanding of the reciprocal rights and obligations of road users and managers. In an effort to encourage "inherently safe road traffic," the Dutch Institute for Road Safety Research (Dutch abbreviation-SWOV) created a similar policy in the 1990s. Sustainably Safety was the label given to this concept. (International Transport Forum., 2016)

2.9.3 Concept and Goals

Safe System is a comprehensive approach to regulating traffic safety that takes into account all of the system's elements, such as the road environment, speed limits, vehicle safety, and post-crash assistance. The ultimate goal is to have no serious accidents or fatalities on the roads. Safe System is a systematic framework for integrating the pillars of Vision Zero in research, policy, and implementation, Vision Zero is the basic ideology that eventually strives for zero deaths from transportation.(Tingvall *et al*., 2000; Trafikverket., Vision Zero in Practice., 2021). Given that several contributing factors frequently combine to produce traffic crashes, Safe System methodically discovers methods in which the four Safe System pillars can cooperate to prevent crashes and mitigate crash effects. (Federal Highway Administration (FHWA)., 2019)

2.9.4 Cardinal Principles

The underlying principles of a Safe System approach are drawn from the principles outlined in the report published by the International Transport Forum of the OECD (OECD/ITF., 2015) (International Transport Forum., 2016; International Transport Forum., 2008.). These are:- (i) Mistakes made by human beings can result in automobile accidents. And as human being is bound to make mistakes on road, making him/her alone the focus of preventive strategy will not yield the desired result. It is impossible to avoid accidents in toto.

(ii) The human body can only withstand a certain amount of impact forces before suffering damage. The inherent fragility of human body leads to disproportionate damage in case of man-machine high impact crash/energy exchange (iii) To prevent collisions that result in serious injury or fatality, there is a shared responsibility among those who design, construct, manage, and utilize roads and vehicles as well as those who offer post-crash care (iv) Making the mobility system safe should be done proactively rather than by waiting for an incident to happen and then responding. So that road users are still protected if one component of the system fails, it must be enhanced throughout to increase its impacts. (v) No major harm or death should be permitted in a mobility system. Faster mobility should not come at the expense of safety. Instead, a mobility system needs to be both secure and effective. The five cardinal principles of Safe Systems approach are summarized in Fig. 2.5.

Fig. 2.5. Principles of Safe System Approach
(Source: PIARC., 2011)

2.9.5 Four Pillars

The Safe System method focuses on four components or pillars, namely (i) safe people (behaviour), (ii) safe vehicles, (iii) safe roads and roadsides, and (iv) safe speeds, for the prevention of major injuries that may arise from a collision. Without a clear description of how each of these quadrants interacts with and operates within the system, the four pillars mentioned above are traditionally portrayed as a circle with four quadrants. It is widely acknowledged that there is now a fifth pillar, known as "emergency response." (PIARC, 2011).

2.9.6 Five Pillars

The revised approach suggests five pillars: safer road users, safer vehicles, safer roads and mobility, safer speeds and safer post-crash care. (World Health Organization., 2015).

2.9.6.1 Safer Road Users

The first and most important action required to reduce RTIs is effective legislation that defines safety regulations and penalises risky behaviour. The majority of nations have national legislation that address the major risk factors, such as speeding, driving while intoxicated, and not using kid restraints, motorcycle helmets, or seat belts. Since 2011, a total of 17 nations have updated their legal frameworks to reflect best practises in order to address one or more significant RTI risk factors. However, there has not been much progress achieved globally in expanding the scope of national laws to cover all significant risk factors. (World Health Organization., 2015).

2.9.6.2 Safer Vehicles

There are more than 1.8 billion registered vehicles worldwide, and more than half of them are in LMICs (World Health Organization., 2008.). Rapid motorization has resulted from the rising demand for mobility (particularly in LMICs), which presents difficulties for safer transportation. In addition to protecting persons inside of vehicles, safer vehicle strategies now safeguard those outside of them. As automakers improved cutting-edge technology intended to avoid or lessen crashes, they added it to passenger vehicle models. Although there is little information on the effectiveness of safety technologies, some of them, such crash avoidance systems, have the potential to reduce RTIs. (Jermakian *et al*., 2011; World Health Organization., 2013) According to a French study, between 2000 and 2010, improved vehicle safety technologies directly prevented 27,365 car occupants and 1,083 pedestrians from being killed in crashes, despite the fact that public safety measures (like speed cameras) helped to reduce the number of fatal road crashes by more than 75%. (Page *et al*., 2011). In addition, a review of the literature on road safety interventions reveals that the use of electronic stability control systems was linked to a 2% to 41% percent decrease in RTIs. The study also found that the most effective interventions are those that lessen or completely eliminate the risk of RTIs and do not rely on modifying the behaviour of other road users. (Novoa *et al*., 2009). However, because of the high cost and insufficient government safety restrictions on the automotive industry, safer vehicles are hard to come by in LMICs. Latin New Car Assessment Program (NCAP) tested several automobile models on the Latin American market and discovered that some of the best-selling vehicles were ones with the lowest safety equipment ratings (one out of five stars). Additionally, while frontal airbags for the driver and front passenger have been standard on cars in the US since 1999, they were often an option on car models in LMICs (Chorba, 2009). The rise in motorised two-wheelers (motorcycles and electric bikes, or e-bikes) in LMICs, particularly in South-East Asia and Africa, is even more worrying than the increase in four-wheeled vehicles. For instance, in 2011 similar vehicles were accepted in Malaysia and Thailand with a ratio of three and four people per vehicle, respectively.(Sekine., 2014). Motorcycle crash death rates were much higher in both nations: 62% in Malaysia and 73% in Thailand. (World Health Organization., 2015). As part of the UN's Decade of Action for Road Safety, the Global NCAP offers a stakeholder movement to urge the adoption and implementation of harmonised motor vehicle standards in LMICs to promote safer automobiles (Yumpu., 2014).

2.9.6.3 Safer Roads and Mobility

RTIs dramatically rise when road networks are poorly built or do not have enough safety precautions. Results of the International Road Assessment Program in LMICs reveal that a majority of the roads evaluated in these nations—84 percent of the roadways where pedestrians are present—do not have pathways are regarded as having the greatest level of risk. (World Health Organization.,2013). In these nations, vulnerable road users account for a significant fraction (60 percent) of all traffic fatalities. (World Health Organization., 2013). An increasing number of nations have made changes to their national transportation plans to promote alternate forms of transportation like biking and walking or to enhance funding for public transportation in order to deal with rising motorization and RTIs. (World Health Organization., 2013) However, these methods frequently lacked the necessary resources or techniques for dealing with varied traffic situations, which could have prevented the interventions from having the desired impact on vulnerable road users. (World Health Organization., 2013). For instance, it has been demonstrated that segregating more vulnerable road users—such as pedestrians, motorcyclists, and cyclists—from larger and faster cars while supporting initiatives like city cycling reduces accidents and fatalities. (Herrstedt., 1998; Radin *et al.,* 2005; Gomes and Cardoso., 2012; Wittink *et al*., 2001). However, only 91 nations have laws that physically divide vulnerable road users from other drivers.(World Health Organization., 2015). Additional safety improvements with a track record of success include, among others, adequate illumination (Radin *et al*., 1996.; Radin *et al*., 2005), lane markings or signage (Ward *et al*., 1989), pedestrian crossings and roadside barriers (Bambach *et al*., 2013). (Duduta et al., 2011; Fuentes and Hernandez., 2013; Mock *et al*., 2003).

2.9.6.4 Safer Speeds

RTIs can be decreased with the help of traffic calming techniques such as the installation of speed bumps or rumble strips. (Changchen *et al*., 2010; Lines *et al*., 2000; Novoa *et al*., 2009). It was discovered that these and other restrictions on vehicle speed in locations with significant concentrations of vulnerable road users cut the incidence of vehicle crashes involving pedestrians by 67 percent. (World Health Organization., 2013). Only 47 nations—representing 950 million people—have adopted sensible urban speed limits, and only 27 of those nations consider the effectiveness of their implementation of these regulations to be good. (World Health Organization., 2015).

2.9.6.5 Safer Post Crash Care

In low-income countries, there are more than twice as many patients who pass away before visiting a hospital.(WHO., 2015). If patients receive timely, efficient pre-hospital care, it is frequently possible to reduce the effects of major injuries, including long-term morbidity or mortality. If people who require trauma care following an automobile accident receive it during the crucial first hour, they have the best chance of surviving. (Vanderschuren and McKune, 2015). With professional pre-hospital care available at the crash site, many lives can be saved and impairments can be reduced. Important pre-hospital care is quick communication, treatment, and transportation of injured individuals to authorised medical facilities. With few interventions, primary care professionals can deliver and administer the majority of these services. A study by Urfi *et al.* in Aligarh, U.P. found that the most crucial enabler for delivering post-crash emergency treatment was a layperson. (Urfi *et al*., 2022).

2.9.7 Key Elements

The key elements of Safe System approach include the following (PIARC., 2011):-

2.9.7.1 Emergency medical management for post-crash care.

2.9.7.2 Understanding of crashes on the network, which requires good data to enable risks across sections of the network to be accurately identified

2.9.7.3 Control of admittance (entry and exit) of drivers to/from the road transport system (licensing arrangements including graduated licensing arrangements)

2.9.7.4 Effective legislation and systems, enforcement and justice system support

2.9.7.5 Educating and informing the public

2.9.8 Impact of Safe Systems Approach

The management of traffic safety in other countries, notably the United States, has progressively begun to be influenced by the Safe System approach in the Netherlands and Sweden. Study by Shi G *et al*. have shown that since the Safe System was implemented in the Netherlands and Sweden, the risk of death has decreased at a rate that is noticeably higher than that in the United States. The gains have been particularly striking when it comes to walkers and bikers, whose death rates are now comparable to those of people who drive cars. (Shi *et al*., 2023).

2.10 Road Crash Data Systems

2.10.1 Data Perspective in Safe Systems Approach

In the 'Safe Systems' approach, the core objective of data management has shifted from analysis of figures (based on hospital and police records), to robust, real-time quantifiable models, and on deeper understanding of crashes. Fixed, target-oriented strategy has given way to more flexible and dynamic ones, achievable by tailor-made policies in tandem with local settings. While complete avoidance of all road crashes may not be feasible, preventing resultant deaths is surely considered an attainable goal, and must be focused on in each setting, as emphasized in this approach. (Gopalakrishnan, 2012). Crash-data analyses also rely on information collected by transport, police, and health authorities. As such, a system should be used to integrate, merge, and validate the various sources of data to better understand the causes of crashes and injury patterns. Such integration of data from various sources has been used successfully in various countries (Alkheder *et al*., 2017; Cao *et al*., 2015; Castro and Kim, 2016; Ghosh *et al*., 2016; Hashmienejad and Hasheminejad, 2017; Kumar and Toshniwal, 2015; Moriya *et al*., 2018; Scott-Parker and Oviedo-Trespalacios, 2017; Taamneh *et al*., 2017; Tiwari *et al*., 2017; Yasin Çodur and Tortum, 2015; Zheng *et al.*, 2019). Road crash data systems should therefore process information in a way that allows for analysis at an aggregate level and facilitates data-driven action. A thorough and well-planned assessment of the current data situation is a prerequisite for arguing the case for improved road safety data, and for informed decision-making about what action to take. This includes translational and operational data on final outcomes such as road crash fatalities and severe injuries, exposure measures such as demographic data and traffic volume, intermediate outcomes such as helmet-wearing rates and mean traffic speeds, and other types of information such as socio-economic costs associated with road traffic injuries. (Salve, 2021).

2.10.2 Data Requirements: Information Systems on Road Safety

The report of the World Health Organization - South East Asian Region (WHO-SEAR) on 'Research Framework for road safety in the South-East Asian region' brings out the lack of operational research in the sphere of road safety, especially in this densely populated region where it is warranted the most, being one of the most road crash prone region in the world. The document mentions that Road safety research being a broad area encompassing different methods and techniques, while involving multiple disciplines and sectors, any research must involve appropriate technology in the data systems, to provide timely and holistic outputs for evidence-based solutions. Further, Road safety research needs to move beyond mere numbers, in order to understand processes and mechanisms, thus enabling translational research, as outlined in the 'Safe Systems Approach'. A significant step towards making road safety data systems more dynamic would be to design an effective data management framework for information archiving, analysis and dissemination. For optimal outcomes, such a framework needs to be based on open-source, freely accessible software solutions; the salient features being a data extraction template (to decipher only the requisite variables from raw data on fatal road crashes), with an objective element like blackspot cluster identification through spatial-temporal analysis, at its nucleus. (WHO., 2015).

2.10.3 Lack of Good Quality Data Systems on Road Crashes

A dynamic, robust data system is the backbone on which any meaningful prevention strategy can be mounted upon. The World Health Organization Manual on road safety Data Systems brings out the lack of data quantity/quantum in the field of road safety, mainly due to under-reporting, low research proportion etc. Even the available data is lacking in quality, because of unreliable and inaccurate data systems. Besides, research on road safety is highly compartmentalized, with each of the stakeholder departments (primary ones like traffic police, health, transport departments, and allied ones like legal, insurance, public works etc.) enriching their own databases vertically, with little cross linkage and data sharing. Even the existing medical literature on the subject is heavily tilted towards clinical data (such as injury profile of road crash victims), with lesser studies on community/societal aspects. It is also noteworthy that the latest advancements in technology have been grossly under-utilized, unharnessed, and untapped to fill the gaps in our understanding of the problem and finding workable solutions to address it (WHO, 2015).

2.10.4 Felt Need for Robust Road Safety Data Systems

It is thus necessary to establish a reliable and comprehensive crash database system to assist in identifying potentially viable countermeasures. Effective road safety management requires data that users can rely on for accuracy, to define road safety problems, identify risks, formulate strategy and develop interventions, set targets and monitor performance. Though data relevant to road safety is collected every day, its utility will be truly translational only if it is properly coded, processed and analysed in a technically appropriate database system. Luoma and Sivak (2007) examined the characteristics and availability of fatal road-crash databases in 20 countries.(Luoma and Sivak, 2007). The authors concluded that most of the crash databases include aggregate data, with substantial restrictions on the availability of disaggregated data. This restriction may significantly limit the possibilities for detailed analyses of crashes that could otherwise improve road safety.

2.10.5 Recommendations to Optimize Data Systems for Road Safety

The world report on road traffic injury prevention highlighted the significance of gathering accurate, trustworthy, and high-quality data on the scope of the problem of road traffic injuries in all countries and suggested that data systems should be put in place to develop evidence-driven policies for road safety. (Peden *et al*., 2004). To establish policies and programs, set goals, track performance, and determine the burden and characteristics of the road safety problem, risk factors, and priority areas, it is necessary to collect high-quality data. By preventing duplication of resources and taking the proper action, this also makes it possible to allocate the necessary resources. For programs promoting road safety, data systems are essential. Systems for collecting data on road safety involve action, evaluation, and data collection. There would not be a meaningful and lasting increase in road safety without continual data-driven identification and management of road injury concerns. (World Health Organization., 2007). While the individual epidemiological facets like frequency-load, distribution and determinants/risk factors of fatal road crashes have been studied in silos, studies offering comprehensive, snapshot views of such fatal road crash data under a single research umbrella are few and far between. It therefore merits attention for such studies to be carried out, wherein profiling of fatal road crashes (which form the focus of prevention in 'safe systems approach') is captured for analysis, to derive targeted approaches.

2.10.6 Definition

The term road crash data system refers to the people, processes, hardware and software involved in collecting and managing information related to road traffic crashes. Systems for processing information on traffic accidents should enable aggregate analysis and support data-driven decision-making. (WHO, 2015).

2.10.7 Components

Good road crash data systems should, at the very least, include accurate crash location information, provide reliable output in a timely manner to support evidence-based decisions, capture nearly all crashes that result in death and a significant portion of those that result in serious injuries, provide adequate detail on the vehicle, the road user, and the road and environment. Use of Geographical Information System (GIS) is one of the salient features of a smart road crash data system. Accurately and regularly collecting comprehensive data on RTIs is vital to monitoring a country's progress in addressing road safety. Such information can be instrumental in guiding a country's health system in planning for and addressing the burden. In addition to mortality and morbidity estimates, reliable information and data on modifiable risk factors, costs associated with RTIs, and age-specific and gender-specific RTI data at both the national and local levels could inform researchers and policy makers about cost-effective interventions, as well as provide implications of the future health and economic burden—which could be a powerful advocacy tool for action. (WHO, 2015).

2.10.8 Efforts to Create Smart Road Crash Data Systems

Current efforts in HICs such as the European Union (EU) project Joint Action for Injury Monitoring in Europe-JAMIE (2011–2014) have enabled participating member states to have a relatively limited but useful set of injury data collected from emergency departments. This project has significantly improved comparable injury surveillance systems across EU Member States. (Bauer *et al*., 2014; Rogmans., 2012; Archives of Public Health., 2013). In LMICs, however, the absence or limited availability of strong and robust injury information systems presents a significant challenge to obtaining consistent and quality data on injuries. These measurement limitations render demonstrating the magnitude of the injury problem or even tracking a nation's progress in addressing it difficult. Establishing simple yet robust data systems in LMICs would facilitate the flow of continuous, reliable, and systematic information on key variables to all stakeholders (Chandran *et al*., 2010; Hofman *et al*., 2005; Kruk *et al*., 2010; Lett *et al*., 2002.; Mock *et al*., 2004; Razzak *et al*., 2005) Integrating systems for collecting key information on risk factors and outcomes into new and existing programs to address RTIs in LMICs therefore is essential to begin closing this gap. (Bachani., 2013; Bachani., 2012; Hyder *et al*., 2013). There thus exists a gap to fill in LMICs, insofar as information requirements in the form of data systems on road crashes are concerned.

2.11 Geographical Information System (GIS) for Road Safety

2.11.1 The Concept

Geographical Information System (GIS) is a computer-based system that allows for the integration, analysis, and visualization of spatial data. It can be used to map accident locations, identify high-risk areas, and evaluate the effectiveness of interventions.

2.11.2 Application in Road Safety

Geographical Information System (GIS) has emerged as a useful tool for understanding and addressing the problem of road accidents and injuries. GIS and data systems have been increasingly used in the field of road safety to prevent accidents and injuries. GIS allows for the integration and analysis of spatial data, such as road network information and accident locations, to identify high-risk areas and develop targeted interventions. One of the primary uses of GIS in road safety is the identification of accident hotspots. By mapping accident locations, GIS can reveal patterns and trends that may not be apparent from raw data alone. For example, a GIS analysis may reveal that a particular intersection or stretch of road has a higher-than-average accident rate. This information can be used to identify priority areas for safety improvements. GIS can also be used to analyse the relationship between road design and accident risk. For example, a GIS analysis might reveal that a particular road design feature, such as a lack of median barriers or poor lighting, is associated with a higher accident rate. This information can be used to inform road design and engineering decisions. GIS can also be used to evaluate the effectiveness of safety countermeasures. For example, a GIS analysis might reveal that the installation of a roundabout at a particular intersection is associated with a reduction in accident rates. This information can be used to identify best practices for road safety interventions. Data systems, on the other hand, provide a means for collecting and storing accident data, which can then be analysed using GIS or other methods (Budzyński et al., 2018).

2.11.3 Empirical Evidence of GIS as Valuable Tool in Road Crash Data Systems

Many studies have used GIS to study road traffic accidents, some examples of which are mentioned hereafter: A study by Aghasi NHM *et al.* in Tehran city used spatio-temporal analysis to study the Urban traffic accidents in Iran's capital city ((Aghasi, 2018). They reported that the spatial analysis and temporal analysis of relative accidents risks point out the risky segments for different zones of the city and different land uses depending on the season, month, day and time. Another study conducted in India by Mahata D *et al.* reported that the spatial analysis of severity shows that there is no direct link between the number of accidents and the severity. The city-wise analysis of RTAs by the vehicle involved, age of the persons, cite, and timing of accidents shows a varying pattern across the cities.(Mahata *et al*., 2019). Azimian *et al.* did Bayesian spatial-temporal analysis to study road traffic accidents in West Virginia. His dissertation proposed an integrated safety screening approach that combines macro- and a micro-level analysis to generate a comprehensive and effective framework for use in transport safety planning.(Azimian *et al*., 2018). Wang M *et al.* similarly used GIS for analyzing traffic accidents in Harbin, China.(Wang *et al*., 2021). Zhan-Moodie M *et al*. used GIS for studying highway congestions and traffic accidents (Zhan-Moodie M *et al.*, 2019). Overall, the literature suggests that GIS and data systems can be powerful tools for improving road safety by identifying high-risk areas and evaluating the effectiveness of interventions. However, more research is needed to fully understand the potential of these tools and to develop best practices for their use in road safety.

2.12 Harnessing Contemporary Technology

2.12.1 Spatial-Temporal Analysis of Road Crash Spots using GIS

Cherry *et al*. suggested that standardizing data-collection methods and accident forms, and incorporating Global Positioning System (GPS) will aid in data accuracy and spatial analysis.(Cherry *et al*., 2006). While GIS is used for mapping and geospatial analysis of data, GPS is primarily used for navigation. The Model Minimum Uniform Crash Criteria (MMUCC) is, for example, a guideline that was created to ensure that officials collect the necessary information to support analysis and improve highway safety (U.S. Department of Transportation [USDOT]. (U.S. Department of Transportation., 2008). Generally, traffic officials face a problem of where and how to implement precautionary measures so that they can have the most significant impact to improve road traffic safety Traffic safety studies explore the effect of various factors on safety performance, either qualitatively or quantitatively, such as the influence of various geometric features of road design, weather conditions, lighting factor, or geographical conditions. Using GIS, the analyst can merge accident and highway data, geo-code accident data and locations, determine accident rate and its frequency, and calculate mean and standard deviation of the accident rate (Liang *et al.*, 2005). This single feature of spatio-temporal analysis using GIS makes the data more objective and amenable to cross-utilization, and offers promising scope for research.

2.13 Techniques for Blackspot Identification using Spatio-Temporal Analysis by GIS

Geographical Information System (GIS) technology is a vital and a popular tool for visualization of road crash data and analysis of hot spots (high density clusters of crashes) in roadways. Road Crash analysis studies aim at the identification of high-rate accident locations and safety deficient areas on the roadways, so that traffic officials can implement precautionary measures and provisions for traffic safety. However, road crash reports are prepared in textual (descriptive) format in most urban settings in India, which need to be transformed into tabular, numerical (objective) format, to derive more meaningful and operationally translatable inferences. Density-Based Spatial Clustering of Applications with Noise (DBSCAN) and Network Kernel Density Estimate (NKDE) are few useful tools in the hands of researchers in this sphere.

2.13.1 Density-Based Spatial Clustering of Applications with Noise (DBSCAN)

Multiple studies in India (Agrawal *et al.*, 2018; Alotaibi, 2018a; Ganjali Khosrowshahi *et al.*, 2021; Nalini *et al.*, 2020; Shinde *et al.*, 2022) and globally (Alotaibi, 2018; Ganjali Khosrowshahi *et al.*, 2021; Huang *et al.*, 2021; Islam *et al.*, 2021; Topcuoglu *et al.*, 2022; Wang *et al.*, 2023; Xia and Yang, 2019) have used DBSCAN to analyse road accident location and identify blackspots.

2.13.2 Network Kernel Density Estimate (NKDE)

Multiple studies have used Network Kernel Density Estimate (NKDE)with respect to road accidents, for hotspot identifications and geospatial clustering of road accidents. (Ahmad *et al*., 2019; Al-Aamri *et al*., 2021; Audu *et al*., 2021; Bassani *et al*., 2020; Dalai and Landge, 2022; Damani and Lakkad, 2018; Fatema and Chakrabarty, 2020; Ganjali Khosrowshahi *et al*., 2021; Kazmi *et al*., 2022; Le *et al*., 2022; Lee and Khattak, 2019; Nazneen *et al*., 2020; Pleerux, 2020; Sandhu *et al*., 2016; Srikanth *et al*., 2019; Srikanth and Srikanth, 2020; Xie and Yan, 2008). The deeper details of both these techniques and the nuances they employ to achieve the goals, are brought out elaborately in the successing chapter, namely 'Materials and Methods'.

3. MATERIALS AND METHODS

3.1 Features of the Study

3.1.1 Study Setting

The study setting is Puducherry district, one of four such districts in the Union Territory of Puducherry. It is bordered on the east by the Bay of Bengal and surrounded in all other directions by Tamil Nadu. Puducherry is an educational and tourist Hub with a population of 9.5 lakh people residing within 293 square kilometer (sq. km). It is divided into four taluks, two municipalities, five communes and three census towns for administrative purposes, and is urban. The district is served by four main roads extending in north, north-west, west and southern directions, and the total road length is 422.77 km. With a vehicle density of 494 per 1000 population, Puducherry is second only to Goa (555) in vehicle density, many times more than the national average of 14 vehicles per 1000 population. Its vehicle density of 106.4 vehicles per km of road is also manifold than the corresponding national figure of 46.3. It has a discontinuous, patchy geographical spread, thus rendering it a cartographer's challenge. The district is divided into four zones (east, west, north, and south) from a traffic police perspective. A map of the location of the study setting is provided in Fig. 3.1 below:-

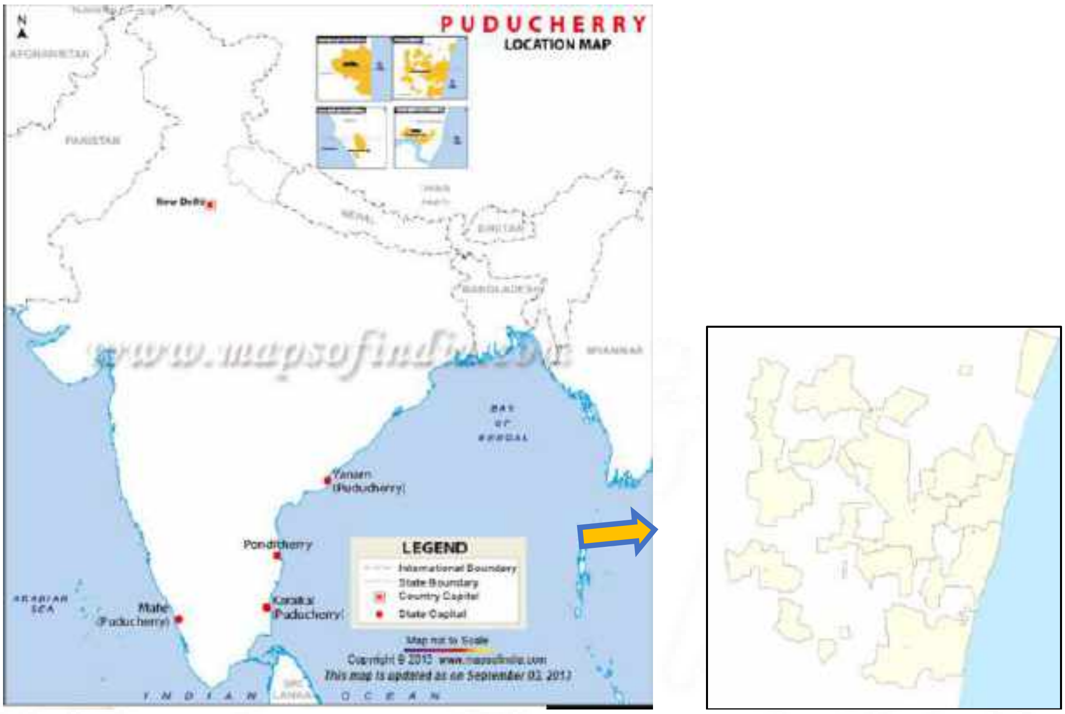


Fig. 3.1. Location and Boundary Map of Puducherry: Inset Map from India
(Sources:*www.mapsofindia.com*; www.py.gov.in, https://www.team-bhp.com)

3.1.2 Study Type-Design

The study is descriptive-observational in design, done using quantitative research methods by analysis of records.

3.1.3 Study Period

The study concept was initially formulated in 2016 and finalized in 2017. Data for a three-year period (2016-2018) was obtained from traffic police authorities in Puducherry.

3.2. Operational Definitions

3.2.1 Road

For the purpose of this study, 'Road' is defined as a 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. Included are paved roads and other roads with a stabilized base, e.g. gravel roads. Roads also cover streets, bridges, tunnels, supporting structures, junctions, crossings and interchanges.

3.2.2 Road Traffic Crash

A collision or incident involving at least one road vehicle in motion on a public rr private road to which the public has tthe right to to access. Included are collisions between road vehicles, vehicles and pedestrians, vehicles and animals or fixed obstacles, and with one road vehicle alone. Included are collisions between road and rail vehicles. Multi-vehicle collisions are counted as only one crash, provided that any successive collisions happen within a very short time period.

3.2.3 Road Traffic Injury (or Casualty)

A person who has sustained physical damage (i.e. injury) due to a road traffic crash.

3.2.4 Fatal Road Crash

Any road traffic crash resulting in a person killed immediately or dying within 30 days due to the collision.

3.2.5 Urban setting

All places with a municipality, corporation, cantonment board or notified town area committee, etc. OR All other sites which satisfied the following criteria:- (i) A minimum population of 5,000; (ii) At least 75 per cent of the male main working population engaged in non-agricultural pursuits; and (iii) A density of population of at least 400 persons per square kilometre (sq.km.).

3.4.6 South India

The area including the five southern Indian states of Andhra Pradesh, Karnataka, Kerala, Tamil Nadu and Telangana, as well as the three union territories of Andaman and Nicobar islands, Lakshadweep and Puducherry.

3.4.7 Data Systems

An organized collection of symbols; and the processes that may be used to operate on such symbols. A data system is defined in terms of some data model and bears a resemblance to the idea of a physical symbol system.

3.4.8 Road Crash Data System

The people, processes, hardware and software involved in collecting and managing information related to road traffic crashes.

3.4.9 Processes

A series of actions or steps taken in order to achieve a particular end.

3.4.10 Mechanism

A natural or established process by which something takes place or is brought about.

3.4.11 Framework

The basic structure underlying a system, concept, or text.

3.4.12 Profile

An outline or description of a person, event or issue/point of interest.

3.4.13 Geographical Information System

An electronic system designed to capture, store, manipulate, analyse, manage, and present spatial or geographic data.

3.4.14 Spatio-Temporal Analysis

Systematic analysis of data collected across both space and time that aims at the description of a phenomenon in a particular location and period of time.

3.4.15 Blackspots

Clusters or areas of dense occurrence of an event or phenomenon.

3.5 *Data Sources*

3.5.1 First Data Source : Road Crash Data from Traffic Police Records

After obtaining necessary administrative and ethical clearances from appropriate authorities, road crash data for three years (2016-18) was accessed from the records of the traffic police department, Puducherry. This raw data (the first data source was available as excel files (*.xlsx*), 12 excel sheets, one for each year-zone subset (03 years X 04 zones); personal details were anonymized. However, only fatal crash data were available in different formats for each zone and year, while crash location data was entered only in descriptive terms. The date and time were mentioned in the same column in different styles. This dataset was unsuitable for analysis; hence the authorities were approached to rework the source data and provide standardized datasheets amenable to analysis. Consequently, data on all crashes (both fatal and non-fatal) with crash locations geo-coordinated as per latitude-longitude of the crash site was provided by the traffic police department. However, this revised dataset was also non-uniform, with different column styles in each sheet and zones indicated as rows. After that, a data extraction template was developed to capture all details in a standardized format. This data frame in excel sheet format consisted of one column for each variable, with a unique identifier ID assigned for each study subject/record. The latitude-longitude details of crash locations were extracted onto two columns, and date-time details were extracted onto two columns in standardized formats. Thus, a standardized data frame suitable for analysis was extracted from the raw data. A sample table (anonymised) to illustrate the data extraction template is provided in Table 3.1.

Table 3.1. Standardized Data Frame Using Data Extraction Template

ID NO.	DATE	TIME	IPC SEC	TYPE	LAT	LONG	VICT AGE	VICT VEH	VICT GEND
2078	19 June 2017	3:21:36 PM	U/s 279 & 337 IPC	Grievous	11.9328	79.8122	40	CAR	Female

Table 3.1. Standardized Data Frame Using Data Extraction Template (Continued..)

VICT OCCUPANCY	VICT VEH MAKE	ACCU AGE	ACCU VEH MAKE	ACCU VEH	ACCU GEND	ZONE	MISC
Driver	Maruti Swift Dzire Car	54	Tipper Lorry.	LORRY	Male	EAST	Rash driving

Note/ Legend.

ID No.=Unique Identification Number (for each record), IPC=Indian Penal Code, Lat=Latitude, Long=Longitude, Vict=Victim, Accu=Accused, Zone=Traffic zone, Misc=Miscellaneous

3.5.2 Second Data Source : Administrative Boundaries Map of Puducherry

The second data source used for the study was a map of the administrative boundaries of Puducherry. This was accessed from the Survey of India and through the Achutha Menon Centre for Health Science Studies (AMCHSS) spatial resources. The boundaries file was in shape files (*.shp*)-polygons. A prototype map of the administrative boundaries of Puducherry thus obtained is provided in Fig. 3.2.

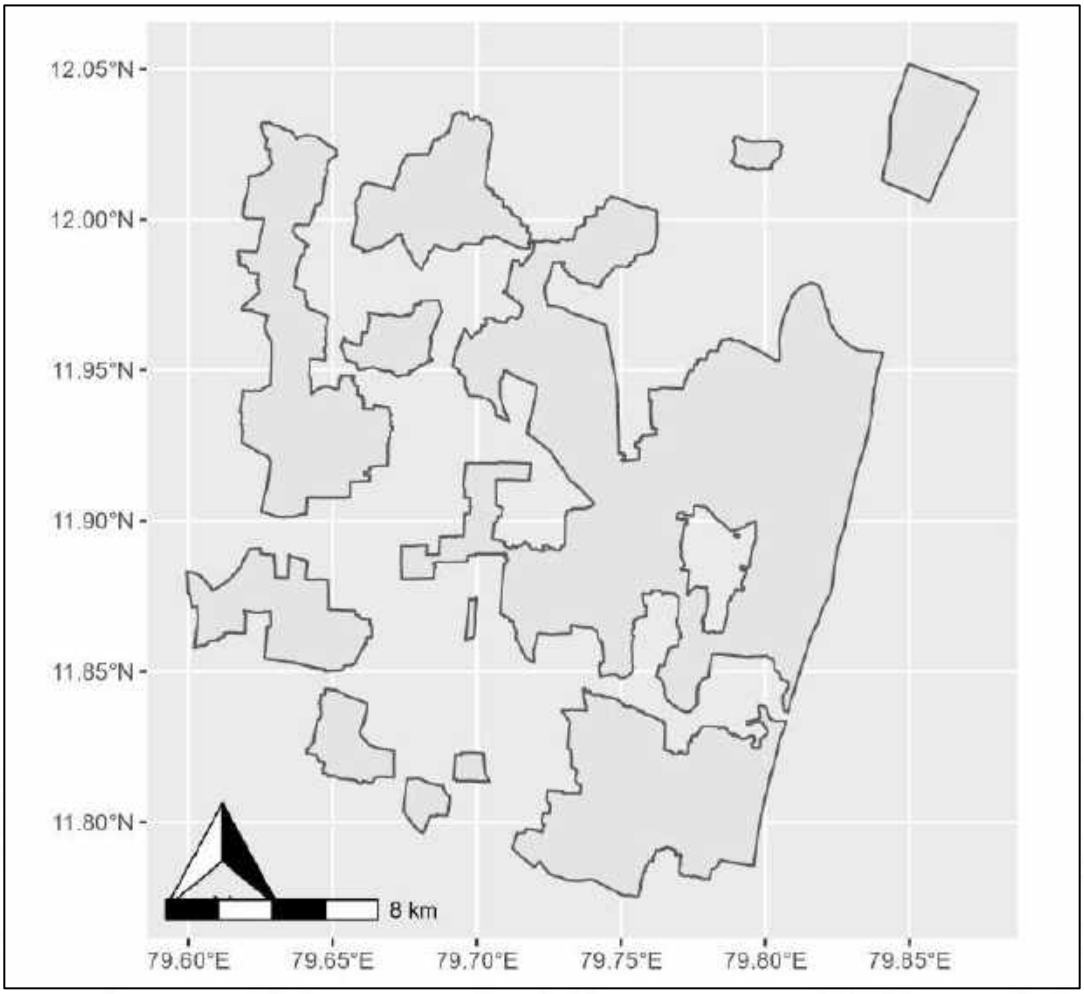


Fig. 3.2. Map of Administrative Boundaries of Puducherry (Source: AMCHSS Spatial Resources)

3.5.3 Third Data Source : Road Network Map of Puducherry

The third data source was the Puducherry Road network map. The initial baseline road network map of Puducherry was accessed from Open Street Map (OSM) as shape files (*.shp*) lines. However, this map contained many segments-features in bits and hence was too cluttered to make any analysis feasible. Therefore, government sources (Public Works Department-PWD) in the study setting were approached to seek a more precise road network map. However, the same was available only in PDF final output format for selected roads; while the source input file (created using AUTOCAD software programme) could not be accessed.

Hence the issue persisted. A sample map of the road network of Puducherry obtained from the PWD Department is provided in Fig. 3.3.

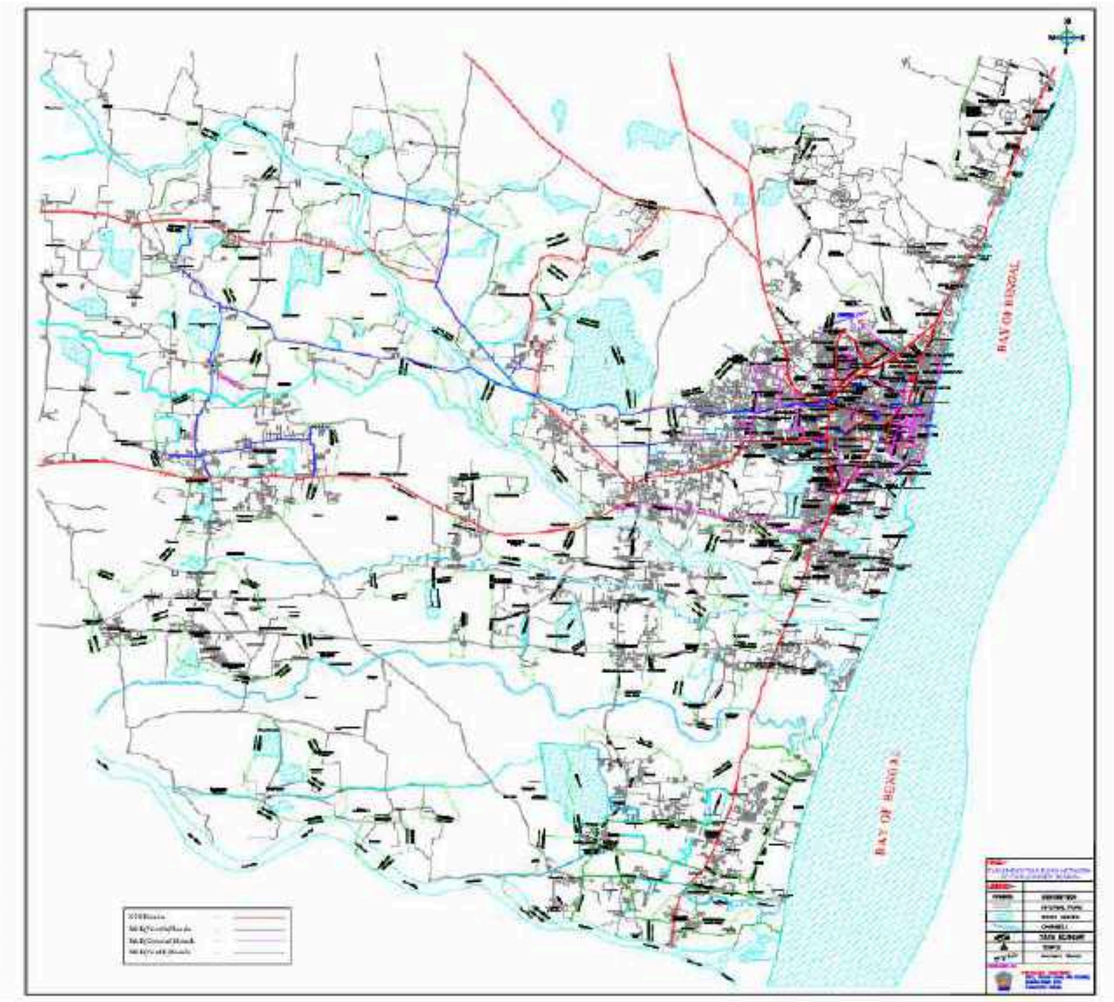


Fig. 3.3. Road Network Map of Puducherry
(Source: Public Works Department, Govt. of Puducherry)

Concurrently, the fragmented segments of the road network were combined into single stretches, and a combined network map was arrived at; still, this map also was very dense and unamenable to the crash spot analysis planned. Therefore, subject experts in geology were consulted, who suggested that the available map extracted from OSM be cleaned/ pruned using certain tools. Consequently, the master network map was re-scrutinized, with each road segment being manually identified and non-affected/ irrelevant road segments removed manually using QGIS software. Thereafter, the dangling, 'orphan' road segments (leading to/from nowhere) with a thresh (threshold) length of 250 m or less were identified and removed using the *smoothR* function in the R software. Thus, a refined road network map was available for analysis. The series of maps arrived at using this process are provided in Fig. 3.4(a), Fig. 3.4(b) and Fig. 3.4(c).

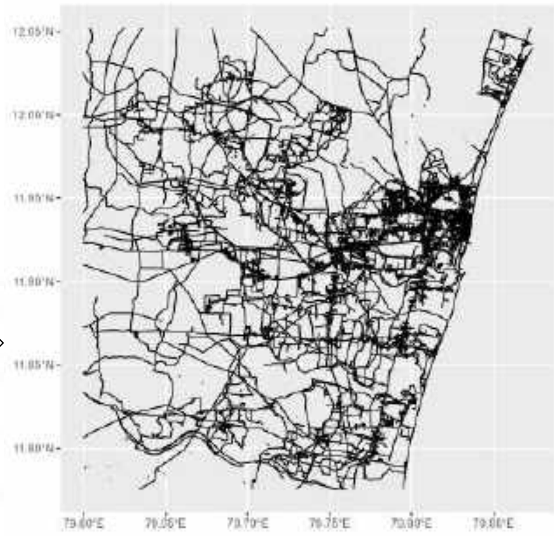


Fig. 3.4(b) Road Network Map
Reworked using QGIS software

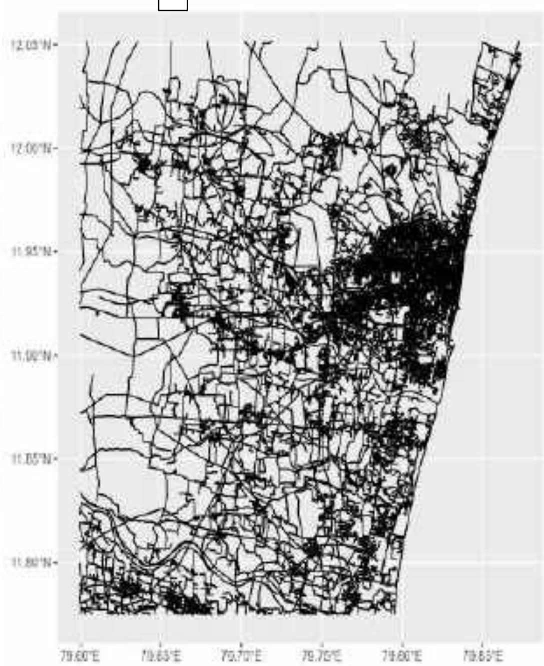


Fig. 3.4(a) Original Combined Road Network Map

Fig. 3.4(c) Final Road Network Map used for Analysis, refined by R software

Fig. 3.4(a), Fig. 3.4(b) and Fig. 3.4(c). Serial maps of Puducherry road network, representing sequence of pruning adopted to declutter

3.6 Data Analysis Plan

3.6.1 First Phase

The first phase of data analysis plan involved a description of crash characteristics. The distribution of crashes was analysed per year of occurrence, traffic zone, injury type (severity) and time of day. Details of individuals involved in crashes were then analysed, for injury type (fatal/grievous/simple), the profile of the victim and accused as per age, gender, vehicle and occupancy. R, an open-source, easy-to-reproduce, multi-platform compatible software was used for data analysis. Packages specific to the analysis of crash and individual characteristics were applied, including *'tidyverse', 'janitor', 'lubridate', 'hms', 'ggplot', 'gtsummary',* etc.

3.6.2 Second Phase

3.6.2.1 Spatio-Temporal Analysis using Machine Learning Techniques

Phase 2 of the data analysis plan involved spatio-temporal analysis of crash spots using the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm. Clustering is a technique in unsupervised Machine Learning (ML) branch of Artificial Intelligence (AI) that groups data points into clusters based on the similarity of information for the data points in the dataset. Two commonly used clustering techniques are:- (i) Kernel(K)-Means clustering and (ii) DBSCAN.

3.6.2.2 Kernel-Means Clustering

K-means clustering is a partition/ centroid-based technique where the number of clusters needs to be pre-determined *a priori*, and it is unsuitable for datasets with many outliers/noisy datasets.

3.6.2.3 Density-Based Spatial Clustering of Applications with Noise (DBSCAN)

DBSCAN, on the other hand, is a density-based algorithm where no *a-priori* assumptions are needed on the number of density clusters. The three pre-requisites to carry out the DBSCAN algorithm on a dataset are:- (i) *K-Nearest Neighbours (KNN)*: assumes the similarity between the new case/data and available cases and puts the new case into the category, that is most similar to the available categories, (ii) *minPts*: minimum number of points (a threshold) clustered together for a region to be considered dense and (iii) *Epsilon-eps (ε)*: A distance measure that will be used to locate the points in the neighbourhood of any point. R packages, '*dbscan*', '*sf*' and '*fpc*' were applied to the dataset to implement the DBSCAN algorithm. For study purposes, *MinPts* of 30 and *eps* of 0.005 were used to map all crashes, with the corresponding readings for fatal crashes being 05 and 0.02, respectively; for non-fatal crashes, 10 *MinPts* and 0.01 *eps* were used.

3.6.2.4 Differences between K-Means Clustering and DBSCAN

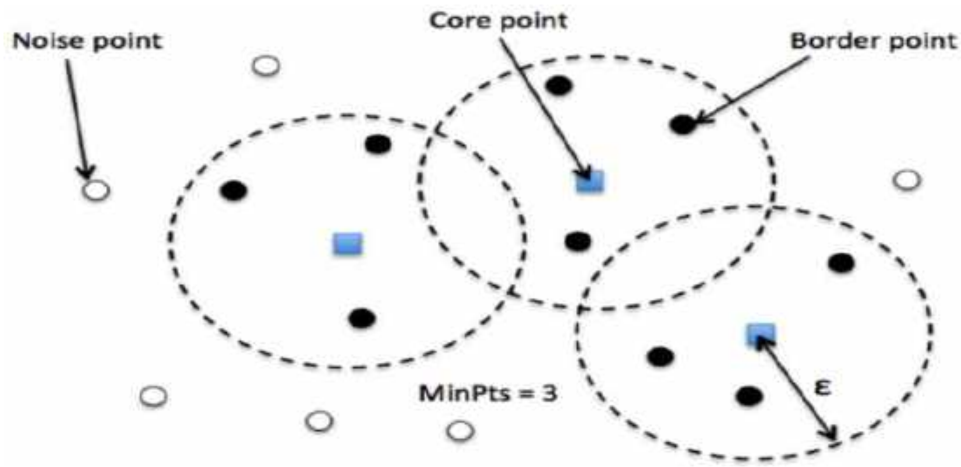
The salient differences between K-Means Clustering and DBSCAN algorithms are provided in Table 3.2:-

Table 3.2. Salient Differences Between K-Means Clustering and DBSCAN

Aspect	**K-Means Clustering**	**DBSCAN**
Basis	Centroid/ partition based	Density-based
Assumptions	Number of clusters pre-determined; sensitive to no. of clusters	No *a-priori* assumptions are needed on number of clusters
Suitability	Not suitable for data sets with many outliers and noisy data sets	Suitable for data sets with many outliers and noisy data sets
Parameters required	One parameter required (No. of clusters)	Three parameters required (KNN, minpts & epsilon)

3.6.2.4 Illustration of DBSCAN Process and Comparative Modalities

A figurative representation of the DBSCAN process is depicted in Fig. 3.5, whereas the varying modalities adopted by K-Means Clustering and DBSCAN algorithms in spatio-temporal analysis of same dataset is provided in Fig. 3.6.



- **Core** — This is a point that has at least *m* points within distance *n* from itself.
- **Border** — This is a point that has at least one Core point at a distance *n*.
- **Noise** — This is a point that is neither a Core nor a Border. And it has less than *m* points within distance *n* from itself.

Fig. 3.5. Spatio-Temporal Analysis Process by DBSCAN

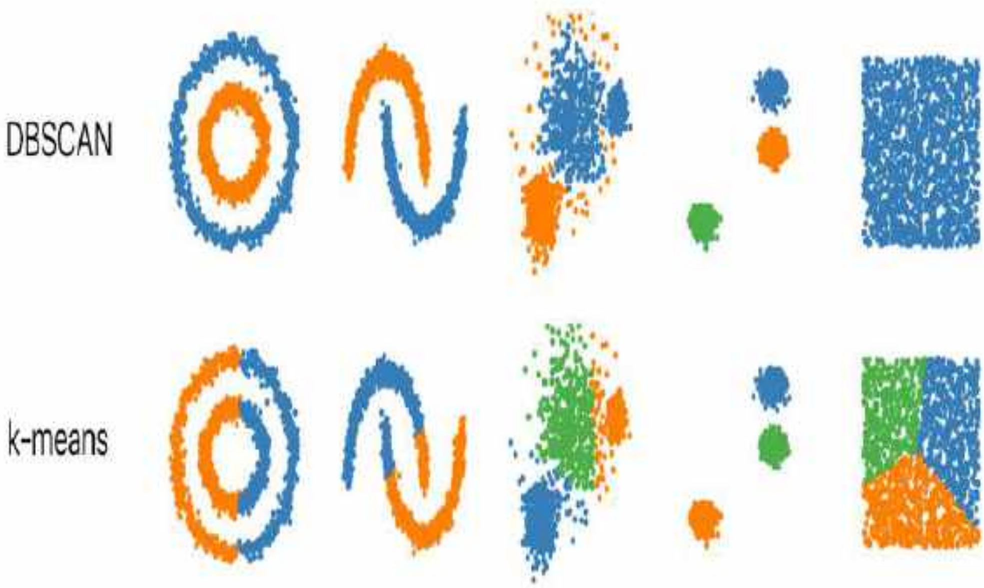


Fig. 3.6. Spatio-Temporal Analysis of Dataset by DBSCAN and K-Means Clustering

Cui X, Wang J, Wu F, Li J, Gong X, Zhao Y, Zhu R. Extracting Main Center Pattern from Road Networks Using Density-Based Clustering with Fuzzy Neighborhood. *ISPRS International Journal of Geo-Information*. 2019; 8(5):238. https://doi.org/10.3390/ijgi8050238

3.6.3 Third Phase

The third phase of data analysis plan involved the application of Network Kernel Density Estimate (NKDE) method on the dataset to estimate crash density. NKDE is one of the latest methods to estimate event density in network spaces, the other being planar Kernel Density Estimate (KDE). The basic advantage of KDE over DBSCAN is that it is specific to spaces involving road networks. While planar KDE analyses the density of events (datapoints) in a planar space using pixels by measuring Euclidean distance, NKDE analyses event density in linear space using *lixels* (linear pixels) by measuring network distance. Parameters required for NKDE are *Lixel length* (length of line on a given network split into lixels according to a chosen resolution) and *bandwidth* (distance within which the 'influence' of the point lies). *Lixel length* of 300 meters and *bandwidth* of 500 meters were used for the study. Among the three subtypes of NKDE, namely simple, discontinuous, and continuous NKDE, the discontinuous NKDE was used considering the study requirements, objectives and available data. R packages' *spnetworks', 'tidygraph'* and *'igraphs'* were applied to the dataset while performing NKDE analysis. The salient features and differences between types of NKDE are listed in Table 3.3.

Table 3.3. Salient Features of and Differences Between Types of NKDE

SIMPLE NKDE	DISCONTINUOUS NKDE	CONTINUOUS NKDE
Quick, intuitive	Deliberate, counter-intuitive	Combines best facets of simple and discontinuous
It does not consider intersections	Caters for intersections	Requires network map outside study area also requires a correction factor
Overestimates	Sharp differences (underestimates)	Balances by including the best features of simple and discontinuous NKDE

4 RESULTS

4.1 Number of Records Analysed

A total of 5202 crash records from 2016 to 2018 were analysed for the crash and individual characteristics. On an average, data was unavailable for about 6% of certain variables like age (accused and victim age), vehicle and occupancy. Complete (100%) data was available for the remaining variables.

4.2 Distribution of Road Crashes

4.2.1 As per Year and Traffic Zone

Year-wise and zone-wise distribution of road crashes in Puducherry during the study period is provided in Table 4.1. The year 2016 witnessed a maximum number of crashes (1904), with the count decreasing to 1682 crashes in 2017 and further to 1611 crashes in 2018. The West traffic zone accounted for most crashes (31%) in each of the three years, accounting for 31% in 2016, and 32% each in the years 2017 & 2018. East zone witnessed a steady drop in crashes over the years , with 2016 accounting for 43.2% of all crashes , which dropped to 25.9% in 2018.

Table 4.1. Year-wise and Zone-wise Distribution of Road Crashes in Puducherry

Zone	**east**, N = 1,083[1]	**north**, N = 1,286[1]	**south**, N = 1,194[1]	**west**, N = 1,634[1]	**Overall**, N = 5,197[1]
Year					
2016	468 (25%)	421 (22%)	432 (23%)	583 (31%)	1,904 (100%)
2017	334 (20%)	447 (27%)	363 (22%)	538 (32%)	1,682 (100%)
2018	281 (17%)	418 (26%)	399 (25%)	513 (32%)	1,611 (100%)

[1] n (%)

4.2.2 As per Severity of Injury

However, fatal crashes rose over these three years, from 172 deaths in 2016 to 201 fatalities in 2017, which further rose to 212 deaths in 2018. More than one-tenth (11.4%) of all crashes were fatal; nearly two-fifths (38.1%) resulted in grievous injuries to the victims, while 37.6% of crash victims sustained simple injuries. The crash fatality rate (number of deaths per 100 crashes) was nearly equal in both south (14%) and west (13%) zones. Vehicle damages, with no injury to humans, also accounted for a small proportion (3.3%) of all crashes. The distribution of road crashes, as per injury severity, across the various zones, is provided in Table 4.2.

Table 4.2. Zone-wise and Year-wise Distribution of Road Crashes as per Injury Type

Type of Accident	traffic obstruction, N = 101[1]	damages, N = 172[1]	simple, N = 1,962[1]	grievous, N = 2,369[1]	fatal, N = 593[1]	Overall, N = 5,197[1]
year						
2016	43 (43%)	70 (41%)	779 (40%)	840 (35%)	172 (29%)	1,904 (37%)
2017	17 (17%)	61 (35%)	671 (34%)	724 (31%)	209 (35%)	1,682 (32%)
2018	41 (41%)	41 (24%)	512 (26%)	805 (34%)	212 (36%)	1,611 (31%)
zone						
east	41 (41%)	61 (35%)	395 (20%)	493 (21%)	93 (16%)	1,083 (21%)
north	46 (46%)	81 (47%)	357 (18%)	677 (29%)	125 (21%)	1,286 (25%)
south	7 (6.9%)	8 (4.7%)	710 (36%)	308 (13%)	161 (27%)	1,194 (23%)
west	7 (6.9%)	22 (13%)	500 (25%)	891 (38%)	214 (36%)	1,634 (31%)

[1] n (%)

4.2.3 As per Day, Time and Vehicle Type

A bimodal distribution of fatal crashes over the day was observed, with peaks in the morning (8 am-12 noon) and again in the evening (6-10 pm). Non-fatal crashes followed a similar pattern on most days of the week. However, the sole exception to this distribution was Sundays, wherein most crashes occurred in the late evening and night hours. This bimodal distribution was observed to uniformly involve all types of vehicles; however, it was more pronounced and clearer in the case of two-wheelers and least in the case of three-wheelers. The distribution of fatal crashes by day of the week and time of the day is provided in Fig. 4.1, whereas similar distribution of non-fatal crashes is provided in Fig. 4.2. The distribution of crashes as per vehicle type and time of day is provided in Bar Chart in Fig. 4.3, whereas the same data is provided as Frequency Polygon in Fig. 4.4. Distribution of all crashes as per day, time and vehicle is provided in Fig. 4.5, while that of fatal crashes is given in Fig. 4.6.

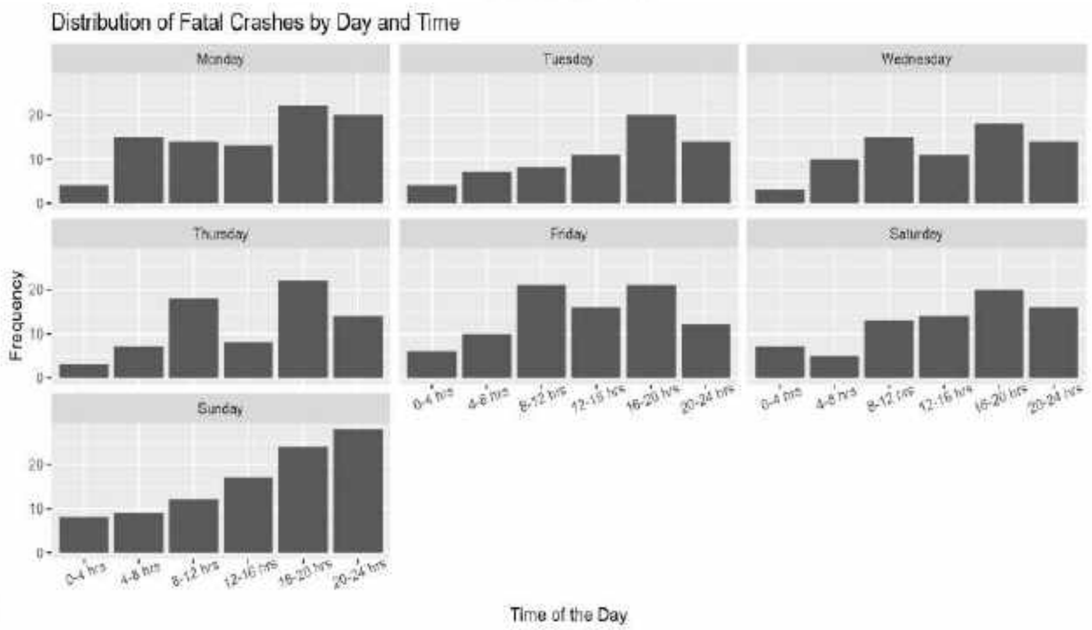


Fig. 4.1. Distribution of fatal crashes by day of week and time of day

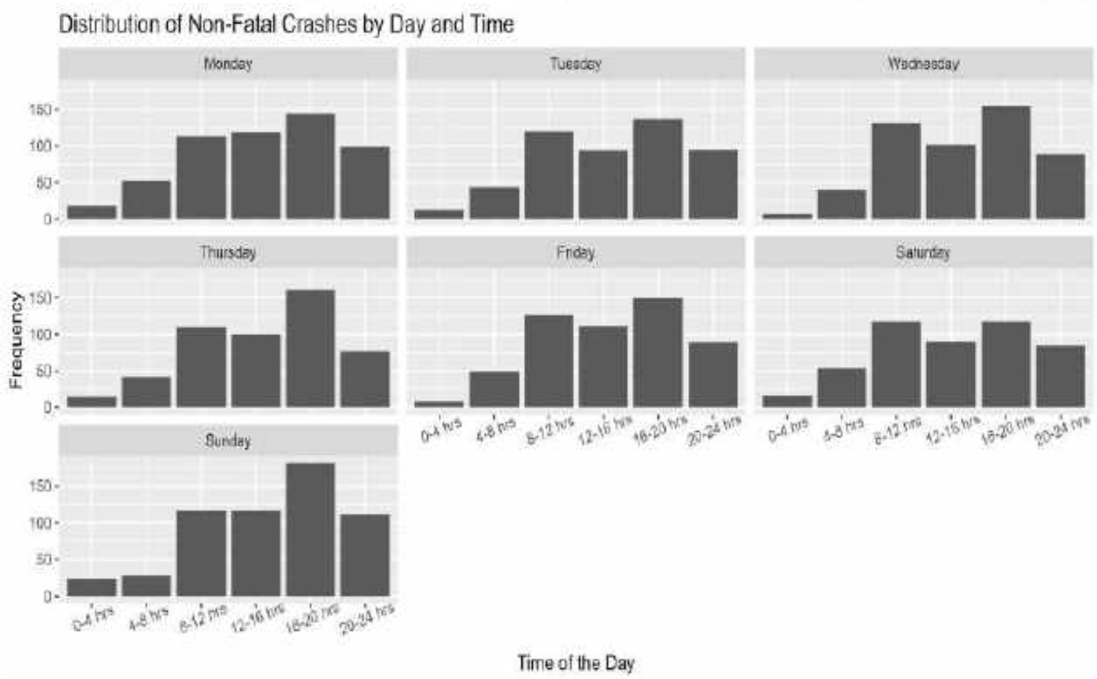


Fig. 4.2. Distribution of Non-fatal crashes by day of week and time of day

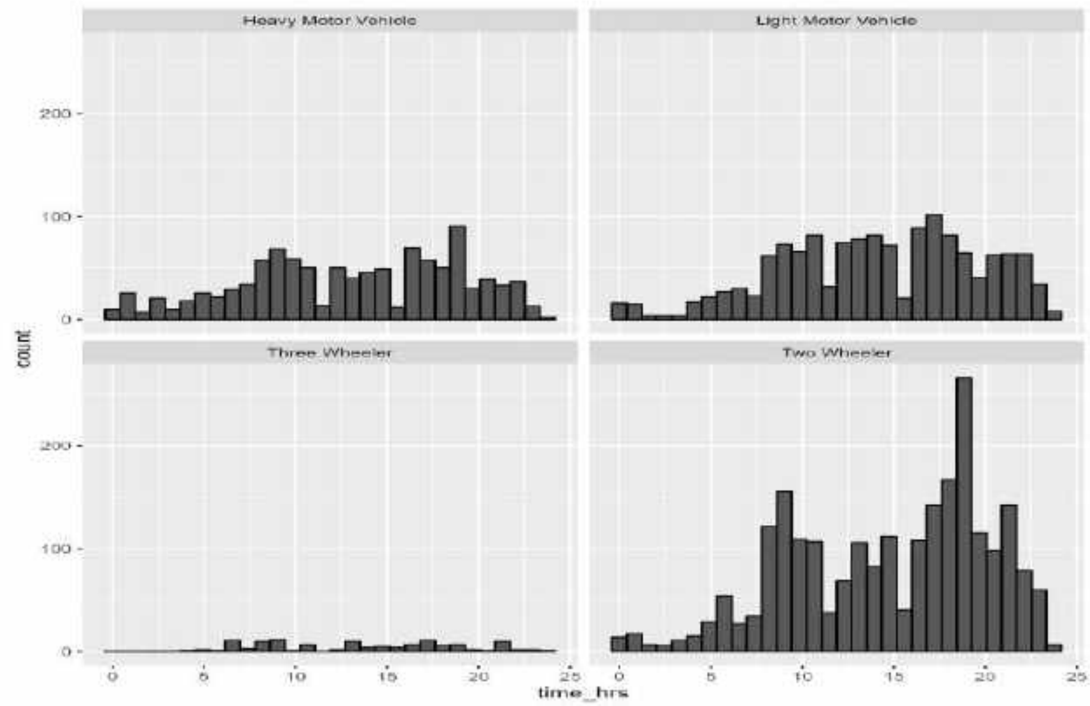


Fig. 4.3 Distribution of crashes by vehicle type and time of day (Bar Chart)

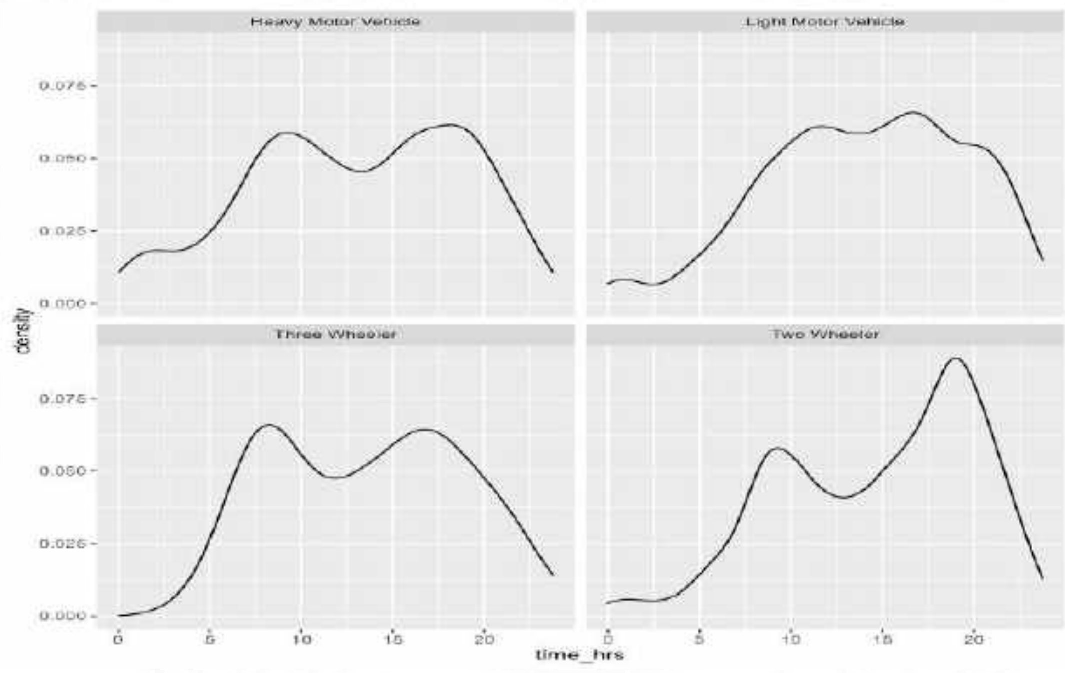


Fig. 4.4. Distribution of crashes by vehicle type and time of day (frequency polygon)

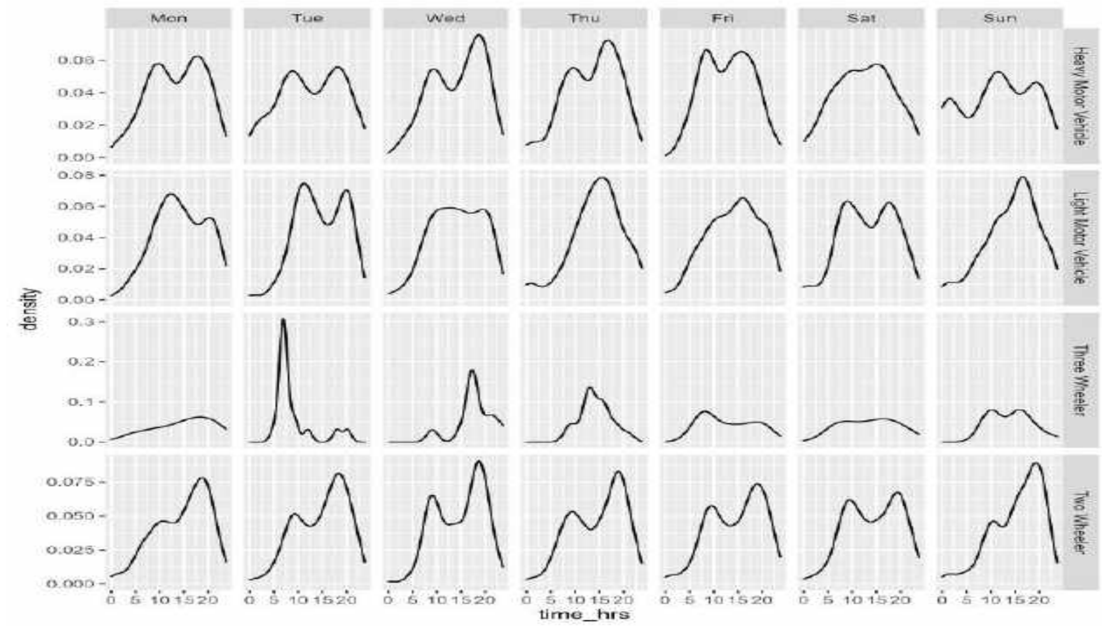


Fig. 4.5. Distribution of all crashes as per day, time and vehicle type

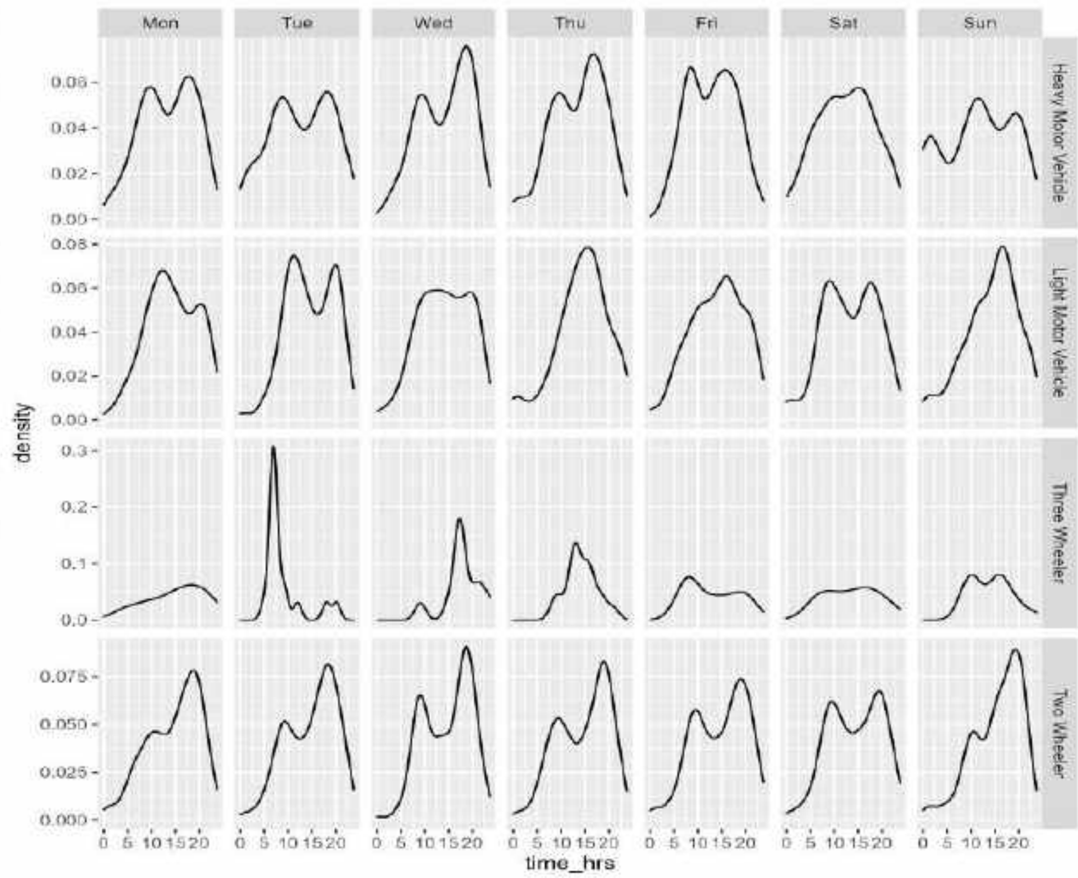


Fig. 4.6. Distribution of fatal crashes as per day, time and vehicle type

4.2.4 As per Age of Victim and Accused

The median age of the crash accused (24 years) was lower compared to the victims' median age (26 years). This difference in median age was wider (7 years) in the case of fatal crashes (median victim age 32 years vs accused age 25 years) as compared to non-fatal crashes (2 years; victim age 26 years vs accused age 24 years). Most crash victims (56.2%) belonged to the productive age group of 15-40 years. Age-wise distribution of crash victims is provided in Fig. 4.7, whereas the distribution of age groups among crash accused is provided in Fig. 4.8. A comparative depiction of the accused and victims as per age is provided in Fig. 4.9.

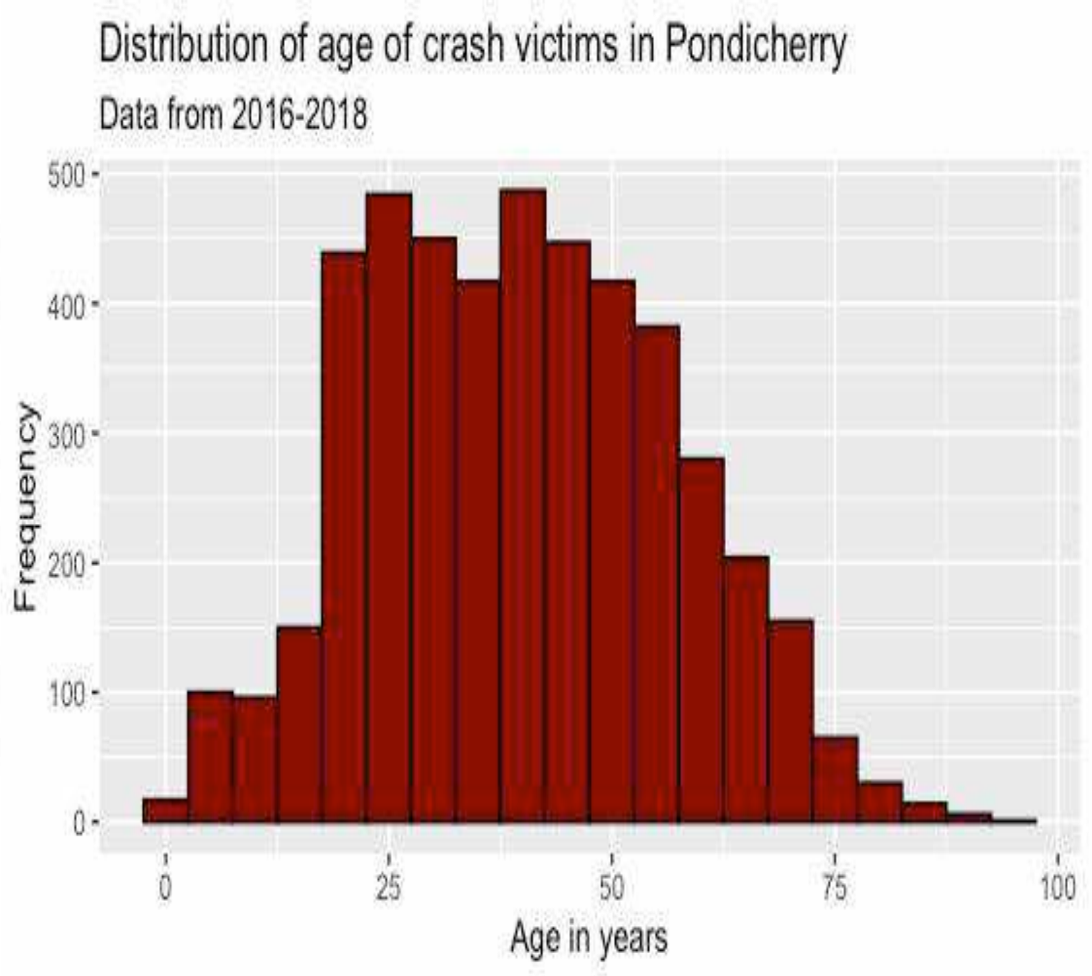


Fig. 4.7. Age-wise distribution of Crash Victims

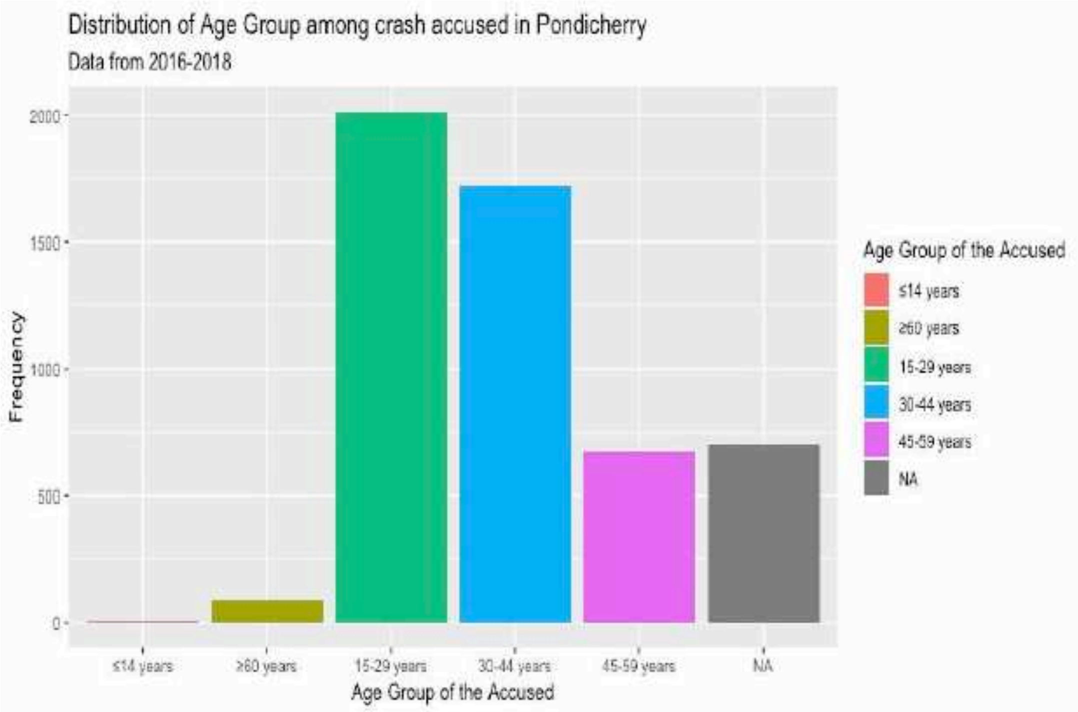


Fig. 4.8. Distribution of Crash Accused as per Age Group

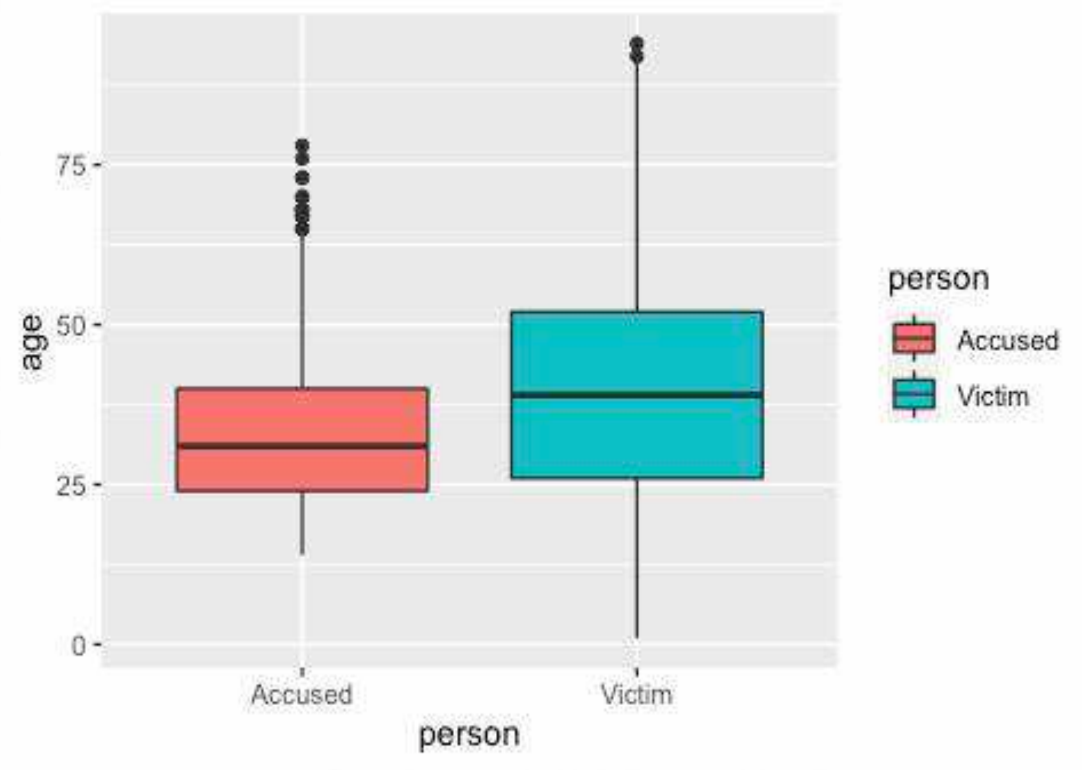


Fig. 4.9. Comparison of Accused and Victim as per Age

4.2.5 As per Under-age of Crash Accused

Under-age driving was associated with a small proportion of overall crashes (1.9%) and fatal ones (2.5%). Distribution of Underage among crash accused is as provided in Fig. 4.10.

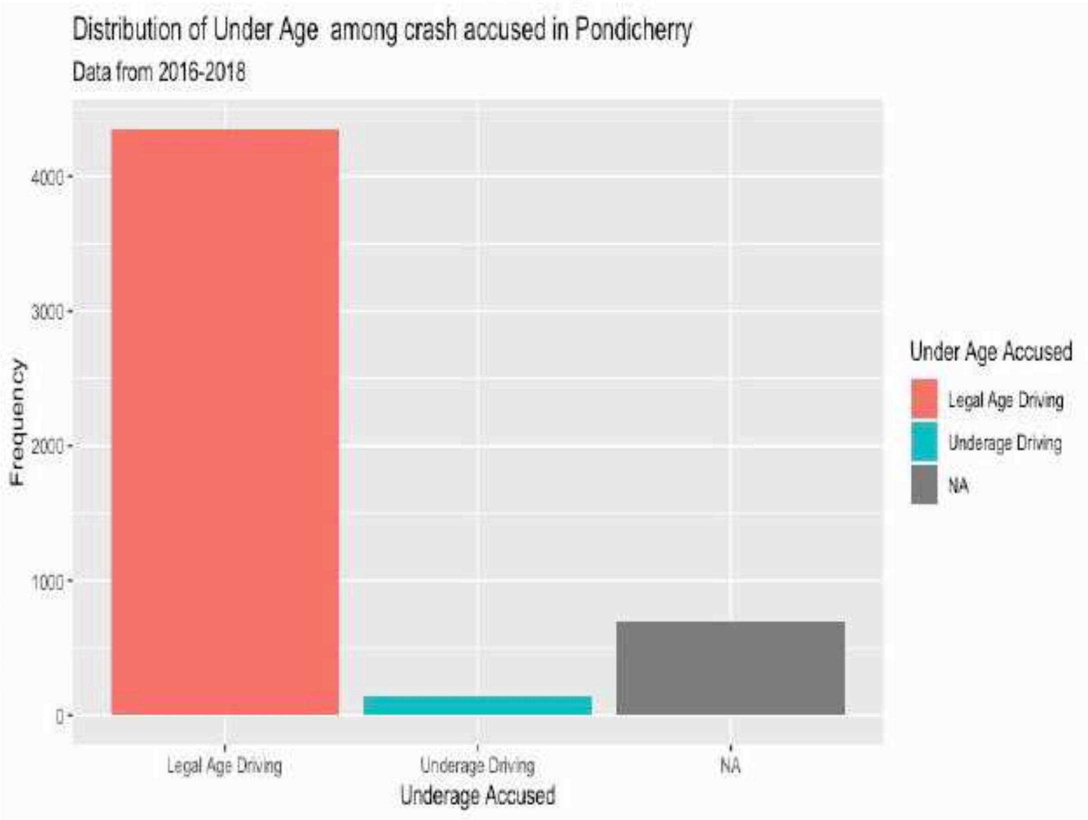


Fig. 4.10. Distribution of Under-age among crash accused

4.2.6 As per Gender of Victim and Accused

There was a preponderance of males amongst the crash victims (83.2%) and those accused (99.6%), with one victim being transgender. This finding was observed to be true for fatal crashes as well. The distribution of gender among crash victims is provided in Fig. 4.11, while that among crash accused is provided in Fig. 4.12.

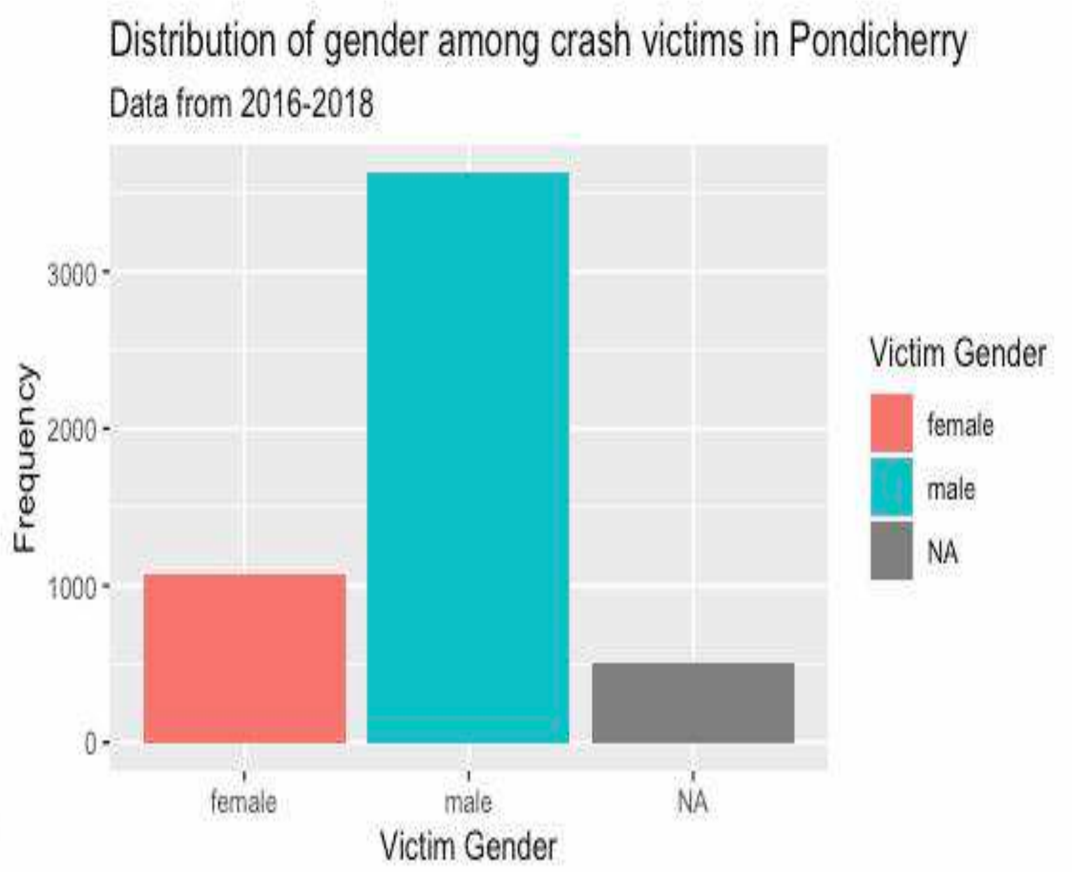


Fig. 4.11. Distribution of gender among crash victims

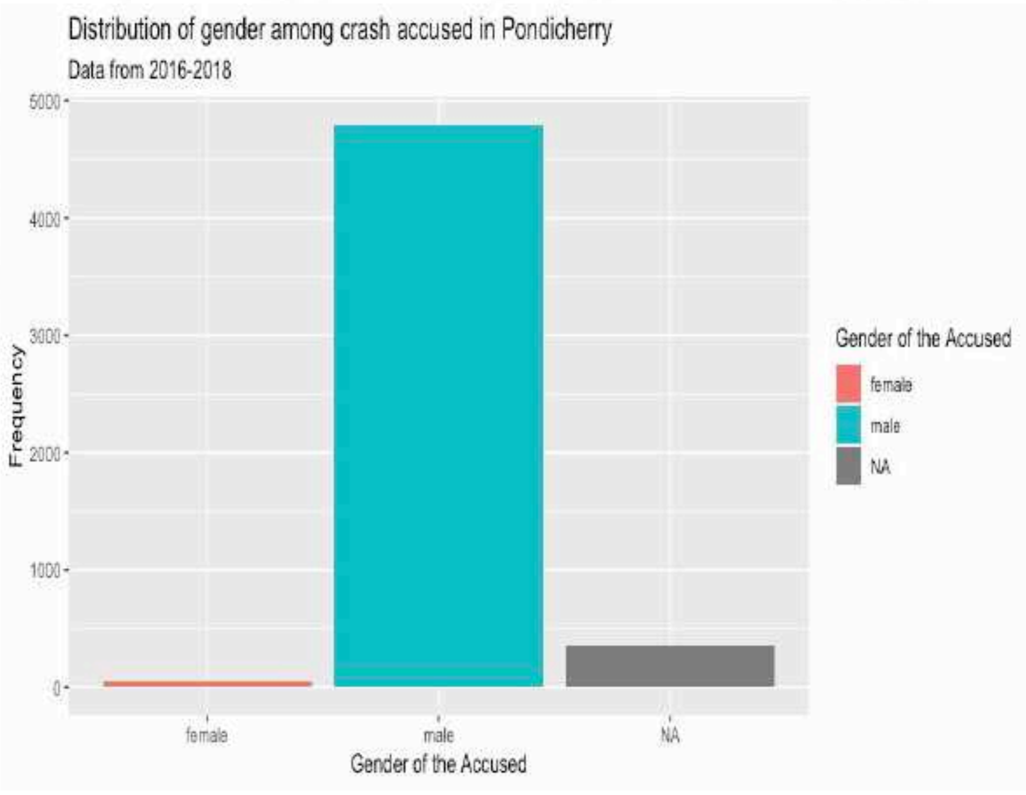


Fig. 4.12. Distribution of gender among crash accused

4.2.7 As per Age and Gender of Crash Victims: Bivariate Analysis

Bivariate analysis of age and gender amongst crash victims revealed that the proportion of female victims was highest (35% - 37.5%) in younger age groups below eight years and lowest (17.6%) in middle age group. The distribution of age group and gender among crash victims is provided in Fig. 4.13.

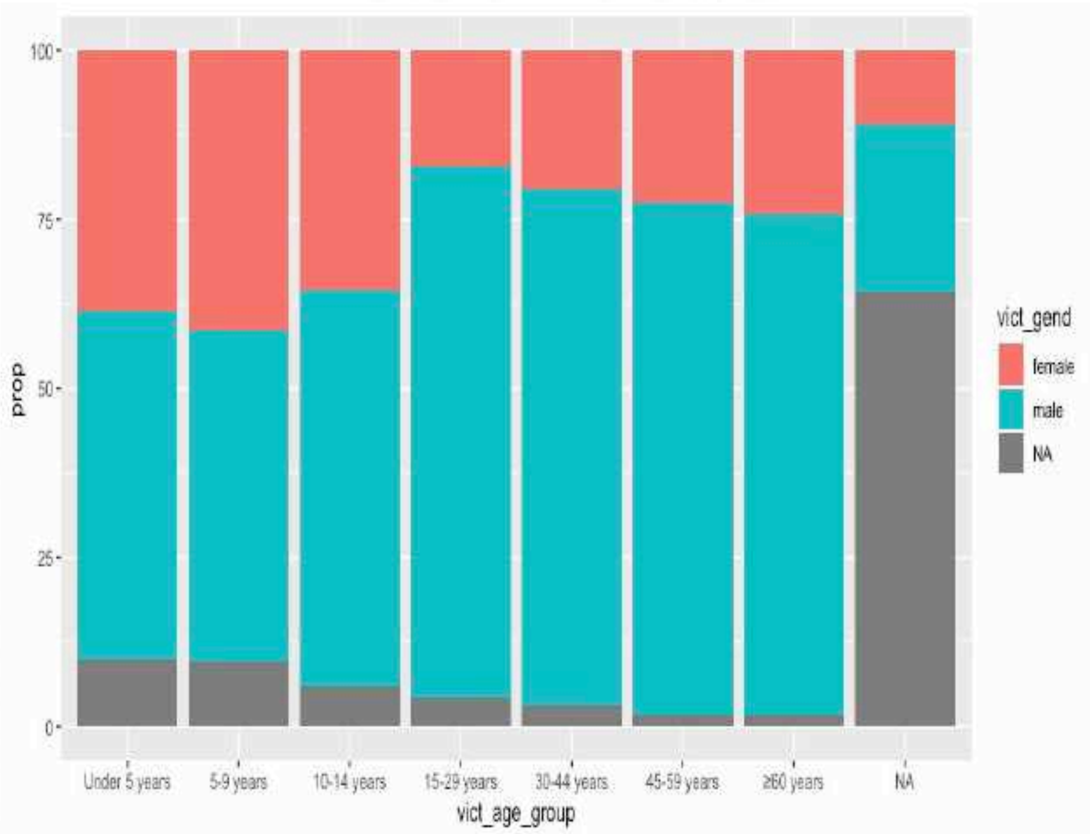


Fig. 4.13. Distribution of Age Group and Gender among Crash Victims

4.2.8 As per Vehicle of Crash Victims

Regarding vehicle type, vulnerable road users(pedestrians, bicycles and two-wheelers) bore the brunt of crashes, accounting for more than two-thirds (67.5%) of all crashes and about 69.8% of fatal crashes. The distribution of vehicle type among crash victims is provided in Fig. 4.14.

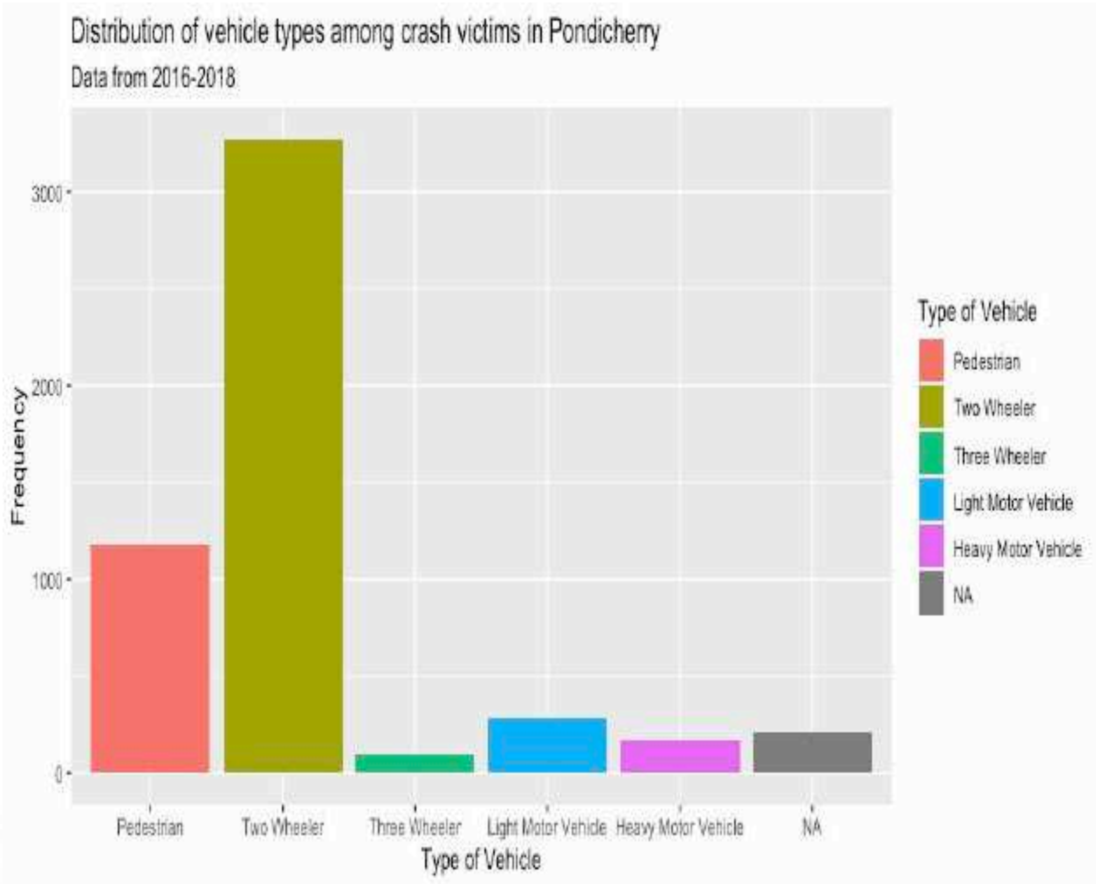


Fig. 4.14. Distribution of Vehicle Type among Crash Victims

4.2.9 As per Vehicle Type of Crash Victims and Accused

An interesting finding was that two-wheelers were both the perpetrators (accused) and the victims in most crashes, both fatal and non-fatal. Nearly two-thirds (67%) of crashes occurred between two-wheelers and two-wheelers. A little under three-fourths (72%) of all crashes involving light motor vehicles had two-wheelers as victims. A comparison of crash victims and accused as per vehicle type is provided in Table 4.3.

Table 4.3. Comparison of Crash Victims and Accused as per Vehicle Type

Accused Vechicle	Heavy Motor Vehicle, N = 1,074[1]	Light Motor Vehicle, N = 1,418[1]	Three Wheeler, N = 122[1]	Two Wheeler, N = 2,350[1]	Overall, N = 4,964[1]
Victim Vehicle					
Pedestrian	171 (17%)	221 (16%)	12 (10%)	716 (31%)	1,120 (23%)
Two Wheeler	572 (55%)	991 (72%)	75 (65%)	1,568 (67%)	3,206 (66%)
Three Wheeler	27 (2.6%)	31 (2.2%)	26 (22%)	7 (0.3%)	91 (1.9%)
Light Motor Vehicle	112 (11%)	129 (9.3%)	3 (2.6%)	35 (1.5%)	279 (5.7%)
Heavy Motor Vehicle	154 (15%)	8 (0.6%)	0 (0%)	2 (<0.1%)	164 (3.4%)

[1] n (%)

4.2.10 As per Vehicle Occupancy

Vehicle occupancy seemed to play a role in crashes, including fatal ones, with drivers being victims in 41% of all crashes and 55% of fatal ones. Two-wheelers were an exception to this observation, with drivers and pillion riders equally being vulnerable to crashes and deaths.

4.3 Crash Hotspot Mapping

4.3.1 Number of Records Analysed

When crash location details were geo-coordinated for hotspot analysis, it was found that 05 locations out of the total 5202 records were erroneous (wrong entry), which fell outside the study area and even in sea location. Thus, finally, 5197 records were taken up for analysis.

4.3.2 Hotspot Mapping of ALL Road Crash Spots Using DBSCAN

4.3.2.1 Road Crash Spot Clusters: 2016 to 2018 (Yearly)

Cluster mapping of road crashes in Puducherry for 2016, 2017, and 2018 is provided in Fig. 4.15, Fig. 4.16 and Fig. 4.17 respectively. DBSCAN analysis of crash spots year-on-year revealed 16 crash clusters in 2016, which reduced to 12 clusters in 2017 and increased to 17 clusters in 2018.

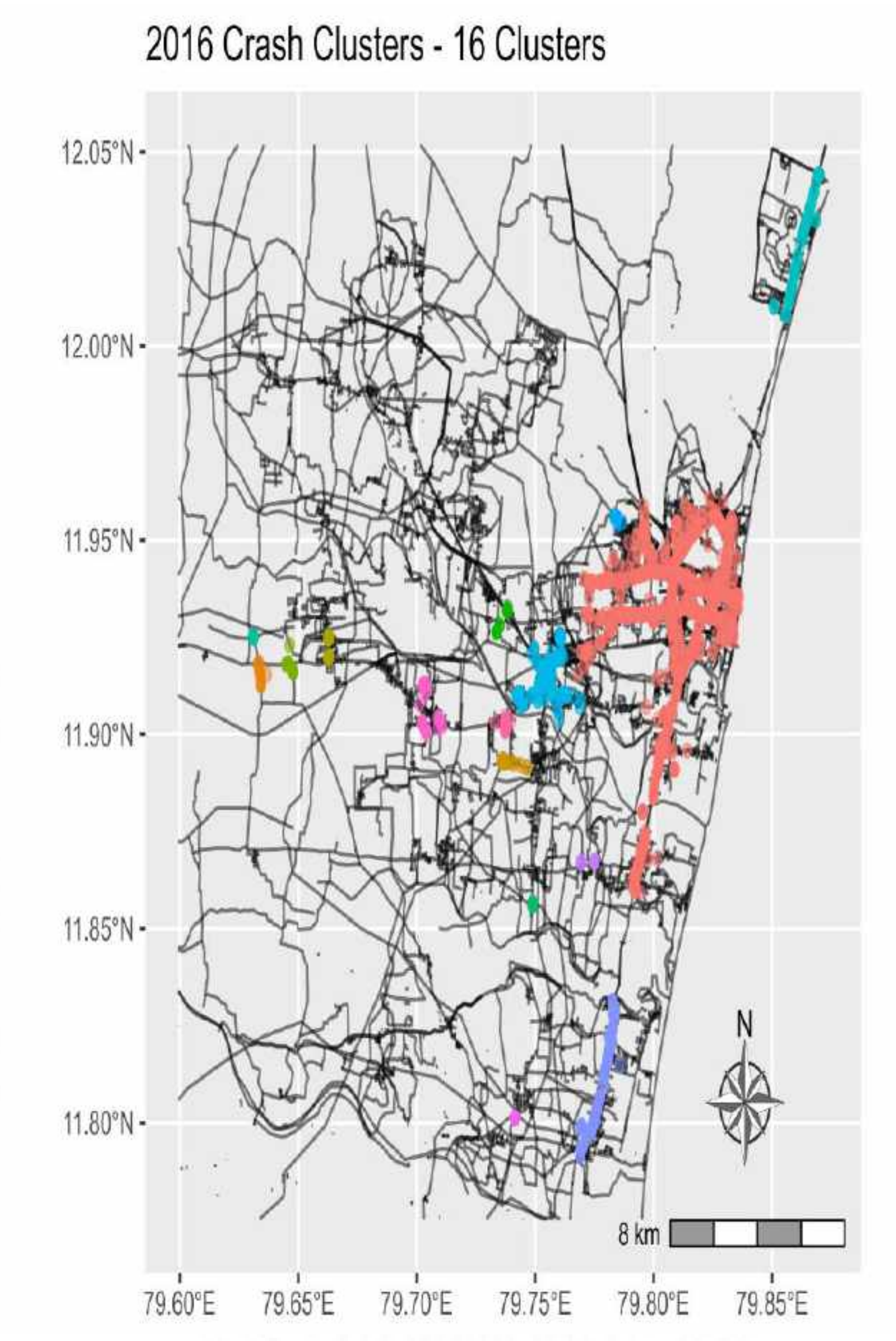


Fig. 4.15. Road crash Clusters Mapping Puducherry 2016: DBSCAN Analysis

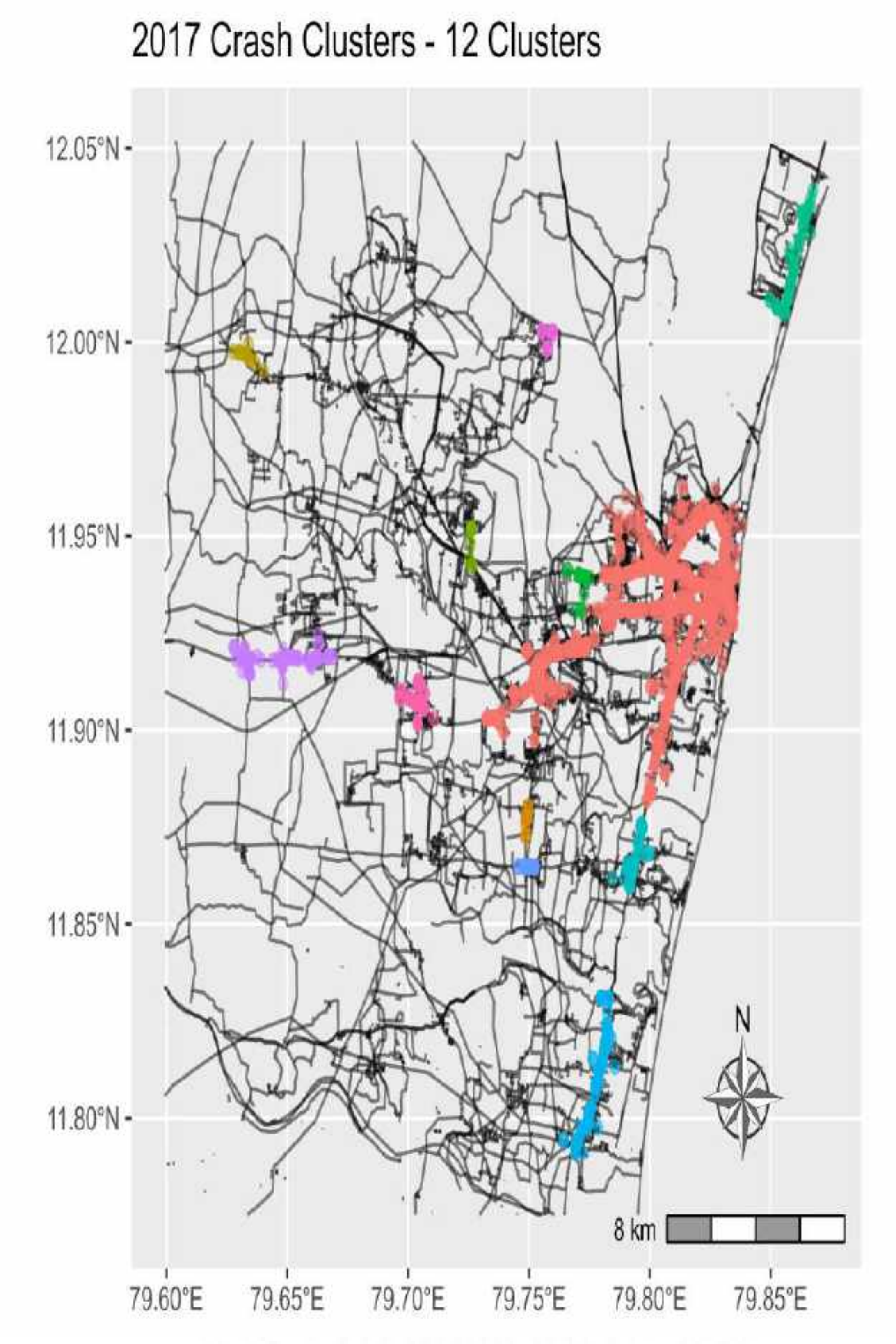


Fig. 4.16. Road crash Clusters Mapping Puducherry 2017: DBSCAN Analysis

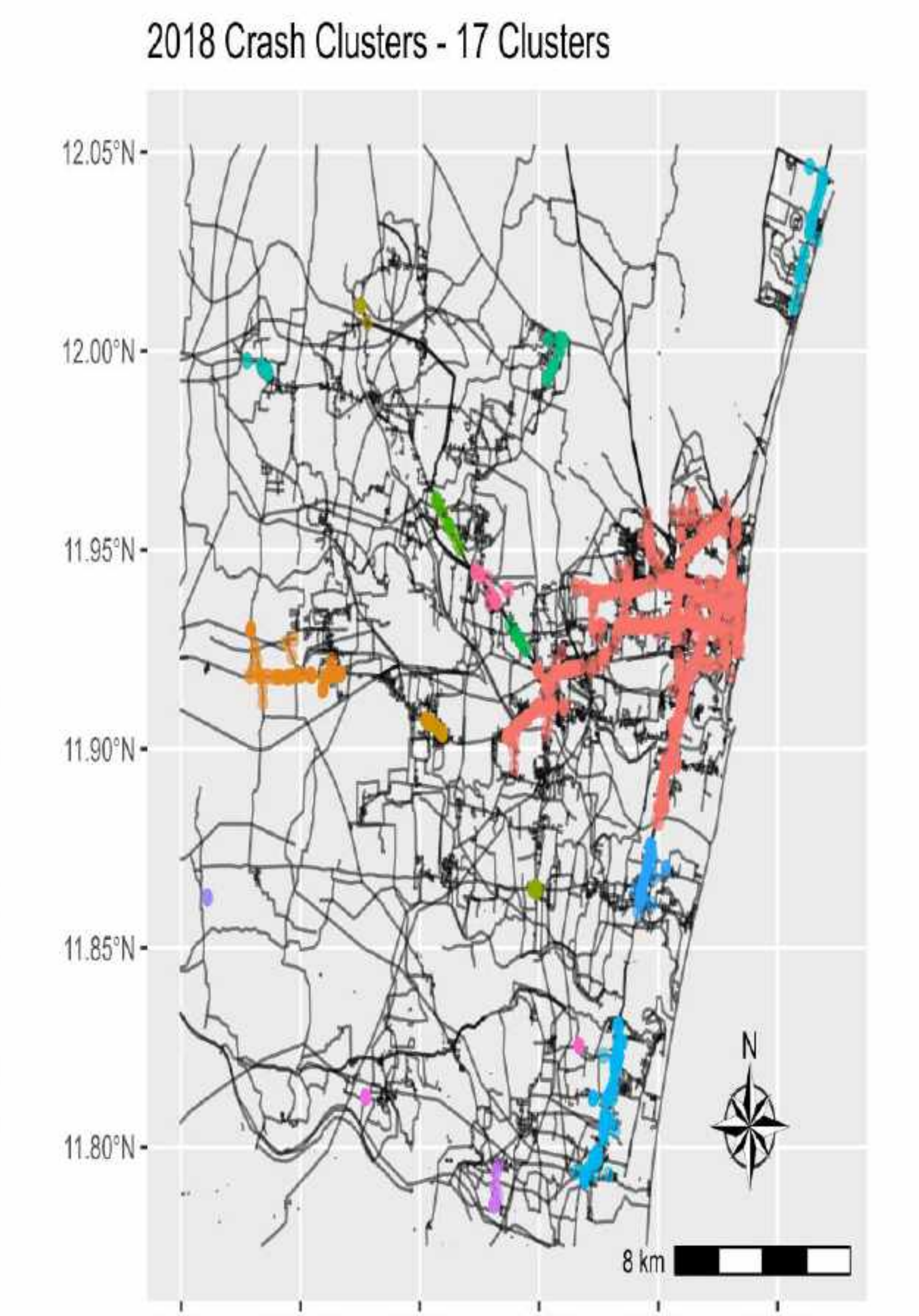


Fig. 4.17 Road crash Clusters Mapping Puducherry 2018: DBSCAN Analysis

4.3.2.2 Distribution Pattern and Trend of Crash Spot Clusters (Half-Yearly)

Crash spots were densely clustered along the four main arterial roads extending from the city in four directions. This was true with respect to both overall crashes and fatal ones. Analysis of crash spot clusters on a half-yearly basis revealed 10 clusters each in the first and second halves of 2016. The corresponding clusters were 6 and 7 in 2017, while the year 2018 witnessed 11 and 10 clusters respectively. A V-shaped curve was observed on half-yearly cluster density mapping, with a high number of clusters on both the start and end years, with a dip in the middle year under study. This finding was in tandem with the annual density since the same v-shaped curve of the number of clusters was observed on annual cluster density mapping also. Clusters of all road crashes for Half years of 2016, 2017 & 2018 are as provided in Fig. 4.18, Fig. 4.19, Fig. 4.20, Fig. 4.21, Fig. 4.22 and Fig. 4.23. A consolidated map depicting all six half-yearly clusters of the three years under study is provided in Fig. 4.24.

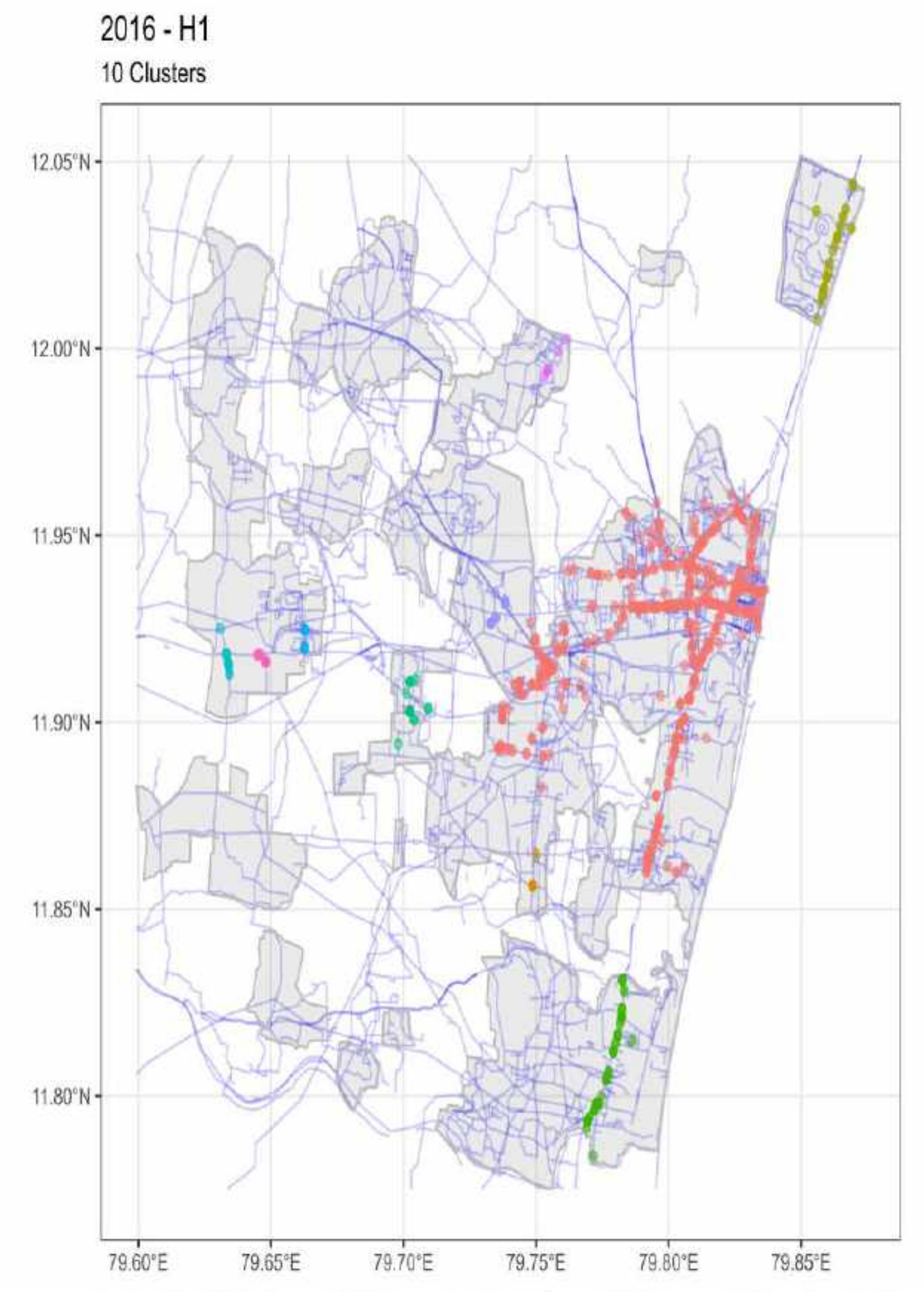


Fig. 4.18 Clusters of ALL road crashes for Half Year (I) of 2016: Mapped by DBSCAN
Note:- Admin boundaries of Puducherry are indicated in grey colour

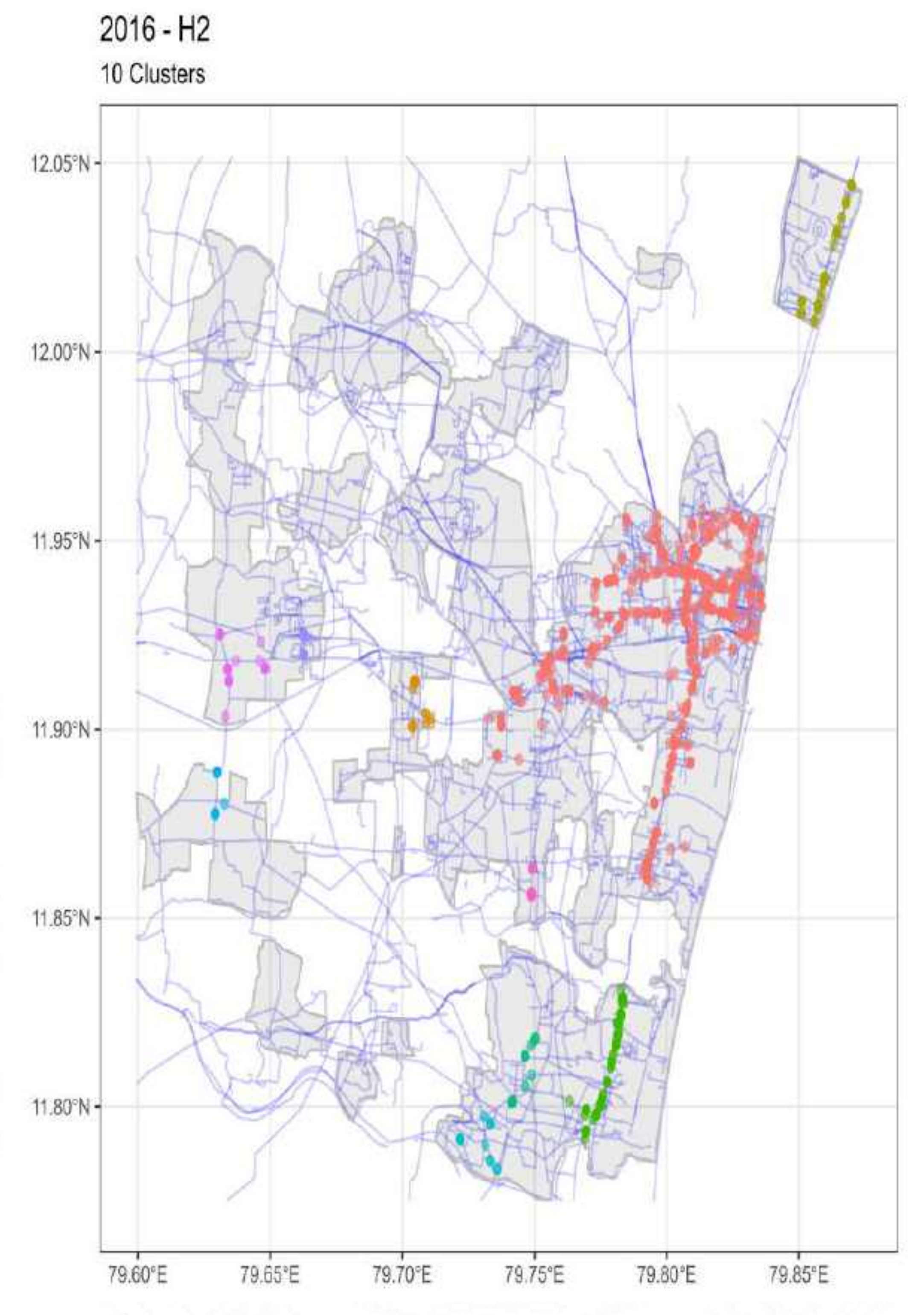


Fig. 4.19. Clusters of ALL road crashes for Half Year (II) of 2016: Mapped by DBSCAN

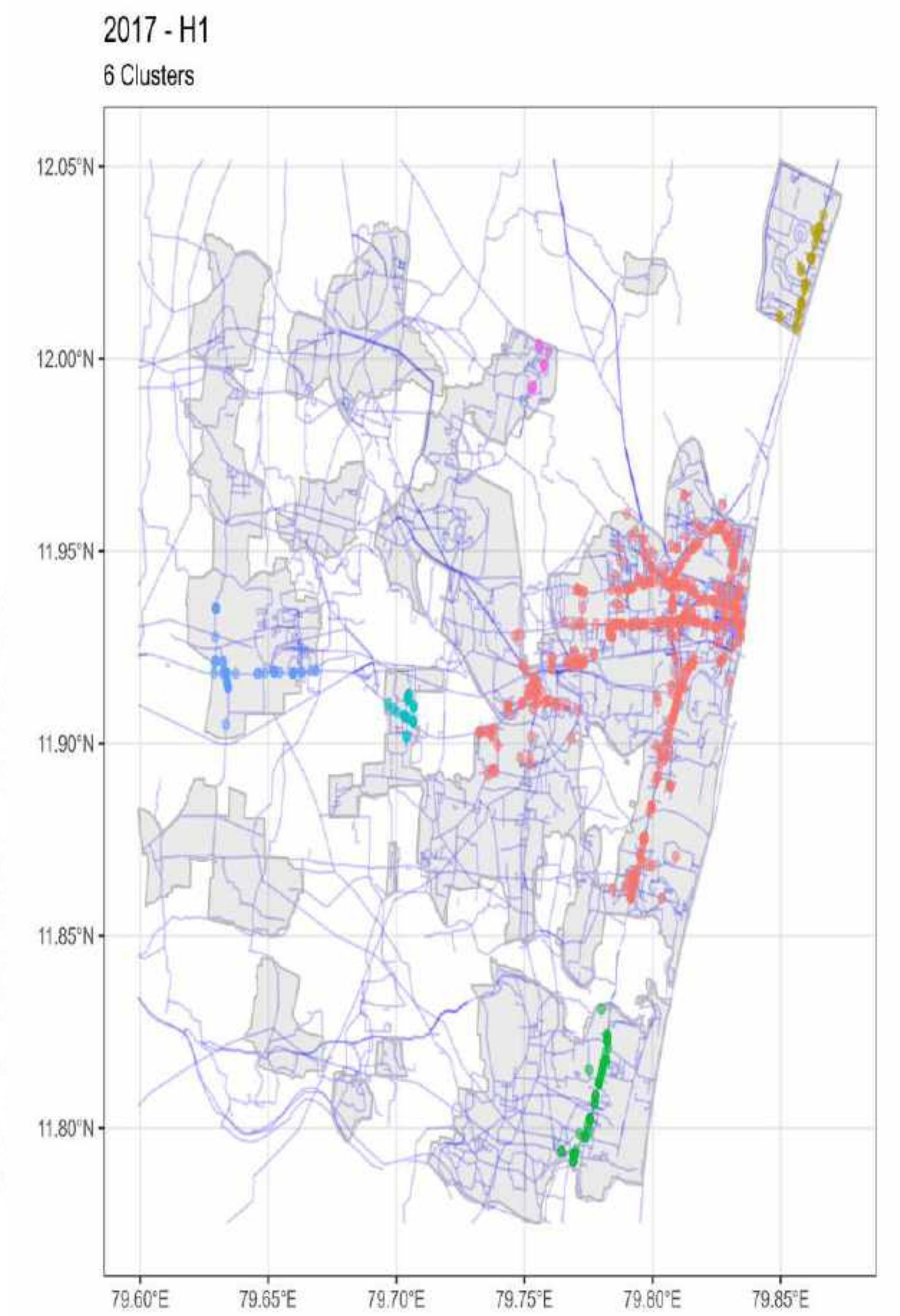


Fig. 4.20. Clusters of ALL road crashes for Half Year (I) of 2017: Mapped by DBSCAN

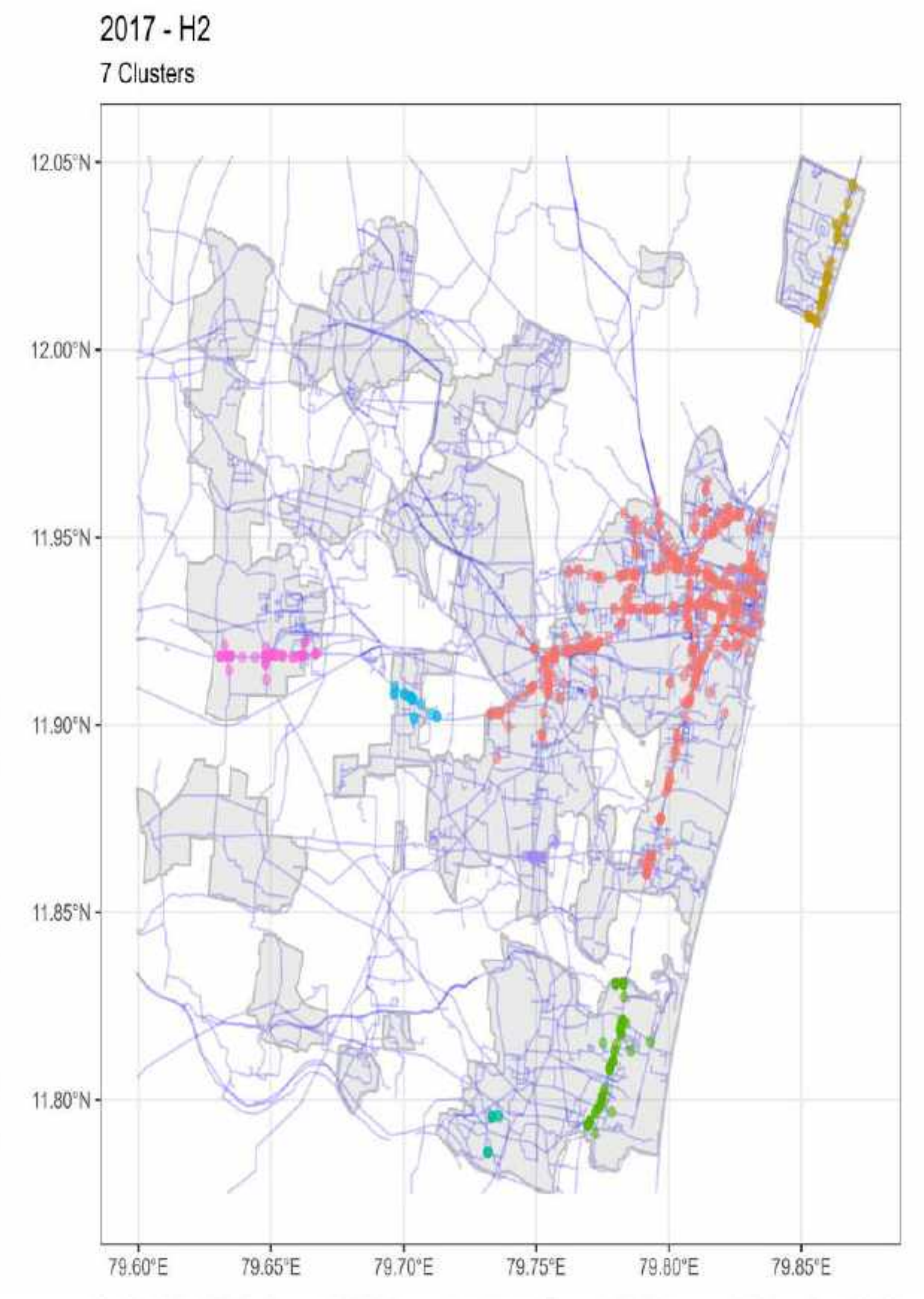


Fig. 4.21. Clusters of ALL road crashes for Half Year (II) of 2017: Mapped by DBSCAN

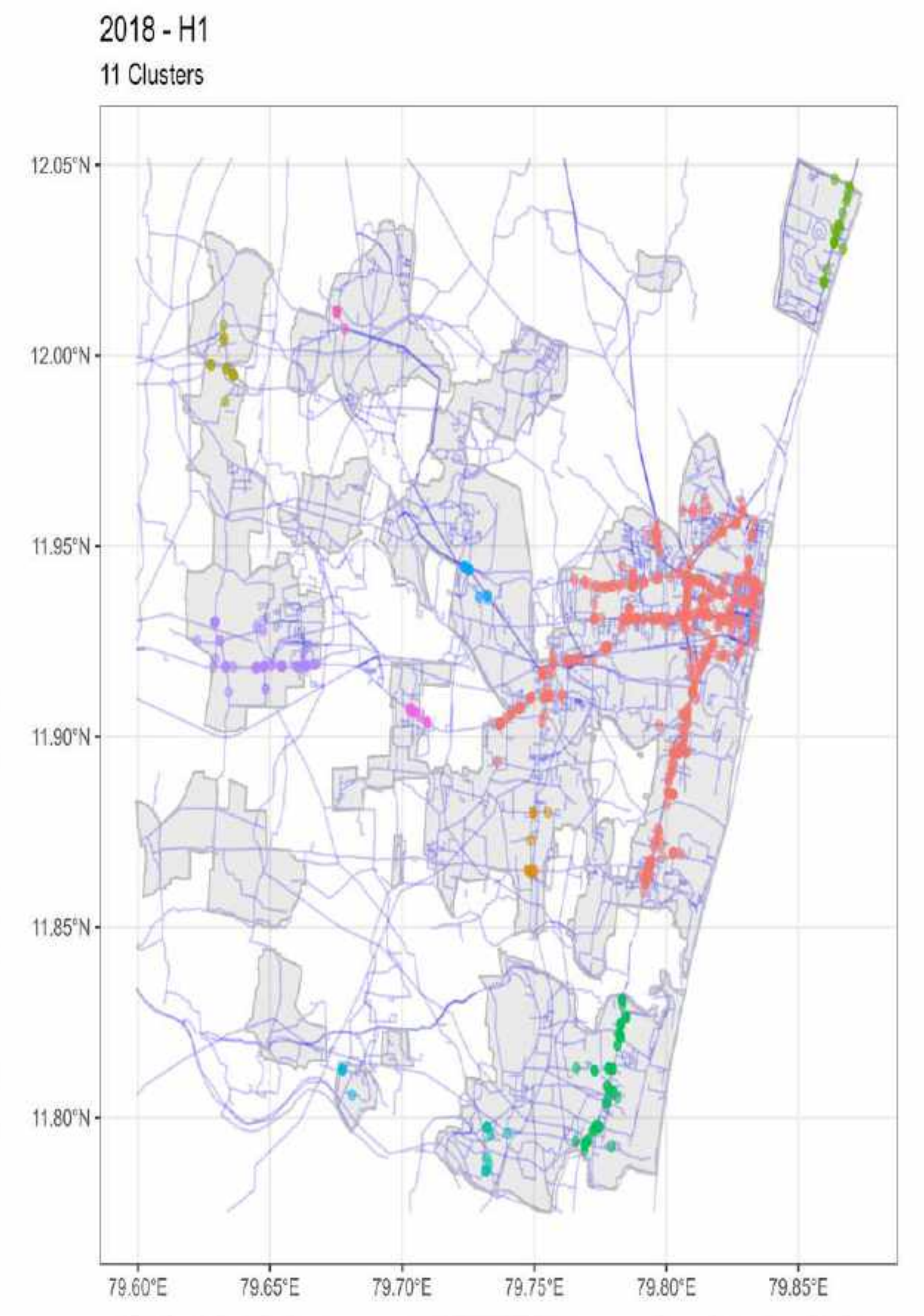


Fig. 4.22. Clusters of ALL road crashes for Half Year (I) of 2018: Mapped by DBSCAN

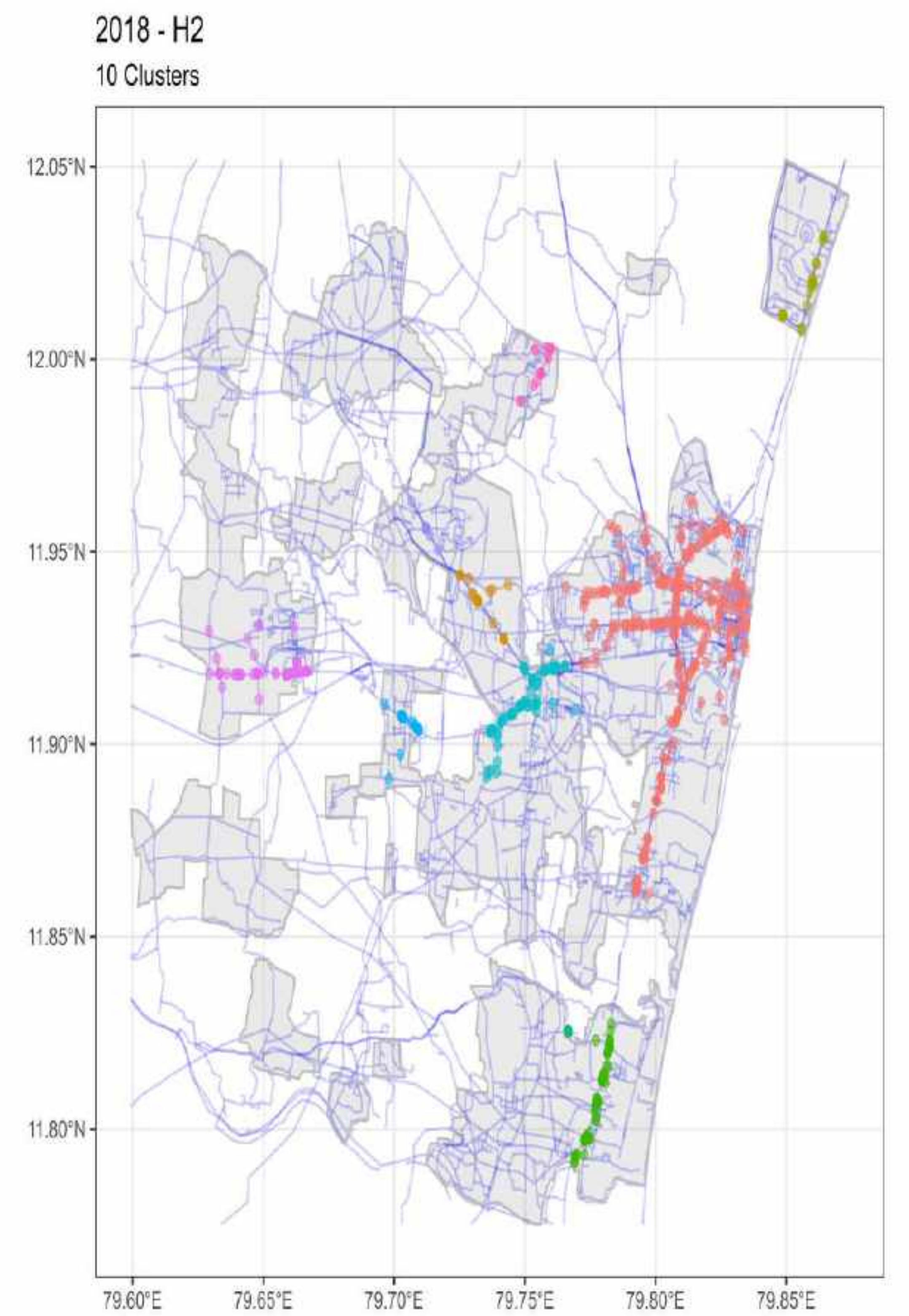


Fig. 4.23. Clusters of ALL road crashes for Half Year (II) of 2018: Mapped by DBSCAN

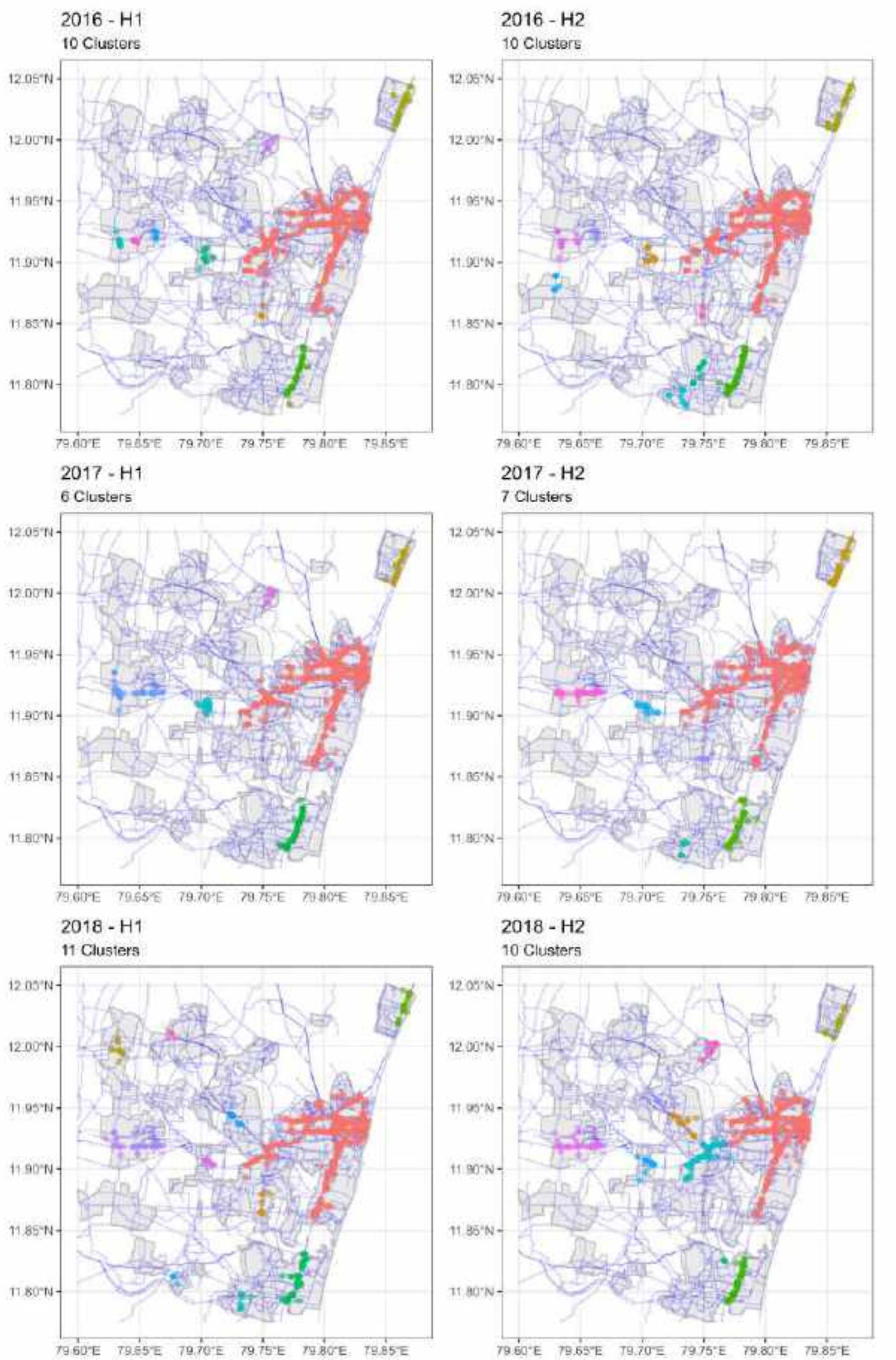


Fig. 4.24. Consolidated Map of ALL road crash spot clusters: Half-year blocks for 2016-2018; Mapping by DBSCAN

4.3.2.2 Distribution Pattern and Trend of Crash Spot Clusters (Quaterly)

Analysis of crash spot clusters (ALL crashes- both fatal & non-fatal) every quarter for the three-year study period (2016-18) revealed 5 clusters in Quarter 1 (Q1) of 2016, 4 clusters in Q2, and 5 clusters each in Q3 and Q4 of 2016. The corresponding number of clusters in 2017 were five each in all four quarters (Q1-Q4). In 2018, Q1 had 5 clusters, whereas Q2, Q3 and Q4 had 8, 4 and 6 clusters, respectively. However, the DBSCAN analysis of crash spot clusters quarterly did not yield any significant value addition over and above the half-yearly analysis. Hence, deriving inferences were based on crash spot cluster mapping till the half-year blocks level. A consolidated map of ALL crash spot clusters in Puducherry quarterly for 2016-2018, analysed using the DBSCAN algorithm, is provided in Fig. 4.25.

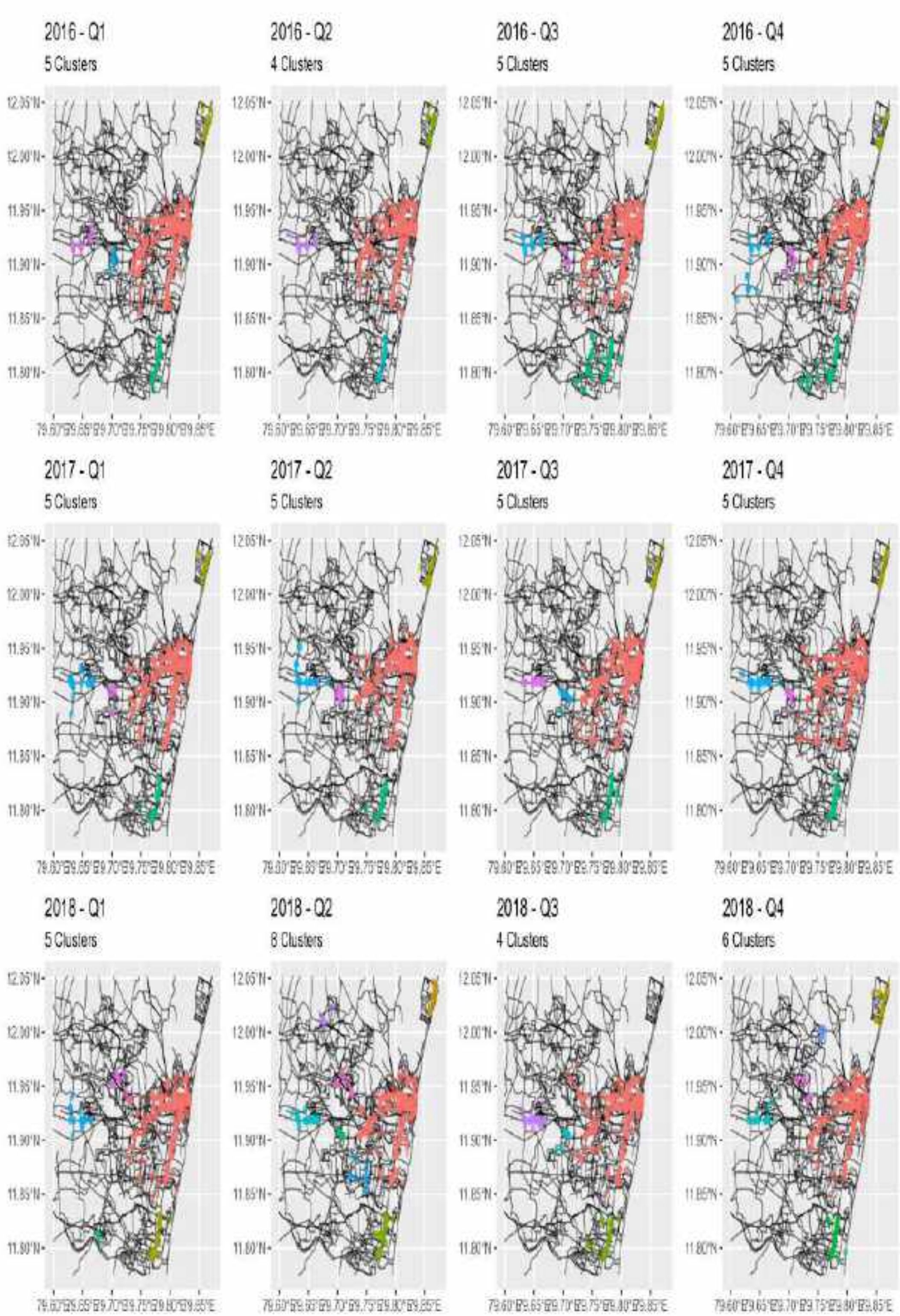


Fig. 4.25. Consolidated Map of ALL road crash spot clusters: Quarterly blocks for 2016-2018; Mapped by DBSCAN

4.3.3 Hotspot Mapping of FATAL Road Crash Spots using DBSCAN

4.3.3.1 *Fatal Road Crash Spot Clusters: 2016 to 2018 (Yearly)*

Fatal road crash spot clusters, when mapped on a year-on-year basis using DBSCAN, revealed 4 clusters in 2016, while there were six fatal crash spot clusters in 2017 and 4 clusters in 2018. The distribution and location of fatal crash spot clusters matched those of all (both fatal and non-fatal) crash spot clusters. The yearly mapping of fatal crash spot clusters from 2016 to 2018 is provided in Fig. 4.26.

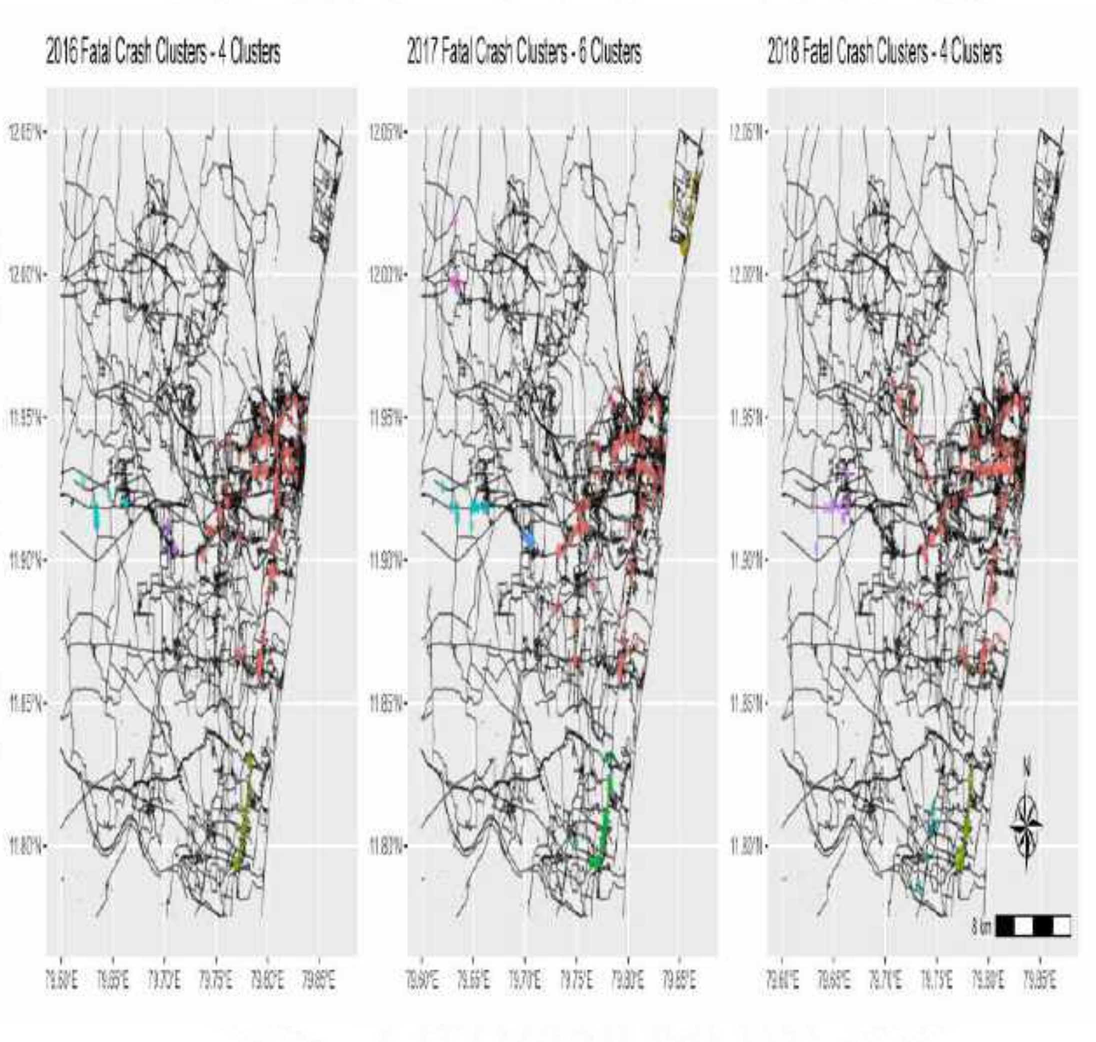


Fig. 4.26. Consolidated Map of FATAL road crash spot clusters: Yearly blocks for 2016-2018; Mapped by DBSCAN

4.3.3.2 Fatal Road Crash Spot Clusters: 2016 to 2018 (Half-Yearly)

Fatal road crash spot clusters, when mapped on a half-yearly basis over the three years, revealed 3 clusters in each of the six half-year blocks (H1 to H6), except in the second half of 2017 (H4) in which there were 4 clusters. This distribution revalidated/ reinforced the cluster location mapping arrived at by analysis on a year-on-year basis. A consolidated map of fatal crash spot clusters on a half-yearly basis from 2016 to 2018 is provided in Fig. 4.27.

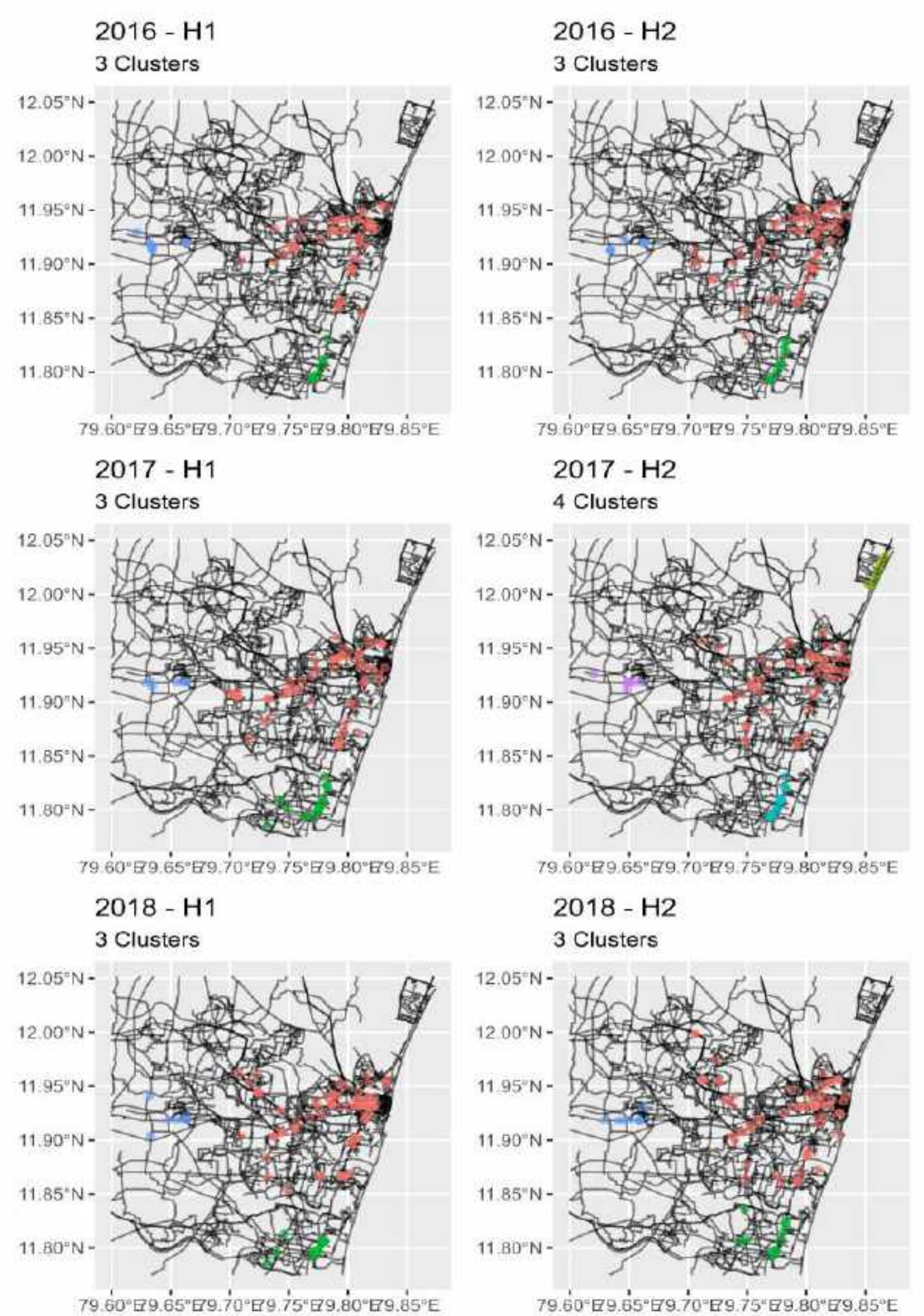


Fig 4.27. Consolidated Map of FATAL road crash spot clusters: Half-Yearly blocks 2016-2018; Mapped by DBSCAN

4.3.4 Trend-Pattern of Road Crash Spot Clusters with DBSCAN Analysis

A noteworthy finding emerging from DBSCAN analysis was that crash clusters tended to evolve in a particular pattern, with smaller patchy clusters of one year coalescing to form a single large cluster in the next year. This further enlarged and elongated in the succeeding year to form a larger, longer cluster. However, no significant inter-zonal differences were discernible between the clusters in the four traffic zones. Both fatal and non-fatal clusters were near-similar in their distribution, with no significant differences in distribution. Crash spots in one large cluster located in the central township area of Puducherry were observed to be from all traffic zones. Mapping crash spots against the administrative boundaries map of Puducherry enabled clearer visualization of clusters.

4.4 Crash Spot Analysis Using NKDE

4.4.1 Mapping of ALL Crashspot Clusters (Yearly & Half-Yearly Patterns)

Crash spot analysis using Network Kernel Density Estimate (NKDE) method revealed deeper insights into cluster locations and patterns over the 3-year study period. The number of clusters on a yearly, half-yearly and quarterly basis was nearly the same as found in the DBSCAN analysis. Patchy clusters, especially in the west zone in 2016, coalesced to form a larger cluster in 2017 and expanded in the year 2018. Similarly, a medium-sized cluster observed in the central area in 2016 merged with the adjoining small clusters, formed a large cluster in 2017, and further elongated in 2018.

Crash spot cluster mapping of ALL crashes (both fatal and non-fatal) in Puducherry on a half-yearly basis from 2016 to 2018 is as provided in Fig. 4.28, Fig. 4.29, Fig. 4.30, Fig. 4.31, Fig. 4.32 and Fig. 4.33. A consolidated map of ALL crash spot clusters on a half-yearly basis from 2016 to 2018 is provided in Fig. 4.34.

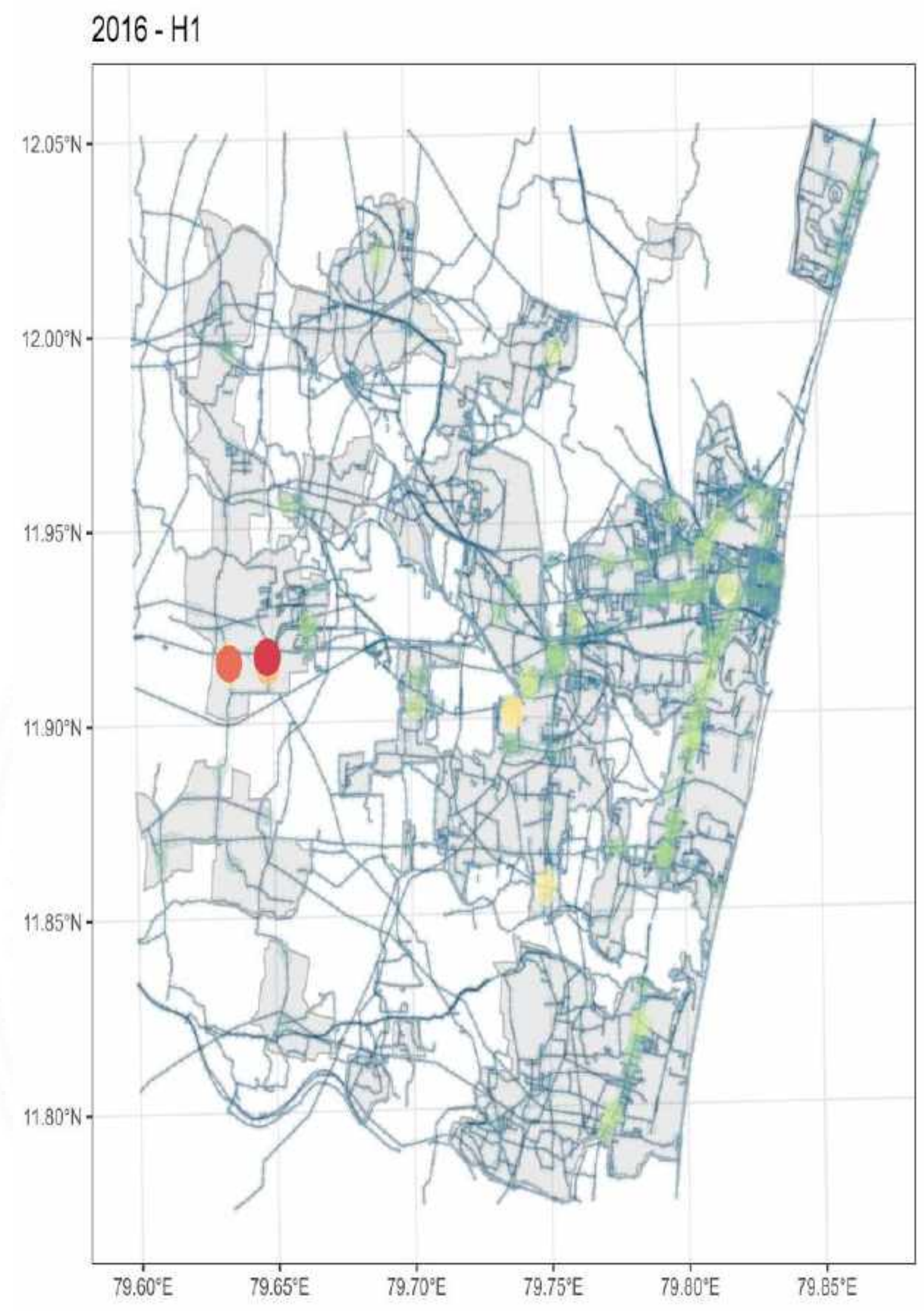


Fig. 4.28. Clusters of ALL road crashes for Half Year (I) of 2016 : Mapped by NKDE

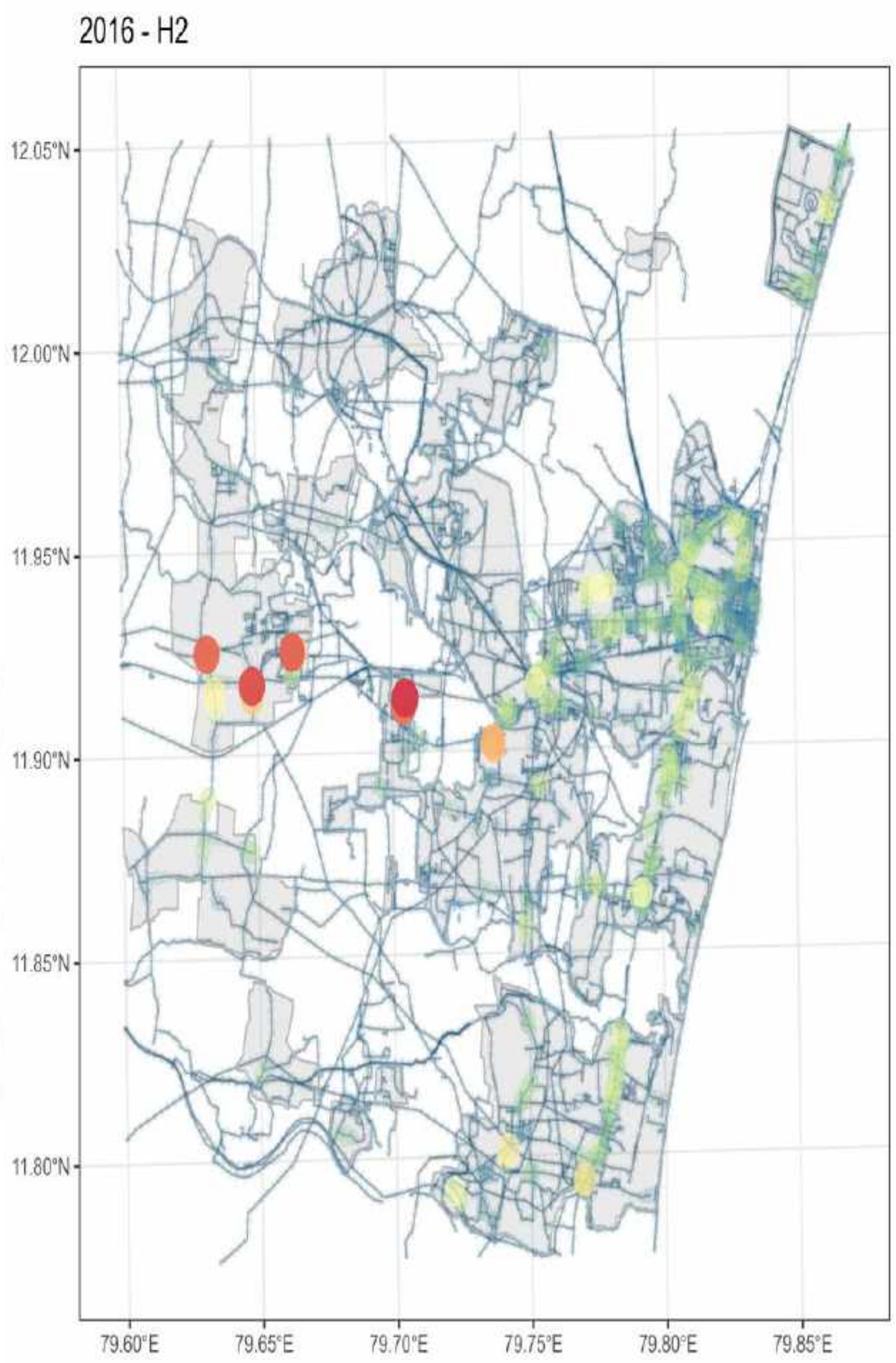


Fig. 4.29. Clusters of ALL road crashes for Half Year (II) of 2016 : Mapped by NKDE

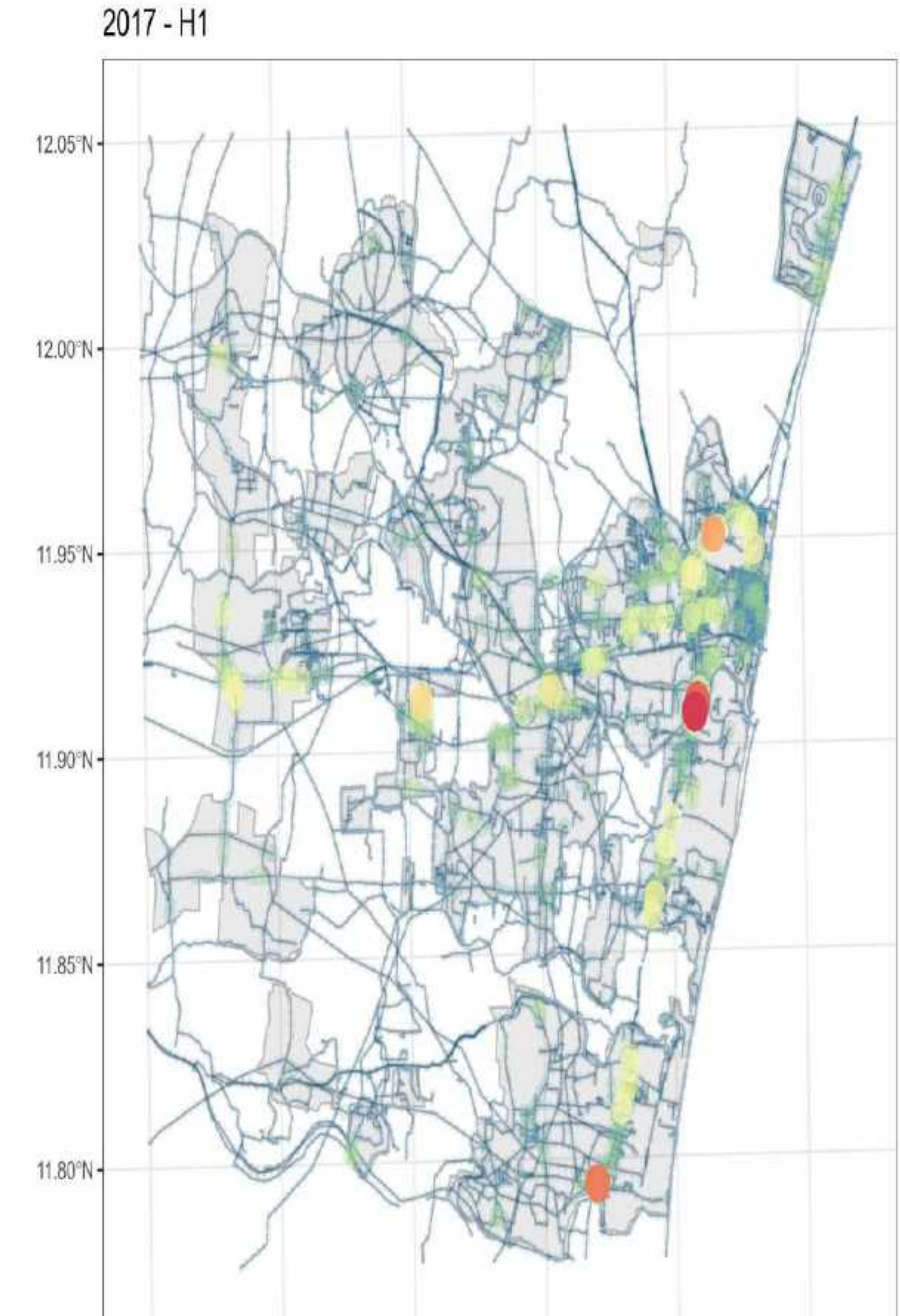


Fig. 4.30. Clusters of ALL road crashes for Half Year (I) of 2017 : Mapped by NKDE

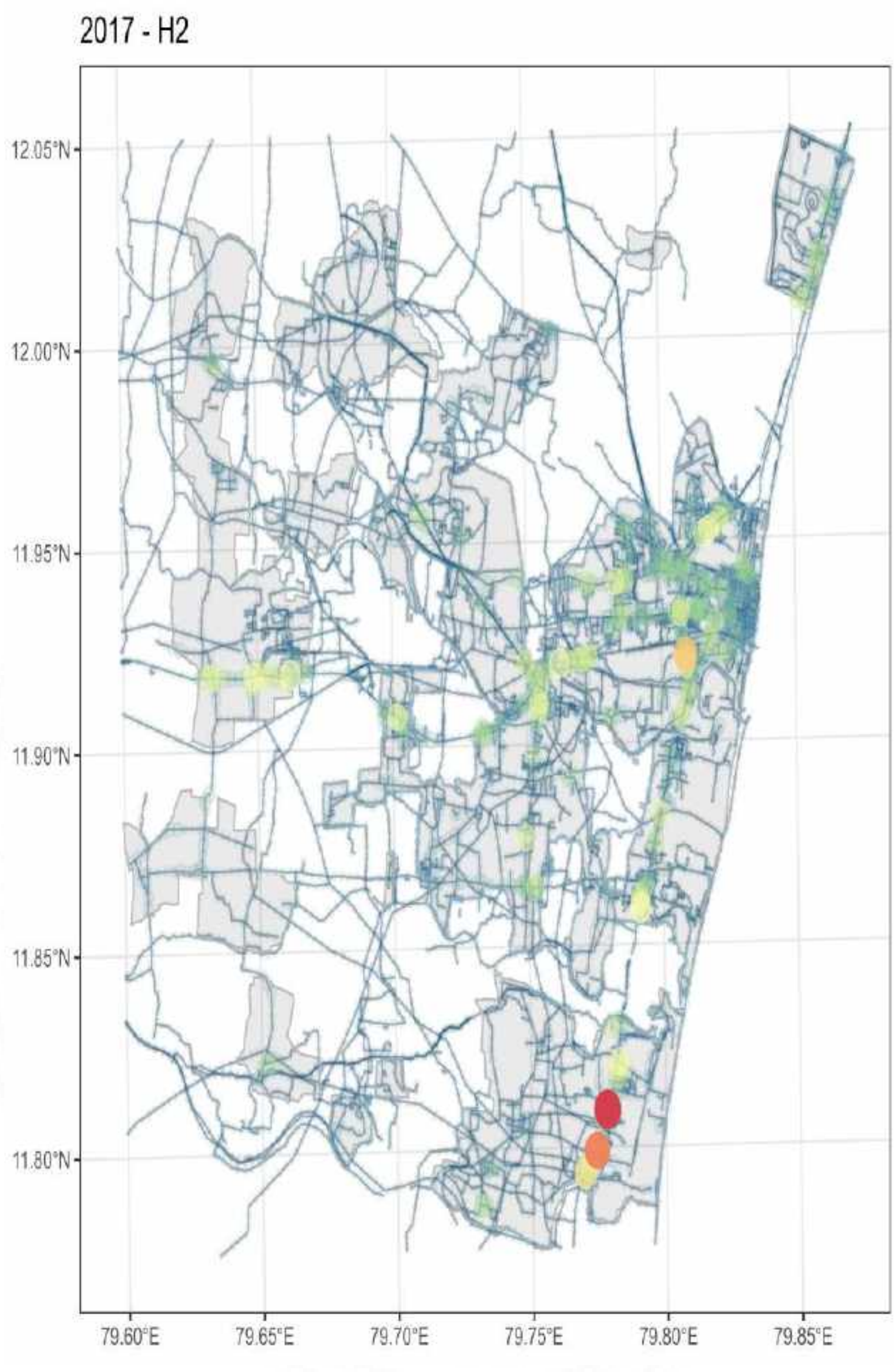


Fig. 4.31. Clusters of ALL road crashes for Half Year (II) of 2017: Mapped by NKDE

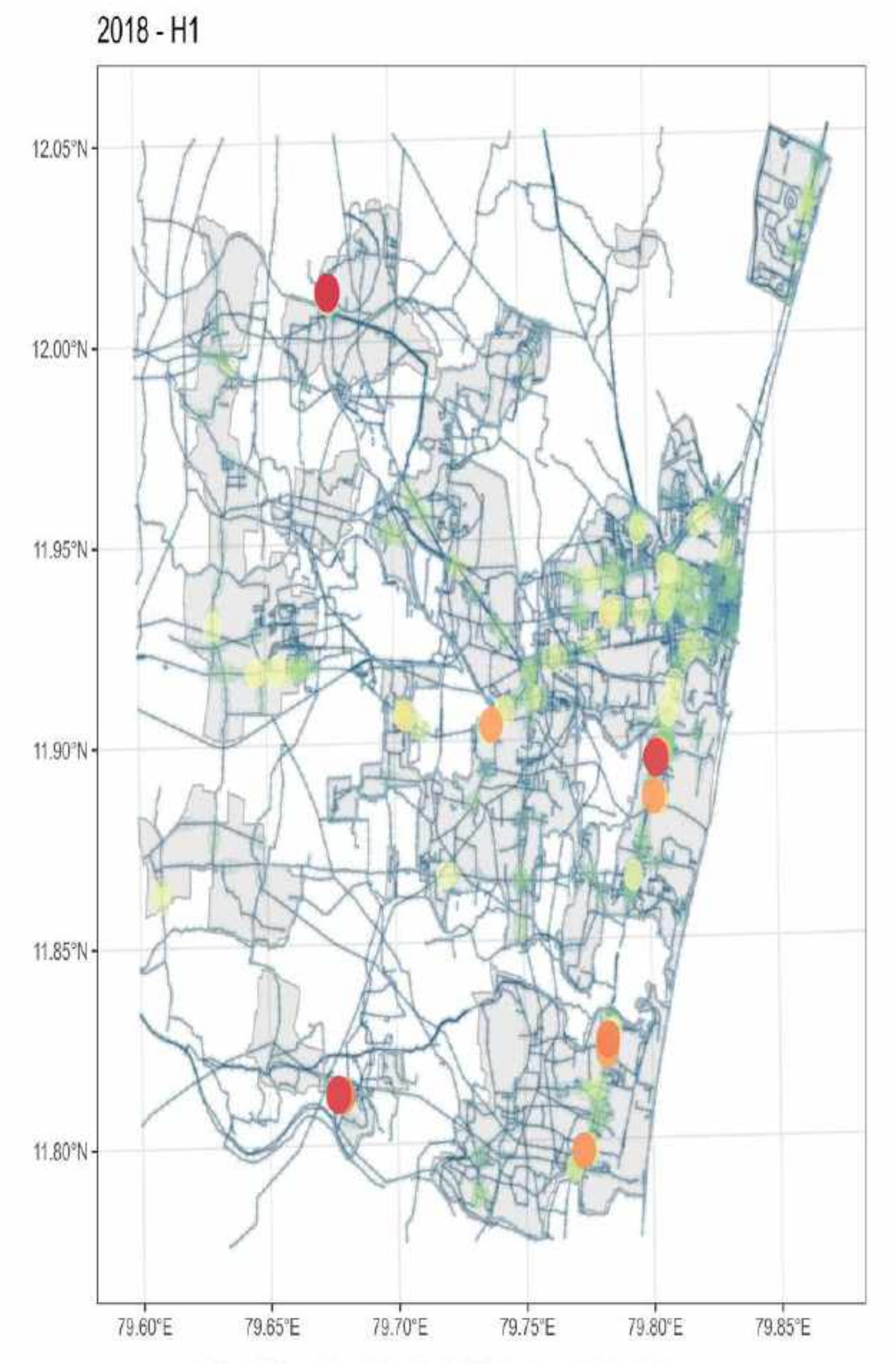


Fig. 4.32. Clusters of ALL road crashes for Half Year (I) of 2018: Mapped by NKDE

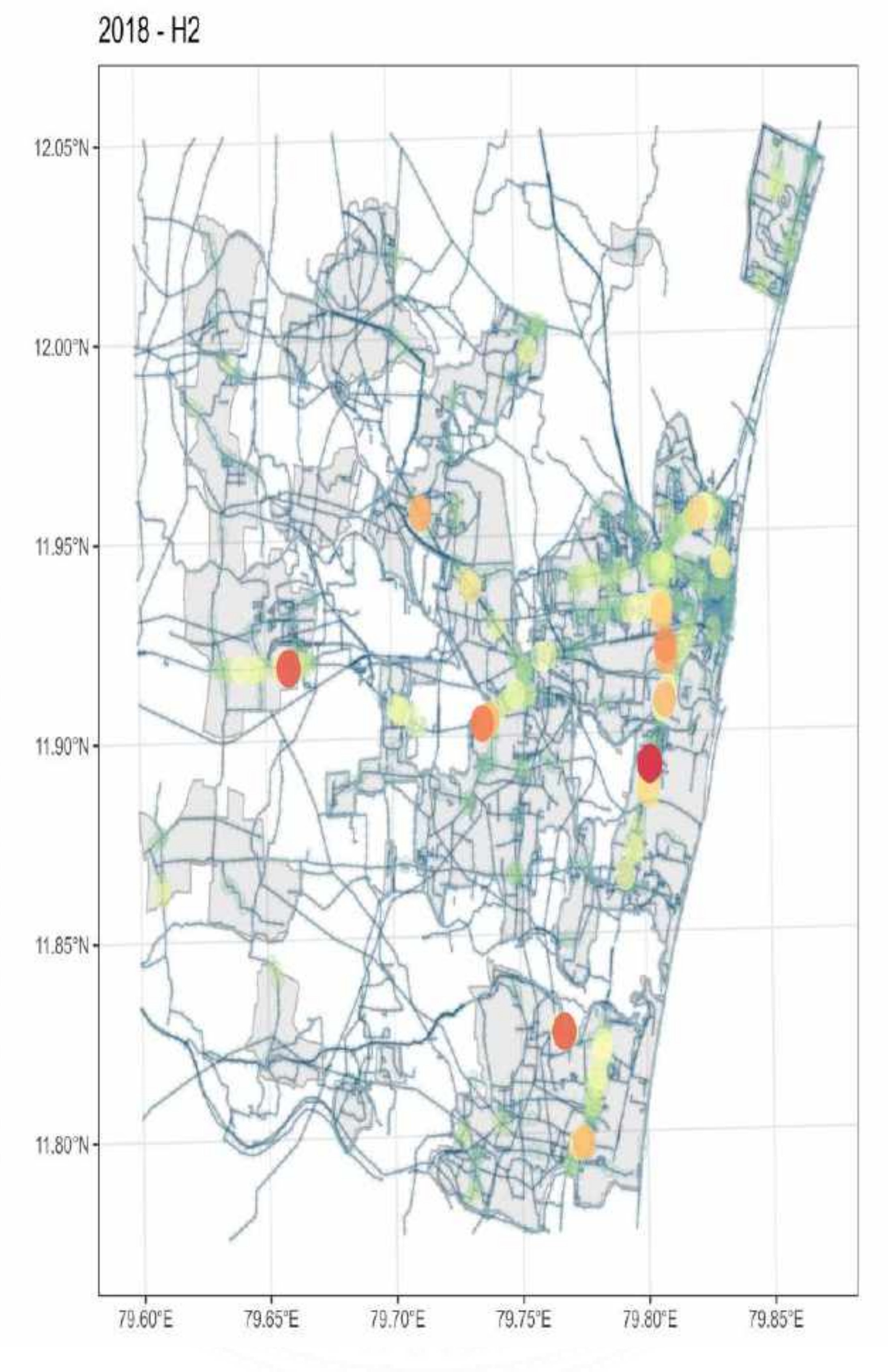


Fig . 4.33. Clusters of ALL road crashes for Half Year (II) of 2018 : Mapped by NKDE

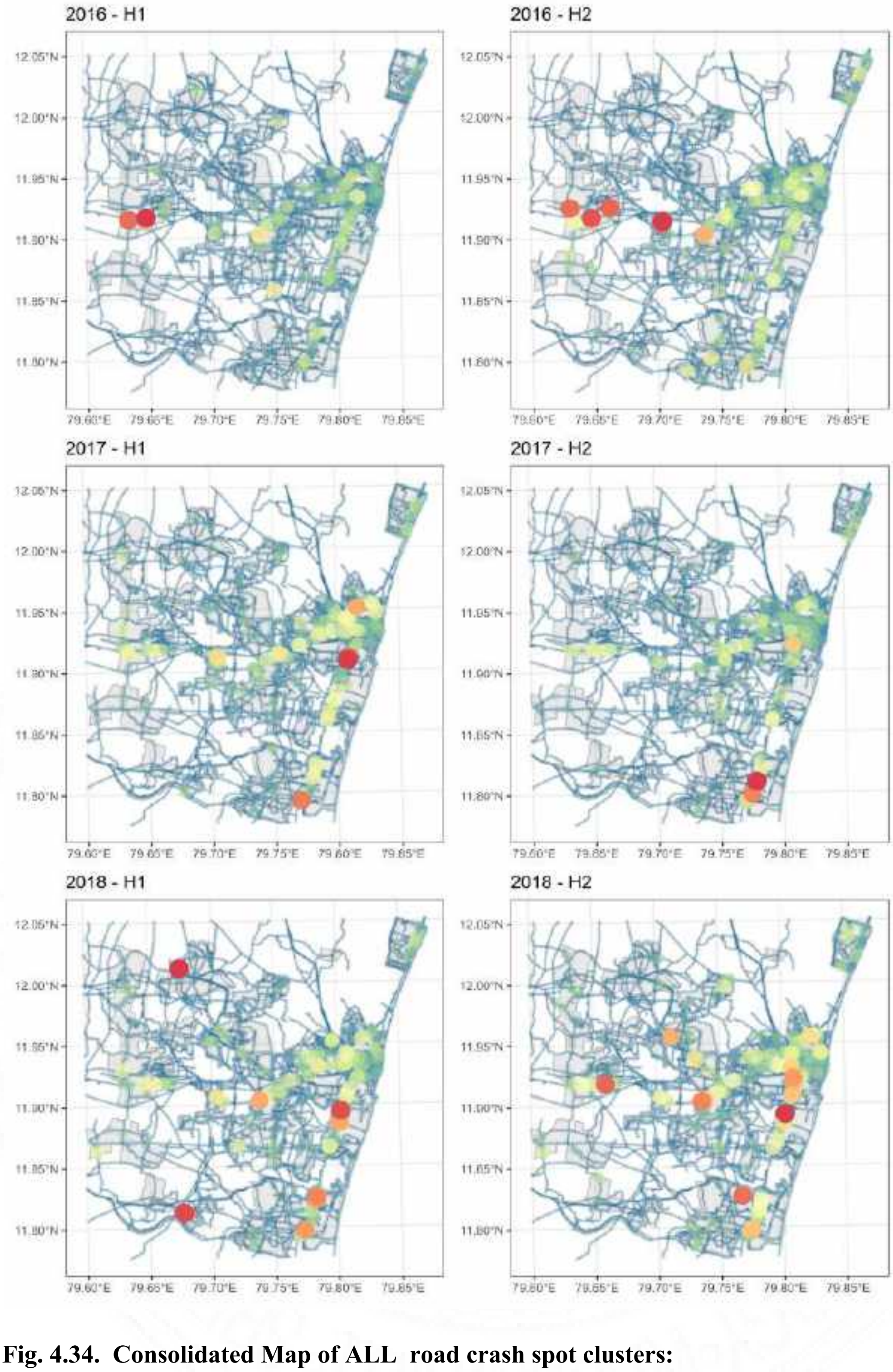


Fig. 4.34. Consolidated Map of ALL road crash spot clusters: Half-Yearly blocks for 2016-2018: Mapped by NKDE

4.4.2 Mapping of FATAL Crashspot Clusters (Yearly & Half-Yearly Patterns)

Fatal road crash spot clusters, when mapped on a half-yearly basis using the NKDE method, revealed 4 clusters each in H1 & H2 of 2016, while the corresponding number of fatal crash spot clusters in 2017 were 6 in H1 and 4 clusters in H2 of 2017. The year 2018 witnessed three fatal crash spot clusters in H1 and 4 clusters in H2. The distribution and location of fatal crash spot clusters more or less matched those of all (both fatal and non-fatal) crash spot clusters and were also similar to the findings arrived at using the DBSCAN method. Half-yearly mapping of fatal crash spot clusters from 2016 to 2018 using the NKDE method is provided in Fig. 4.35, Fig. 4.36, Fig. 4.37, Fig. 4.38, Fig. 4.39 and Fig. 4.40. A consolidated map of FATAL road crash spot clusters in half-yearly blocks for 2016-2018, done using the NKDE method, is provided in Fig. 4.41.

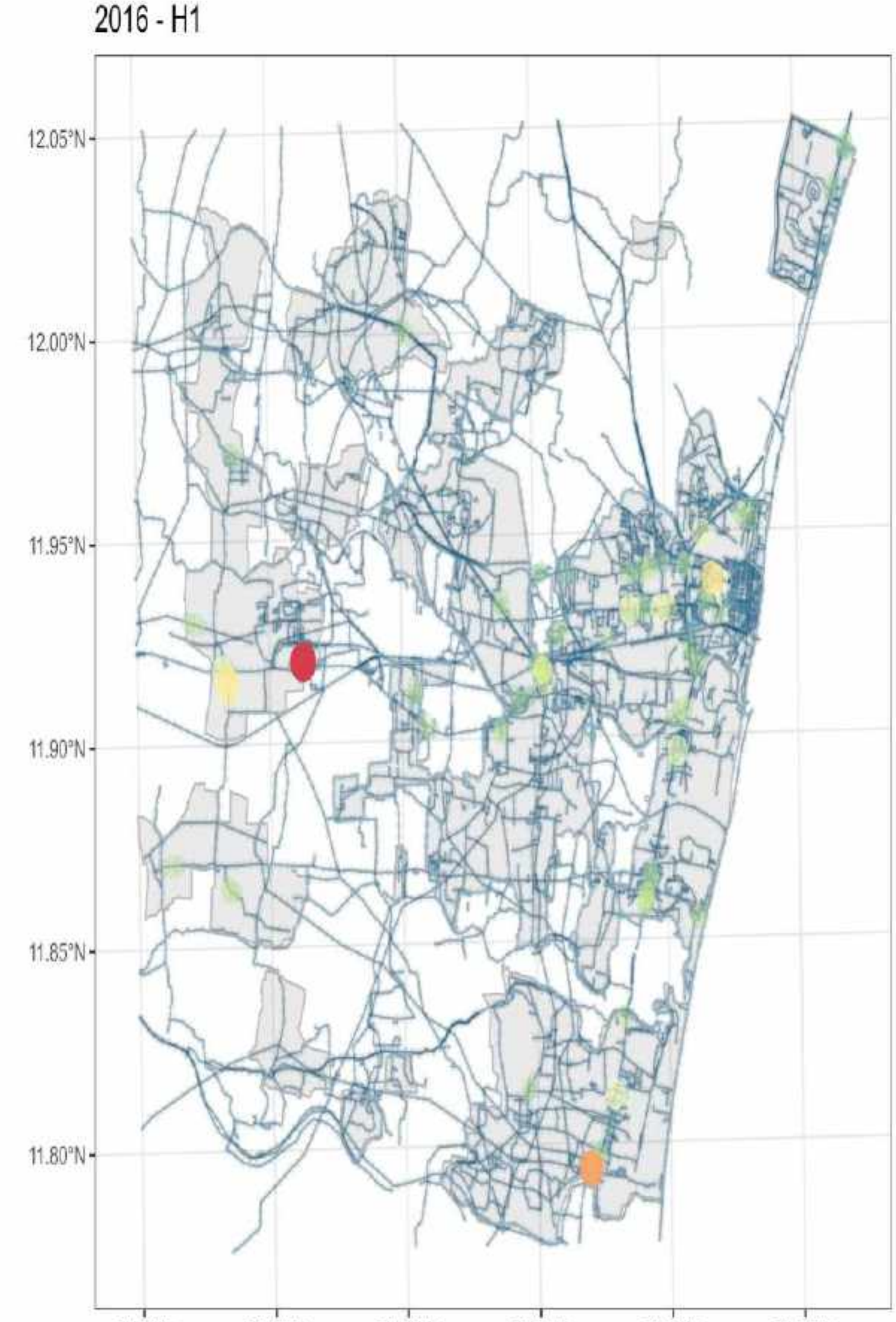


Fig. 4.35. Clusters of FATAL road crash spots for Half Year (I) of 2016 : Mapped by NKDE

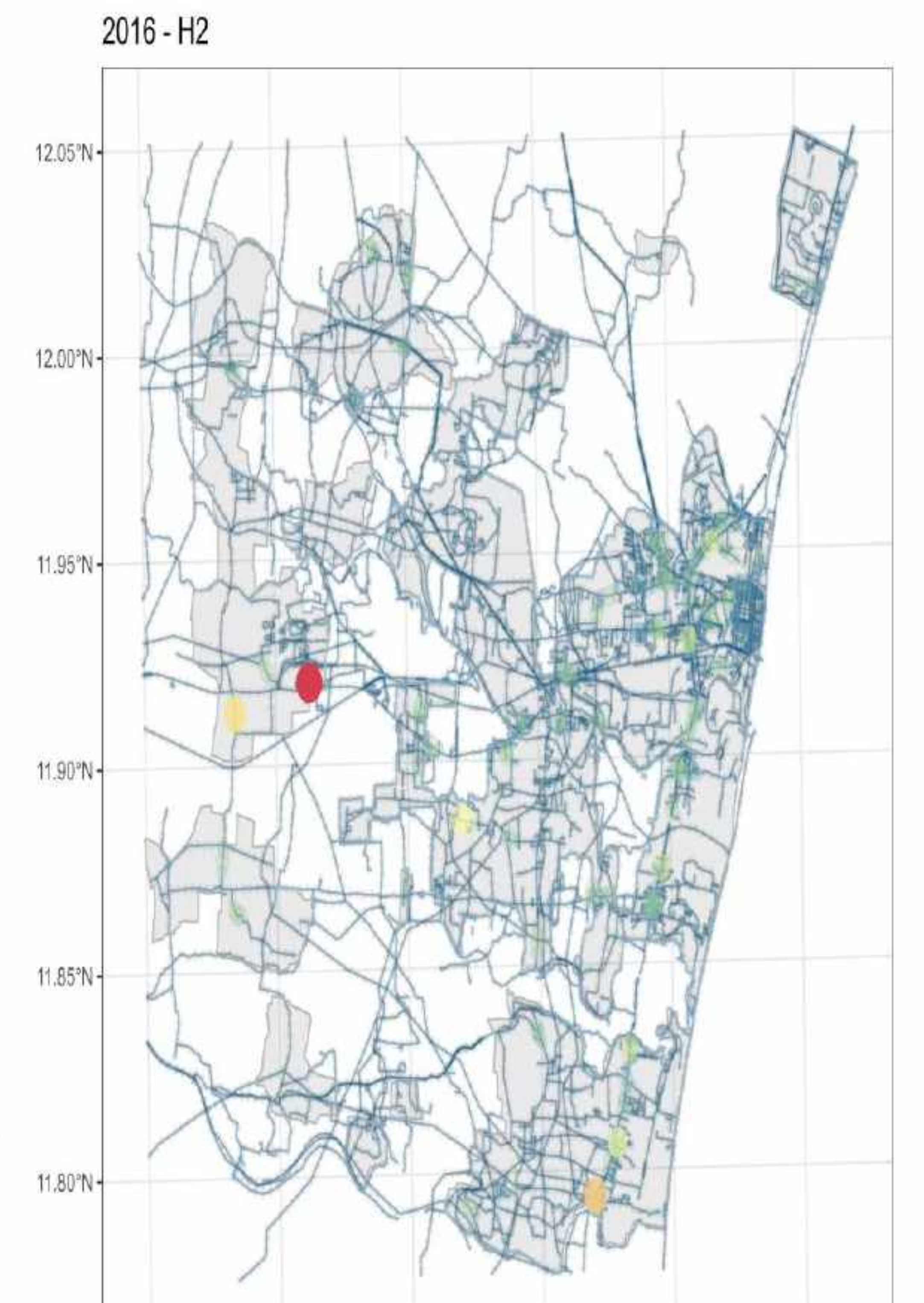


Fig. 4.36. Clusters of FATAL road crash spots for Half Year (II) of 2016 : Mapped by NKDE

Fig. 4.37. Clusters of FATAL road crash spots for Half Year (I) of 2017 : Mapped by NKDE

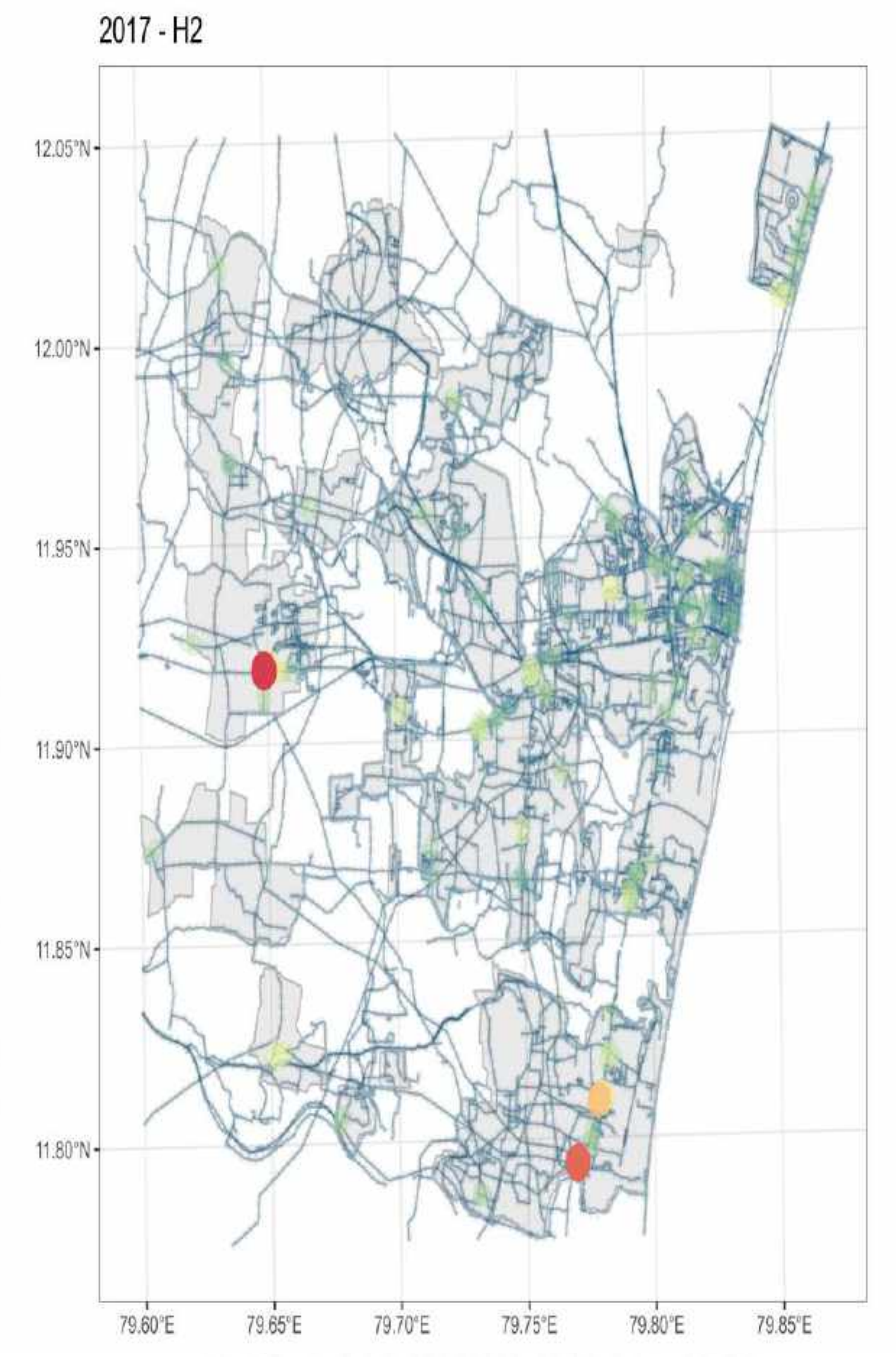


Fig. 4.38. Clusters of FATAL road crash spots for Half Year (II) of 2017: Mapped by NKDE

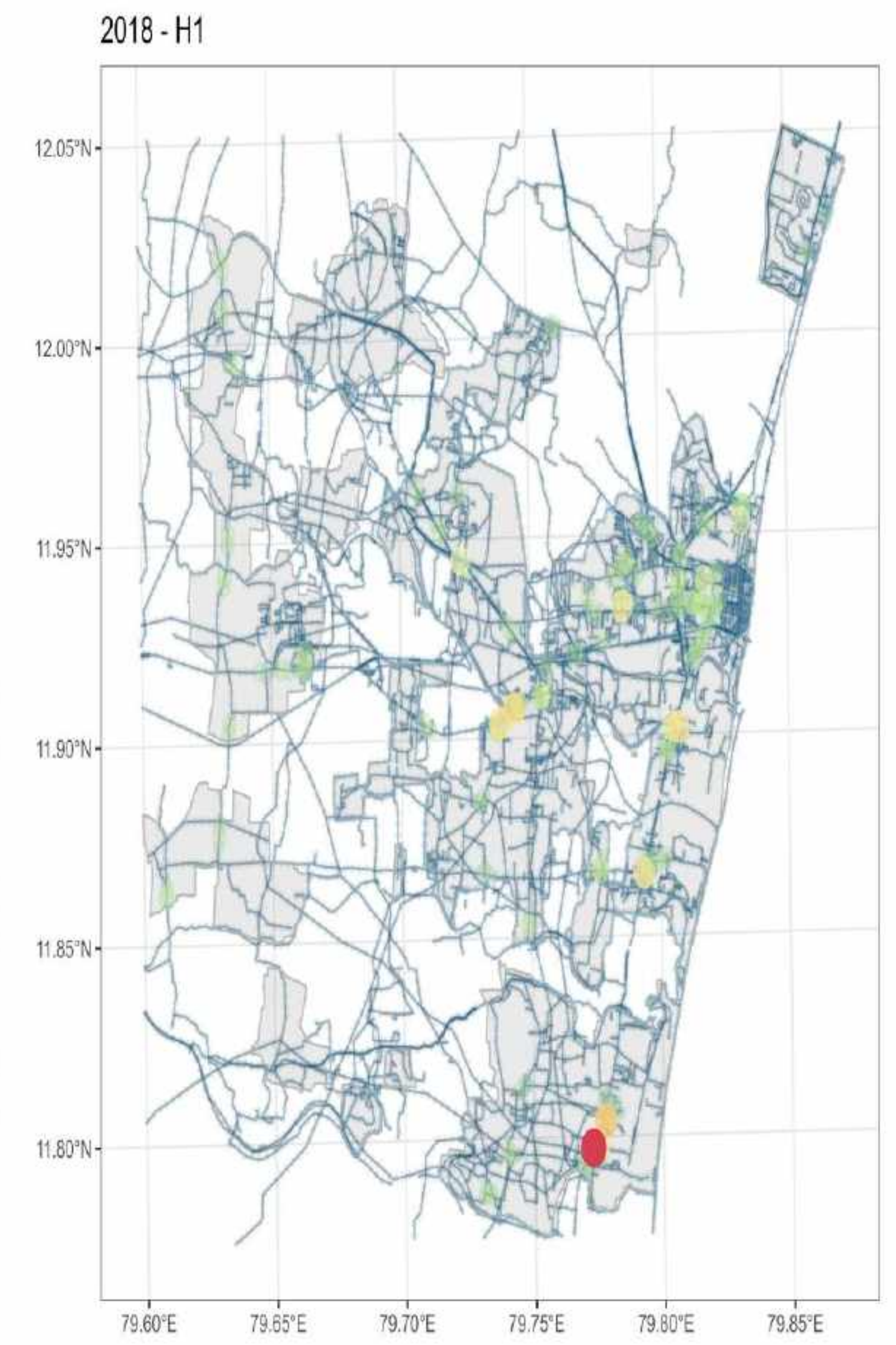


Fig. 4.39. Clusters of FATAL road crash spots for Half Year (I) of 2018 : Mapped by NKDE

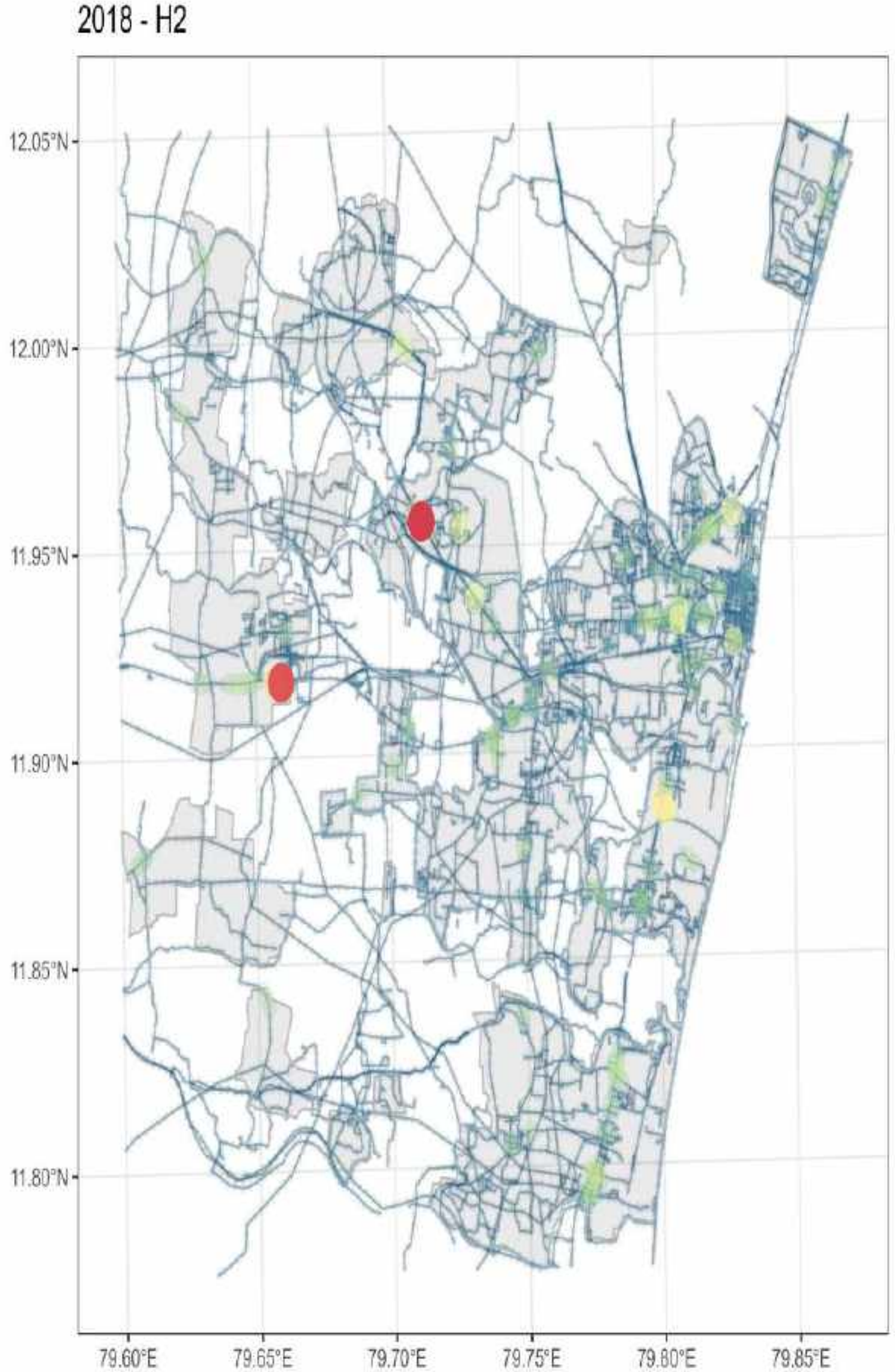


Fig. 4.40. Clusters of FATAL road crash spots for Half Year (II) of 2018 : Mapped by NKDE

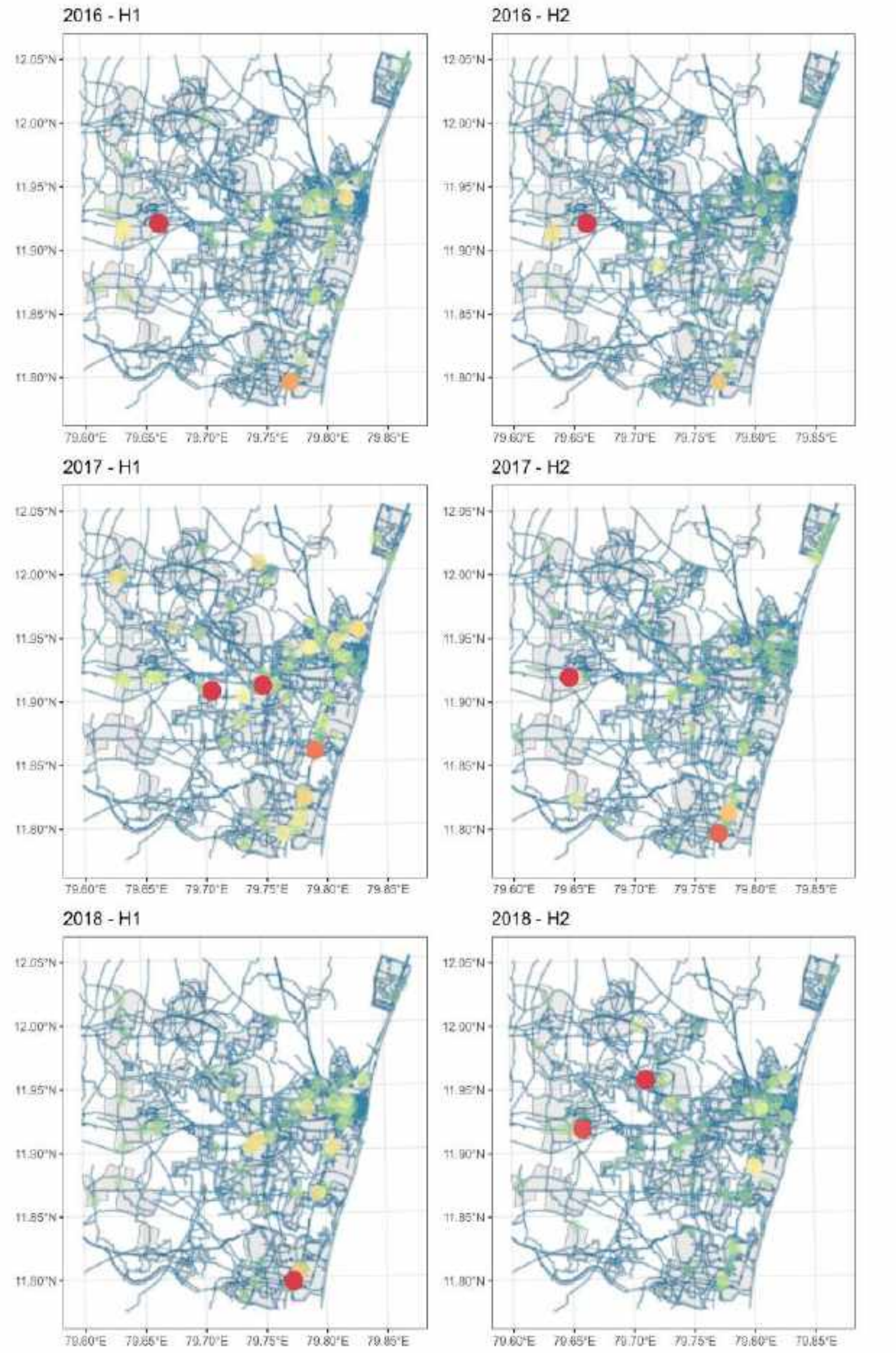


Fig. 4.41 Consolidated Map of FATAL road crash spot clusters: Half- Yearly blocks for 2016-2018; Mapped by NKDE

4.5 *Analysis of Road Crash Cluster Characteristics*

4.5.1 Comparison of Clusters and Non-Clusters: Time of Crash

Clusters and non-clusters showed statistically significant findings regarding crash time, accused vehicle and traffic zone. Most crashes occurred between 1200h-1800h in both clusters (38%) and non-clusters (33%), with the least crashes between 0000h-0600h (6.6% and 8.9%, respectively). The distribution of road crash clusters, as per the time of crash is provided in Fig. 4.42.

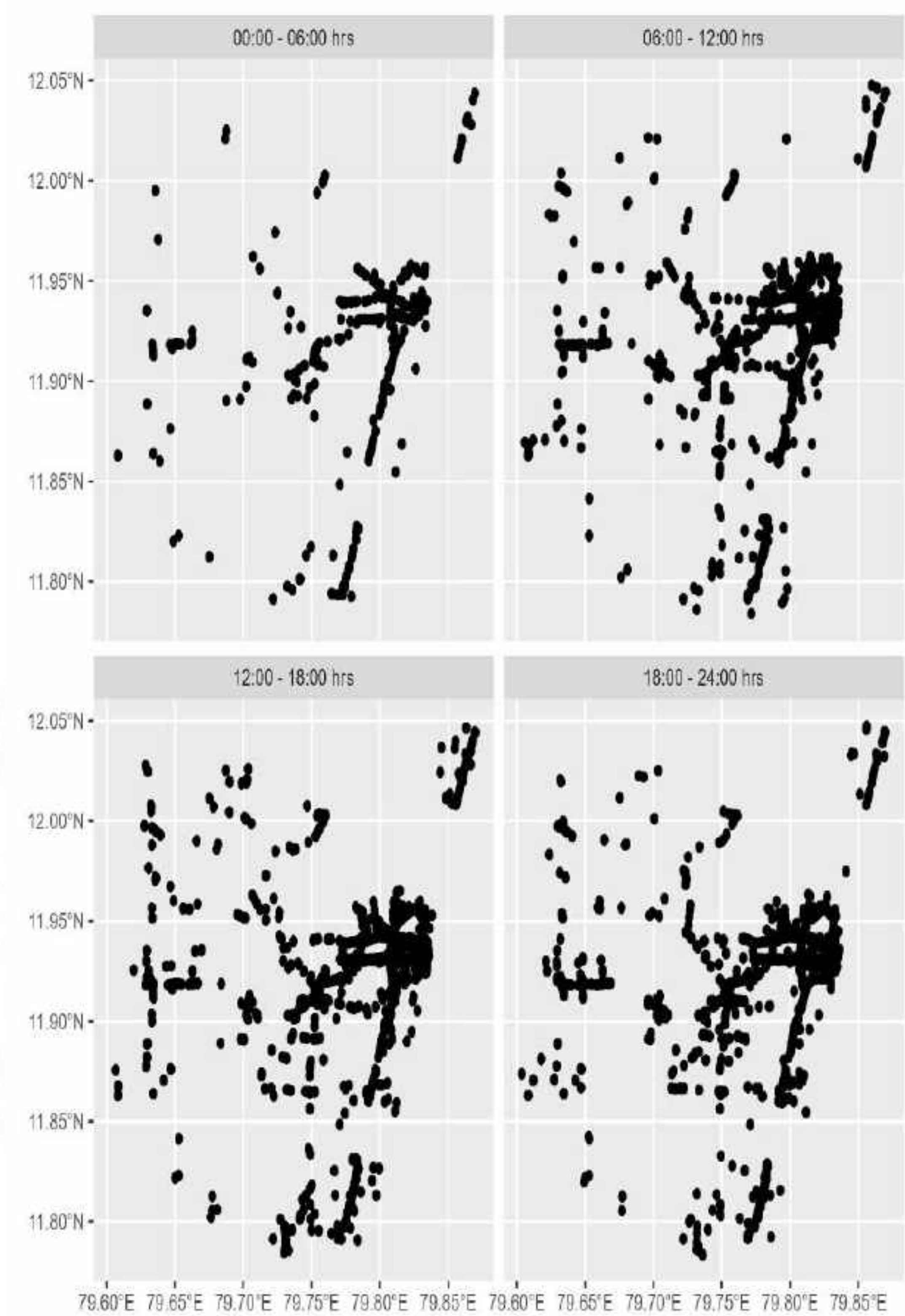


Fig. 4.42. Distribution of road crash clusters as per time of crash

4.5.2 Clusters and Non-Clusters: Crash Time, Vehicle Type and Traffic Zone

Characteristics of road crash clusters and non-clusters as per the time of the crash, accused vehicle, and Traffic zones are provided in Table 4.4. Two-wheelers were the most commonly accused vehicle in both clusters (57%) and non-clusters (45%). Non-clusters were spread equally across all four zones (north: 29%, south: 21%, east: 26% and west: 24%). However, crash spot clusters were predominantly located in the west (58%) and south (32%) traffic zones.

Table 4.4. Clusters and Non-clusters: Comparison as per crash time, Accused Vehicle and Traffic Zone

Characteristic	**clustered**, N = 1,069[1]	**not clustered**, N = 4,128[1]	**p-value**[2]
Time of Road Crash			<0.001
00:00 - 06:00 hrs	70 (6.6%)	366 (8.9%)	
06:00 - 12:00 hrs	270 (25%)	1,267 (31%)	
12:00 - 18:00 hrs	409 (38%)	1,341 (33%)	
18:00 - 24:00 hrs	319 (30%)	1,145 (28%)	
Unknown	1	9	
Vehicle of Accused			<0.001
Heavy Motor Vehicle	209 (20%)	865 (22%)	
Light Motor Vehicle	234 (22%)	1,184 (30%)	
Three Wheeler	12 (1.1%)	110 (2.8%)	
Two Wheeler	594 (57%)	1,756 (45%)	
Unknown	20	213	
Traffic Zone			<0.001
east	26 (2.4%)	1,057 (26%)	
north	76 (7.1%)	1,210 (29%)	
south	344 (32%)	850 (21%)	
west	623 (58%)	1,011 (24%)	

[1] n (%)
[2] Pearson's Chi-squared test

4.5.3 Clusters and Non-Clusters: Individual Variables of Crash-Affected Persons

Characteristics of clusters and non-clusters of road crashes concerning variables on individuals involved were statistically not significant. These variables include the age and gender of both the accused and the victim. Characteristics of clusters and non-clusters concerning individuals involved in the crash (age and gender) are provided in Table 4.5.

Table 4.5. Characteristics of Individuals involved in crashes : Clusters and Non-clusters

Individual Characteristics	**fatal**, N = 593[1]	**non-fatal**, N = 4,604[1]	**Overall**, N = 5,197[1]
Age of Accused	32 (25, 41)	31 (24, 40)	31 (24, 40)
Unknown	100	601	701
Age Group of Accused			
≤14 years	0 (0%)	5 (0.1%)	5 (0.1%)
≥60 years	11 (2.2%)	79 (2.0%)	90 (2.0%)
15-29 years	201 (41%)	1,812 (45%)	2,013 (45%)
30-44 years	208 (42%)	1,507 (38%)	1,715 (38%)
45-59 years	73 (15%)	600 (15%)	673 (15%)
Unknown	100	601	701
Gender of Accused			
female	2 (0.4%)	46 (1.1%)	48 (1.0%)
male	531 (100%)	4,263 (99%)	4,794 (99%)
Unknown	60	295	355
Age of Victim	48 (32, 60)	38 (26, 50)	39 (26, 52)
Unknown	36	524	560
Age Group of Victim			
Under 5 years	3 (0.5%)	67 (1.6%)	70 (1.5%)
5-9 years	4 (0.7%)	78 (1.9%)	82 (1.8%)
10-14 years	3 (0.5%)	96 (2.4%)	99 (2.1%)
15-29 years	109 (20%)	1,101 (27%)	1,210 (26%)
30-44 years	118 (21%)	1,200 (29%)	1,318 (28%)
45-59 years	164 (29%)	1,037 (25%)	1,201 (26%)
≥60 years	156 (28%)	501 (12%)	657 (14%)
Unknown	36	524	560
Gender of Victim			
female	99 (17%)	965 (23%)	1,064 (23%)
male	471 (83%)	3,157 (77%)	3,628 (77%)
Transgender	0 (0%)	1 (<0.1%)	1 (<0.1%)
Unknown	23	481	504

[1] Median (IQR); n (%)

5. DISCUSSION

5.1 Relevance of Present Study in Optimizing Road Safety

Fatalities due to road traffic accidents have risen globally, especially in India. It directly creates a significant public health burden to society in terms of DALYs and Out-of-Pocket expenditures and indirectly through loss of livelihood or death of bread-earners. Road traffic accidents are predictable and preventable, and using robust data systems with geographical information systems has much potential to mitigate them. The present study is a small step in using an open-source tool to develop data-driven solutions for robust data systems using data from Puducherry.

5.2 DecreasingTrend of Overall Crashes, But Increasing Fatalities

The present study analysed 5202 road traffic crashes from 2016-2018. A decreasing trend in road traffic crashes was observed, from 1904 in 2016 to 1611 in 2018 in Puducherry. However, fatal crashes increased from 2016 to 2018; from 157 deaths to 164 deaths respectively as reported by the ADSI report and report on Road accidents in India, by the Ministry of Road Transport and Highways. (MoRTH, 2021; NCRB, 2016, 2017, 2018, 2021). The MoRTH report on Road Accidents for 2021 reported 1,693 road accidents in 2017, 1,597 in 2018, and 1,392 in 2019, showing a similar decreasing trend. (MoRTH, 2021). The breakdown of crashes and fatalities in terms of Zones in Puducherry matched the report from NCRB and the MoRTH. (Ministry of Road Transport & Highways, 2021; NCRB, 2016, 2017, 2018, 2021). This trend could be explained in one way by the day-by-day increasing top speeds of vehicles and increasing number of vehicles on the road, that is, the growing density. However, we cannot elaborate on the particular reason for this as our present study did not have deeper variables to study this further.

5.3 Road Crashes in Puducherry - A Worrying Trend

5.3.1 High Crash Rates and Fatalities

In the past six years, 1,044 people were killed, and 7,164 were injured in road accidents in the UT. This shows that an average of four people are injured daily, and about 15 people are killed monthly in this UT. In 2020, there were approximately 969 accidents on the roads of Puducherry, an Indian Union Territory. (Puducherry-Annual Traffic Accident Report 2020, 2021). Traffic irregularities significantly contribute to yearly fatalities, injuries, and property losses. In 2020, vehicle overspeeding was the main factor in fatal traffic collisions. (Sun, 2022). Puducherry has the highest rate of unintentional deaths in the nation, as per the most recent data from National Crime Records Bureau (NCRB) under the Ministry of Home Affairs (MHA). It topped the list of 19 States and Union Territories with more "accidental deaths" than the national average.

5.3.2 Reasons for High Crash Rate in Puducherry

The high road crash rates in Puducherry can due to various reasons, including lack of staff, poor road engineering, traffic offences, and inadequate traffic rules. Causes for crashes include poor road conditions, a lack of signs and speed limits, poor illumination, driving under the influence of alcohol, riding in triples, using a mobile phone while riding, and inexperienced riders. The accidents have also been caused by the absence of road dividers and reflectors on the national highways that traverse the whole length and breadth of Puducherry. The problem has been made worse by sub-optimal enforcement of traffic rules and non-adherence by the public, the road users. The issue worsens when more automobiles are on the road per kilometre. The number of cars per 1000 people is likewise increasing. Due to its popularity as a tourist destination, Puducherry has continued to have an increase in visitors recently, which adds to the congestion on the roads for pedestrians and cars, particularly two-wheelers. The increase in educational institutions over the past few decades has contributed to the influx of young people to Puducherry. Two-wheelers, three-wheelers, four-wheelers and large trucks are mixed together and cramped into a small area. The Road Safety Committee has identified 60 "black spots" in the Puducherry area as high-accident locations. Most of the black spots, where accidents are reported virtually every other day, are on the Puducherry-Cuddalore Road (National Highway-NH45) between Marapalam to Kanniyakoil. (Express Bureau, 2022).

5.4 Male preponderance

The majority of the road accidents victim in the present study were found to be male gender, and the gender heterogeneity was more pronounced among the accused. One explanation for this predilection of the male gender for road traffic accidents could be the predominance of males in the practice of outside activities and the usage of vehicles. This is in accordance with national and international studies, all of which reported male preponderance in both the accident victim and accident accused. (Celine and Antony, 2014; Gbamou et al., 2022; Hammad et al., 2022; Kandpal et al., 2015; Shaira et al., 2020; WHO, 2022). Gbamou *et al.* reported the maximum number of road accident victims as males (66.23%) in a study among road traffic accident victims received in an emergency in a hospital in Kenya. (Gbamou *et al*., 2022) Barakat et al. reported almost 60.7% of the victims of road accidents as males.(Barakat, 2022). Kandpal *et al.,* in a study conducted in Gharwal, Uttarakhand, reported 82.7% of victims of road accidents as males compared to only 16.8% as females. (Kandpal *et al*., 2015). Reports from the Ministry of Road Transport and Highways also suggest similar findings as in the present study. (Ministry of Road Transport & Highways, 2020, 2021). A study conducted in a tertiary care hospital in Chennai reported a male-to-female ratio of 6:1 in terms of the distribution of road accident victims concerning gender. (Anantharaman and Muthunarayanan, 2015). Pathak *et al.* reported 84.6% of the accident victims as males in a study conducted among road accident patients reporting to a tertiary care hospital. (Pathak *et al*., 2014). Singh *et al.* reported 88.8% of road accident victims as male. (Singh *et al*., 2011).

5.5 Productive age group mostly harmed

Most road accident victims were aged 15 to 40 years, which is the most productive period in a person's life. This finding is in sync with multiple studies done throughout India (Celine and Antony, 2014; Kandpal *et al*., 2015; Shaira *et al*., 2020) and globally (Anantharaman and Muthunarayanan, 2015; Gbamou *et al*., 2022; Hammad *et al*., 2022; Le *et al*., 2020; Rao and P Kuna, 2019). Pathak *et al.* also reported that a good proportion of road accident patients were aged between 20 and 30 years (34.6%). (Pathak *et al*., 2014). Singh *et al.* reported that most road accident victims were 15-50 years old. (Singh *et al*., 2011). Our study found a peculiar finding that the median age (24 years) of the accused was lower than the median age of the victim (26 years), implying that perpetrators were younger than the victims. This difference was relatively higher in the case of fatal accidents (median age of 32 years for the victim versus 25 years for the accused). Underage driving was associated with a smaller proportion of all road crashes (1.9%) and fatal road crashes (2.5%).

5.6 Timing of Crash: Relationship with Office Hours

The road traffic injuries and fatalities in the present study showed a variation in the time of day, with more fatal crashes during the forenoon duration (8:00 AM – 12:00 Noon) and in the evening (6:00 PM – 10:00 PM). Although conventional knowledge opines that more crashes happen during late night hours, this was not the case with our study. The bimodal distribution of road traffic crashes reported in the present study could be due to the corresponding office timings, with more traffic during the office-going and returning phases of the day. Previous studies have reported a different picture regarding diurnal variation in the frequency of road traffic crashes, with higher crashes reported at night (midnight to 6 AM). (Misra *et al*., 2017). Other studies have shown more accidents during the 6:00 PM to midnight duration. (Gbamou *et al*., 2022; Kandpal *et al*., 2015). However, the analysis of government data is in line with the present study's finding, which reports more accidents from 6:00 PM to

9:00 PM. Although the second peak is reported in the afternoon duration from 3:00 PM to 6:00 PM. (*Hindustan Times*, 2023; Ministry of Road Transport & Highways, 2020, 2021). Another study conducted in a tertiary care hospital reported most road accidents to be taking place between 6 and 10 PM. (Pathak *et al*., 2014). While a study by Singh *et al.* in Haryana reported 6 PM to Midnight as the most frequently occurring time for road accidents. (Singh *et al*., 2011).

5.7 Inter-zonal Similarities

Road crash clusters for fatal and non-fatal incidents were located along the four major arterial roads. No inter-zonal variation was observed in the current study. This emphasizes that similar interventions could be applied across all the zones for better outcomes.

5.8 Vulnerable Road Users Bear the Brunt

Pedestrians are typically the most vulnerable and commonly disregarded of all transportation network users. Walking is a crucial non-motorized form of transportation utilised by pedestrians to link various parts of a multimodal transportation network and create connections with nearby activity centres. Due to growing urbanisation, a rise in vehicle expansion, and a lack of respect for traffic norms by drivers and walkers, traffic accidents involving pedestrians have become a significant safety hazard in most emerging countries, including India. The mix of vehicles with various static and dynamic characteristics makes traffic difficult. Without adhering to any lane discipline, all of these vehicles move on the same road space, taking any place on the road space dependent on the availability of free space.

Additionally, using the same road area as automobiles, pedestrians cause serious confrontations with them. Further, plans for the current road network do not incorporate footpaths, bus stop approaches, bus priority lanes, continuous pedestrian routes, or lanes for slower vehicles like bicycles and rickshaws. This frequently results in clogged roads for motorised vehicles as well as perilous circumstances for pedestrians and slow moving cars. Young men between 16 and 45 years of age comprised more than half of all wounded and fatal pedestrians. The complexity of interactions between pedestrian and automobile traffic is particularly acute at crossings. In developing nations like India, such circumstances are extremely typical on metropolitan highways in medium-sized cities.

At uncontrolled crossroads, traffic and pedestrian movements are managed based on predetermined priorities in developed nations, although priority norms are not always followed in India. Particularly in India, pedestrian behaviour in mixed-traffic situations differs significantly from that in other countries. Even when pedestrian crossing places and signals are present at uncontrolled intersections, pedestrians often choose not to use them, negatively affecting both the pedestrian and the traffic stream characteristics. Generally speaking, pedestrians cross the crossing during the red phase designated for vehicular traffic in most signalised intersections in India. India's transportation planners, traffic engineers, and policymakers are most concerned with ensuring the safety of pedestrians. The study and modelling of pedestrian flow characteristics and road crossing behaviour have received little attention in India.

Studies have shown that age and gender substantially impact pedestrian behaviour, with males more likely than females to exhibit risky road crossing behaviour due to reduced waiting time. (Celine and Antony, 2014; Gbamou et al., 2022; Hammad et al., 2022; Kandpal et al., 2015; Shaira et al., 2020; WHO, 2022). Additionally, models for pedestrian crossing durations and speeds were created to determine crosswalk width (Alhajyaseen *et al*., 2011; Shi *et al*., 2007). Zhang *et al*. looked into the impacts of pedestrian green time, crosswalk length, and pedestrian crossing direction on pedestrian walking speed, all in a signalised crosswalk. The two-gap, risk-taking, two-stage, walk and look, single stage, and rolling pedestrian crossing behaviours were categorised into different groups at various facilities. Studies on pedestrian gap acceptance and crucial gaps have shown that a pedestrian's decision to accept or reject gaps depends on their walking speed and the width of the road, with a margin of two seconds between the two. Studies have also shown that traffic volume, circumstances, weather, and pedestrian safety influence pedestrian crossing behaviour.

5.8 Two-wheelers mostly involved

The present study found that two-wheeler drivers led to the majority of the accidents, and most victims were also two-wheeler users, either the driver or pillion rider. Almost two-thirds (67%) of road accidents happened as a result of a collision between one two-wheeler with another. Pathak *et al.* reported similar findings with two-wheelers as the commonest vehicle involved in vehicular accidents. They reported that motorised two-wheelers were involved in 71.9% of road accidents, while pedestrians were involved in almost 15% (14.8%). (Pathak *et al*., 2014). Singh *et al.* found motorized two-wheelers to be involved in 41.5% of road accident cases. (Singh *et al*., 2011). A study conducted in Mangalore, India, by Jain *et al.* (Jain *et al*., 2009) revealed 1231 two-wheeler incidents between 2000 and 2004. Most (77%) of the victims were in the 18- to 44-year-old age range. The accident rate was more prominent among men (83%) than women (17%). Seventy five people, or 5% of the total, perished from their wounds; 45 passed away immediately. Vehicles with gears were more frequently involved (81%) than those without gears. Most accidents were recorded between 6 and 10 pm. The number of morbidity and fatalities from two-wheeler traffic accidents was significant.

5.9 Vehicle Occupancy

Vehicle occupancy was also found to play a role in road accidents, especially fatal ones, with 41% of victims of all road accidents being drivers and 55% of all deaths being in drivers. Two-wheelers were an exception to this observation, with drivers and pillion riders equally vulnerable to crashes and fatalities.

5.10 Hotspot mapping using DBSCAN

Multiple studies in India (Agrawal *et al*., 2018; Alotaibi, 2018a; Ganjali Khosrowshahi *et al*., 2021; Nalini *et al*., 2020; Shinde *et al*., 2022) and globally (Alotaibi, 2018b; Chang et al., 2021; Ganjali Khosrowshahi et al., 2021; Huang et al., 2021; Islam et al., 2021; Qiu et al., 2016; Topcuoglu et al., 2022; Wang et al., 2023; Xia and Yang, 2019a) have used DBSCAN to analyse road accident location and identify blackspots.

A more effective sampling-based DBSCAN was utilized by Borah and Bhattacharyya *et al*. (Borah and Bhattacharyya, 2004) to cluster massive spatial databases. Due to its activities throughout the entire database, DBSCAN can be found to be demanding regarding data quantity. This is because it needs a significant amount of memory support. The suggested sampling-based DBSCAN beats DBSCAN and its competitors in terms of execution time without sacrificing clustering quality, according to experimental data.

Li *et al.* used the DBSCAN algorithm to analyse the locations of traffic accidents. (Li *et al*., 2017). They used statistical analysis and data processing algorithms on the dataset of fatal accidents. It is an effort to provide advice on driving safely. An *a-priori* method was used to discover association rules, the Naive Bayes classifier was used to create a classification model, and the K-means clustering technique was used to create clusters. Investigations were made into the relationship between the fatality rate and other factors such as weather, drunk driving, and surface conditions such as light and crash style. All fatal incidents that occurred in 2007 on public roads are included in the Fatal Accidents Dataset, which was used.

Ranjith R *et al.* proposed an unsupervised clustering technique, namely Novel Anomaly Detection-Density Based Spatial Clustering of Applications with Noise (NAD-DBSCAN), which clusters the trajectories of moving objects of varying sizes and shapes.(Ranjith *et al*., 2015). Qiu C *et al.* proposed modifying the DBSCAN clustering algorithm with additional parameters that help identify accident-prone traffic locations. (Qiu *et al*., 2016). Agrawal K *et* *al.* developed an android App using an analysis of road accidents in Hyderabad, India, using the DBSCAN algorithm. They analysed data from the year 2010 to 2017, consisting of 11596 records in total. The user gets prompted whenever he goes to areas that are accident-prone, thereby helping prevent road traffic accidents. (Agrawal *et al.*, 2018). Marks C *et al.* used the Iterative DBSCAN method for identifying aggressive driving behaviours within real-world driving datasets. (Marks *et al.*, 2019).

A new approach that forecasts accident-prone areas and indicates the riskiest time of day to drive along that route has been proposed by Khekare *et al.* after analysing data from India's 11 states that were accident-prone while taking into account different time zones. The system was trained to make the best decisions possible based on experience using a machine learning concept. The DBSCAN data method with negative sampling was applied to apply the machine learning principle. (Khekare and Verma, 2021). Rajamani *et al.* developed an improved method to detect black spots on roads using the DBSCAN algorithm. (Rajamani *et al.*, 2021). Topcuoglu B *et al.* used the DBSCAN method to analyse the traffic accident data from the year 2014 to 2021 in Mersin, Turkey. (Topcuoglu *et al.*, 2022)

The accident locations in the current study were concentrated along the four major arterial highways that led out of the city in four separate directions. This held for both total crashes and fatal crashes. The distribution and location of crash spot clusters that resulted in fatalities matched those of all (fatal and non-fatal) crash spot clusters. On half-yearly cluster density mapping, a V-shaped curve was seen, with a large number of clusters on both the start and finish years and a dip in the middle year under observation, which was in accordance with annual cluster density mapping. We did not get any additional information from the quarterly analysis, as compared to the half-yearly analysis.

The DBSCAN study revealed an interesting trend in the evolution of crash clusters, with smaller patchy clusters from one year converging to a single large cluster the following year. This increased in size and length the next year to create an ever larger, more extended cluster. However, there were no appreciable inter-zonal variances amongst the clusters in the four traffic zones. There were no discernible changes in the distributions of the fatal and non-fatal clusters. Crash spots from all traffic zones were seen in one sizable cluster in Puducherry's central township area.

5.11 Hotspot Mapping Using Network Kernel Density Estimation (NKDE)

Initially, the spatial variation of network events was directly measured using planar spatial approaches. (Flahaut *et al.*, 2003; Okabe and Sugihara, 2012). However, using planar approaches to study phenomena with network constraints might result in systematic bias and incorrect pattern interpretations. (Okabe and Sugihara, 2012). It has further been demonstrated that Network KDE is better suited for events with network constraints. Therefore, numerous researchers have made notable strides by converting from planar to network-based approaches. (Nie *et al.*, 2015; Okabe *et al.*, 2009; Xie and Yan, 2008).

Kernel density estimate (KDE) has been used in multiple studies in India (Dalai and Landge, 2022; Damani and Lakkad, 2018; Fatema and Chakrabarty, 2020; Sandhu *et al.*, 2016; Srikanth *et al.*, 2019) and globally (Ahmad *et al.*, 2019; Bassani *et al.*, 2020; Ganjali Khosrowshahi *et al.*, 2021; Kazmi *et al.*, 2022b; Nazneen *et al.*, 2020) to study the geospatial clustering of road traffic accidents and finding the blackspots.

Globally, multiple studies have used network KDE in road traffic accident analysis. (Al-Aamri *et al.*, 2021; Fan *et al.*, 2018; Harirforoush and Bellalite, 2019; Lee and Khattak, 2019; Loo and Yao, 2013; Mohaymany *et al.*, 2013; Nie *et al.*, 2015; Okabe *et al.*, 2009; Pleerux, 2020; Xie and Yan, 2008; Yamada and Thill, 2004).

Xie and Yan proposed a method to extend the planar KDE to the network KDE. (Xie and Yan, 2008). Yamada and Thill studied the crash pattern in Hong Kong using Network KDE from 2008 to 2010, with 30,490 traffic accidents and 1090 kilometres of roads. (Loo and

Yao, 2013). Mohaymany *et al.* did a GIS-based analysis of high-crash-risk road segments using Network KDE in Iran. (Mohaymany *et al*., 2013). Nie *et al.* used Network KDE to identify risk locations for traffic crashes and spatial clustering of accidents in Wuhan, China. (Nie *et al*., 2015). Fan *et al.* conducted an analysis of traffic collisions in the Jianghan District of Wuhan, China using Network KDE. (Fan *et al*., 2018).

Harirforoush *et al.* did a study using Network KDE to explore the traffic accident hotspots in Sherbrooke, Canada. (Harirforoush and Bellalite, 2019). Pleerux N *et al.* studied the accident hotspots in Thailand using Network KDE. (Pleerux, 2020). Al-Aamri AK *et al.* studied the traffic crash hotspots using Network KDE in Muscat, Oman. (Al-Aamri *et al*., 2021)

To the best of our knowledge, we could not find any studies utilizing Network KDE in profiling road traffic accidents in India, highlighting the novelty of the present study.

We must understand the strength of Network KDE over the conventional planar KDE. Network KDE uses network space as the a point event context. The bandwidth and kernel function are calculated using the network distance instead of the Euclidean straight-line distance; and the density is measured as per linear units.

5.12 Similar Results From Both Techniques Applied to Same Dataset

We found near similar results from Network KDE as found from DBSCAN analysis for a number of clusters yearly, half yearly, and quarterly. Crash spot analysis resulted in patchy clusters, especially in the west zone in 2016 which coalesced to form a larger cluster in 2017 and expanded in 2018. Similarly, the medium sized cluster observed in the central area in 2016 merged with the adjoining small clusters and formed a large cluster in 2017, and further elongated in 2018.

5.13 Comparison of Crash Characteristics: Clusters and Non-Clusters

Analysis of clusters obtained through KDE showed statistically significant differences from non-clusters regarding crash time, accused vehicles and traffic zones. More accidents happened in clusters from Noon to 6 PM (38%) compared to non-clusters (33%). Clusters were predominantly located in the west (58%) and south zones (32%). However, non-clusters were spread equally throughout the study area.

More than half of the clusters had two-wheelers as accused vehicles compared to 45% among non-clusters. Characteristics of clusters and non-clusters of road crashes, concerning variables on individuals (age and gender of both the accused and victim) involved in the crash, were statistically not significant.

5.14 Strengths

The use of robust data and use of open-source software are some of the strengths of the present study. The use of an enriched and evolved data frame by converting raw data into analyzable using a data extraction template is one of the study's strengths. Proving data handling in a cartographer's mess such as Puducherry is, in itself, a noteworthy achievement.

The use of both a density-based algorithm (DBSCAN) and network-based (NKDE) algorithm on the same dataset in the framework of a single study makes it unique, especially in the Indian health setting. New technology in the form of NKDE has probably been used for the first time in such settings.

Working with irregular forms is the DBSCAN algorithm's biggest benefit over the alternative method. It allows for the direct usage of precise Global Positioning System (GPS) positions. Junctions are easier to understand when using the DBSCAN approach. These are the only strategies that are genuinely effective in interurban areas. Despite being a relatively resource-intensive algorithm, this implementation used the open source software technologies like the R project.

KDE has the advantage of being easy despite the complicated underlying concepts and processes. This benefits road authority designers and engineers who might be unfamiliar with spatial statistics. Another benefit of employing KDE is that the kernel's bandwidth (search radius) can be used to increase uncertainty around the crash spot precision. Additionally, KDE can prioritize the portions of the roads with considerable clustering based on the cluster ranking technique. The drawback of plain KDE is that it does not reveal the risk exposure of additional road segments with weakly significant clustering. Because of the extremely low frequency, the cluster strength does not show up for some road sections that may be intrinsically dangerous and cause one or two fatalities (Xia and Yang, 2019). The usage of Network KDE instead of conventional KDE makes the present study more robust, as NKDE is more appropriate to study network-constrained phenomenon like road traffic accidents.

The robustness of data and process is proven by the similarity of findings arrived at by both techniques. This also establishes the generalizability and potential for extrapolation of the study process and tools employed. This study is expected to be a useful tool in the hands of key stakeholders for dynamic and informed decision-making.

5.15 Contribution of Research to optimization of road safety

5.15.1 *Promotion of safe system approach for prevention and control of Road Traffic Injuries.* The project improves/sharpens road crash data systems by objectivising the inputs, process and outputs . So, its application enables reduction of fatalities resulting from road crashes. Safe Systems approach admits that road crashes are inevitable, however the resultant fatalities can be eminently prevented. Thus, this study contributes to promotion of safe systems approach in road crash prevention and control.

Road crashes vary spatially and temporally (Anderson, 2015; Zi(Anderson, 2015)akopoulos and Y(Anderson, 2015)annis, 2020). Therefore, it is important to consider spatial dependence and heterogeneity in investigating the effects of road safety and sustainable transportation systems variables and attributes on specific areas and how neighboring areas may influence them. Additionally, understanding the evolution of traffic crashes and identifying hotspots is crucial for achieving traffic safety and informing transportation planning, resource allocation, decision making, and policy implications. However, road safety interventions are often limited to technical specialists who may be shaped by their cultural and institutional contexts. This may result in the prioritization of conventional practices, such as road network expansion, over effective measures to reduce crash risk, such as travel demand management. To address this issue, it is important to foster a multidisciplinary and collaborative approach to road safety that takes into account the social, economic, and environmental factors that influence road use and traffic crashes. This can help ensure that interventions are evidence-based, context-sensitive, and effective in achieving their intended goals. Properly designed and constructed road infrastructure is critical to the safe and efficient transportation of goods and people. For example, well-designed roadways can reduce driver confusion, provide clear guidance to drivers, and prevent accidents caused by inadequate or unclear road markings and signs. Such safely laid out roads can significantly reduce the number of accidents and fatalities (Alarifi *et al*, 2018; Alharbi *et al*, 2022); thus ensure road safety (Mannering and Bhat, 2014).

5.15.2 *Empowering Police Policy makers/program managers to act based on evidence*. The complete road crash data analytical framework in the given setting has been fine-tuned and made robust by incorporating GIS based elements; and placing Geo referenced crash spot mapping at its nucleus. This enables all stakeholders in the road safety paradigm (like traffic police, healthcare personnel, legal , PWD , insurance staff etc.) to work from a common database platform, and derive inferences and plans of action specific to their individual domains . It also entails intersectoral coordination amongst these stakeholders. Use of open-source software, which is reproducible and can be easily applied to get operational inferences makes it a useful tool in the hands of such stakeholders.

Road crash data analysis has emerged as the key workable to support decision-makers in implementing measures for elimination or mitigation of traffic accidents, by delving into core reasons of crashes (Tola et al., 2021). Therefore, addressing traffic accidents in the context of spatial and/or temporal dimensions is needed to determine the best and most consistent solutions to such issues. The national statistics of road crashes provide an overall generic view of the road traffic safety situation; therefore, the interaction between traffic accidents and their environment might not be presented. This is because each road-traffic crash has its own characteristics in terms of the environment, vehicle, road, driver, and traffic-management attributes. Thus, analyzing traffic crashes from a cause-specific perspective is imperative for refining national traffic safety management plans. In this context, various researchers and international agencies have employed spatial and temporal mapping of traffic accidents and created their models for adopting road safety measures. Several approaches have been used to determine the temporal (yearly, monthly, daily, hourly) distributions as well as spatial distribution of traffic accidents along the roads. Statistical-based mapping approaches such as Kernel Density Estimation (KDE), K-means, Moran I, and Getis–Ord are among the most frequently used ones in this domain, since they reflect the statistical significance of traffic-accident hotspots (Bil et al, 2019; Elvik, 2008). Such hotspots are of great value to decision-makers, traffic engineers, traffic researchers, and drivers.

This study confirmed that spatial analysis and statistical techniques within the GIS environment effectively identified traffic accident hotspots and road segments with statistical significance. Mapping the spatiotemporal pattern of traffic-accident hotspots along with the causes and proposed solutions for the hotspot locations would support the decision-makers and traffic-management authorities in prioritizing road maintenance, especially for those with frequent accidents, to improve traffic safety.

5.15.3 *Features unique to Puducherry and Features which are universal.* There are certain features of the study which are unique (specific) to puducherry are those that are universal (general). Those specific to Puducherry are that it is an educational and tourist hub; with resultant steeply high share/proportion of young students and tourists. The place is also a weekend getaway for college goers and IT professionals of the metropolitan cities located in closer vicinity, like Chennai and Bengaluru.

Consequently, there is a high preponderance of two wheelers (both motorised and non-motorised, i.e cyclists, rickshaw etc.). Further, dense concentration of industrial clusters in a small area makes the traffic and transport even more heterogeneous and variegated.

The high preponderance of accidents among pedestrians and two wheelers are some of the universal features (Slater *et al*., 2012), which this study shares with most others carried out in India. Other generic features are the multicultural interaction between communities belonging to different nationalities, presence of many institutions of national importance, etc. These unique feature brings the age profile of most of the pedestrian and two-wheelers in the young age group of about 25 years or lower, which is younger to profile of other areas.

5.15.4 *Incremental Value of GIS Analysis beyond Hotspot Mapping.* The present study has successfully applied machine learning techniques onto road crash data , and created crash spot clusters from it. Thereby, it has taken GIS based spatio-temporal application beyond plain mapping of crash spots. This clustering of crash spots (both fatal and non-fatal) based on latest technology (DBSCAN and NKDE methods) gives it an edge over traditional methods of road crash data analysis

Identification of High-Risk Areas: GIS analysis enables the identification of high-risk crash areas by aggregating crash data within defined spatial boundaries and calculating crash rates. This helps in understanding the concentration of crashes and prioritizing resources for targeted interventions.

Spatial Patterns and Trends: GIS allows for the detection of spatial patterns and trends in crash data. Spatial clustering techniques such as hot spot analysis can reveal areas with statistically significant high or low crash occurrence. This information can be used to develop targeted safety measures.

Multi-Layered Analysis: GIS permits the integration of various datasets, such as traffic volumes, road characteristics, and demographic information, to analyze crash factors comprehensively. Understanding the relationship between these variables aids in identifying potential contributing factors to crashes.

Route and Network Analysis: GIS can be used to analyze crash data along transportation routes or networks. This information is valuable for assessing the safety of specific roads, intersections, or corridors and for optimizing transportation planning.

Predictive Modeling: GIS-based predictive modeling can estimate crash likelihood in areas without historical crash data. This assists in proactive planning and resource allocation for potential high-risk areas.

Evaluation of Safety Interventions: After implementing safety interventions, GIS can be used to assess their effectiveness by comparing crash data before and after the intervention. This aids in refining strategies and understanding the impact of safety measures.

5.16 Limitations

One of the apparent limitations of the present study is its usage of secondary data, which restricts us to only those study variables that were pre-available with the datasets analysed. Further, no standardized data format was available up front, and most of the efforts had to be spent on cleansing the raw dataset. Also, data on other points that have a bearing on road crashes, like locations of educational institutions, liquor shops, religious places, etc., was not available to cross-check/ superimpose on the primary data layer of road crash locations *per se*. The availability of such secondary data layers would have enhanced the depth and width of the study. Additionally, the absence of a single nodal agency to approach and access data greatly hindered the study process. Multiple agencies with variegated agendas were a challenge. Lack of good inter-sectoral coordination amongst key stakeholders like traffic police, health care directorates, insurance agencies, transport department, etc., affected the study's data inputs. The heterogeneous, patchy nature of the area, both geographically and administratively, was another limitation. Baseline road network maps were not available with concerned authorities, nor were resources on road or vehicle details. The road network of interlocked/ interspersed area (Tamil Nadu), which abets Puducherry, was also unavailable, constraining the space and scope available for in-depth analysis. Insufficient hardware systems to handle large-sized datasets were also a limitation.

6 SUMMARY AND CONCLUSIONS

6.1. Summary

6.1.1 This study tried to amalgamate the elements of both descriptive profile of road crash victims, and data-driven spatio-temporal analysis of road crash spots using GIS-based software tools, in a single framework. The findings revalidate our present understanding on distribution of road crash victims with respect to age, gender and vehicle. Overall crash rates seemed to be plateauing, but fatalities resulting from crashes showed a rising trend.

6.1.2 Younger to middle aged males, either pedestrians or two-wheeler users form the largest sub-set of crash victims. Two-wheeler riders were also involved as accused in a significant proportion of crashes, especially fatal ones. Vulnerable road users, mainly pedestrians who use the road only passively, bear the brunt of crashes, including fatal crashes. Those accused in causing the crashes were overwhelmingly males, with age profile younger than victims. Time of crashes (including fatal ones) matches peak traffic time both in morning and evening sessions.

6.1.3 Vehicle Occupancy does not seem to be significantly associated with overall crashes or resultant fatalities.

6.1.4 The value addition provided by ‘R’, an open source, cross-sectoral analysis software is noteworthy in this context.

6.1.5 The utility of DBSCAN as a valuable tool in mapping crash spots and clusters emerging thereof, has been proven once again by this study. Crash spots (all crashes in general and fatal in particular) were found to be clustered along the four main arterial roads leading from and to Puducherry. No major inter-zonal variation was observed amongst the different traffic zones.

6.1.6 Clear pattern of emerging clusters was observed, in that smaller clusters which started forming in a particular zone in the first year under study, coalesced to form a large cluster in the next year. These further extended into a longer cluster in the final year under study. This clustering pattern observed with DBSCAN was validated when Network Kernel Density Estimate (NKDE) was employed at analyse the same dataset. NKDE also gave similar results, thereby assuring the reproducibility of this study.

6.1.7 Significant difference between clusters and no-clusters was observed, in individual characteristics of those involved in the crashes, either as victim or accused.

6.2 Conclusions

The present study tried to understand the epidemiology of the road traffic accidents in Puducherry using robust data systems and evaluating the same for hotspot cluster identification. There is a significantly heterogeneity in terms of gender for road accident victim and accused in Puducherry with majority being male. The highest burden of road accidents falls over the most productive age groups. The accident frequency in Puducherry peaked during forenoon and evening time. Most frequently involved vehicle was two-wheeler, both as victim and accused. The NKDE and DBSCAN analysis showed near similar finding regarding position of clusters, thereby reinforcing the high quotient of reproducibility/ reliability of the study. The workability of a completely data-driven approach from initial data synthesis till final analysis, using an open-source analytical tool on an extracted data frame, has been established. Thus, the study has succeeded in attaining its stated objectives, mainly the third and most important one, by developing a framework for analysis of road crash data in the setting.

6.3 Recommendations

6.3.1 Major Recommendations

The major recommendations of the study are as follows, from an operational and translational perspective:-

6.3.1.1 Prevention of deaths from road crashes , as reiterated in Safe systems approach, must be focussed around epidemiological profile, mainly of victims, but also taking into consideration the offender profile.

6.3.1.2 Developing data extraction template helps in seamless translation of raw data onto inferable format.

6.3.1.3 Cross-analysis of victim and alleged offender profiles must be included as part of data systems, to help achieve this objective.

6.3.1.4 Deeper studies are needed to analyse the correlation between clinical and non-clinical/ socio-demographic profiles.

6.3.1.5 Comprehensive research by connecting important stake-holders in the road safety jigsaw (police, medical, transport, legal, insurance, education, traffic and such sectors) is the felt need of the hour, for optimizing road safety.

6.3.1.6 Developing a high quality template for seamless data capture-processing-analysis-output cycle is important for devising workable road safety strategies.

6.3.1.7 The reproducible algorithms created for road crash data analysis as part of this project are envisaged to enthuse interest in the stakeholders and contribute to better outcomes for road safety in this setting.

6.3.2 Allied Recommendations

Other allied recommendations of the study, from a purely research based academic perspective are as enlisted below:-

6.3.2.1 To determine which type of study approach is suited for these places, in-depth analysis could be performed on various locations such as straight roads, junctions, and parking lots.

6.3.2.2 Sensitivity analysis can be conducted in future studies utilizing various segment lengths and bandwidths. Multi-criteria ranking techniques to give hotspots priority can be explored in future researches.

6.3.2.3 The kriging method can be used to study the effects of exponential, Gaussian, and spherical functions in crash prediction. Based on the integration of the severity of individual accident data in kriging, a single parameter can be used to generate hotspot identification.

Utilizing kriging, determine how crash-influencing elements like the environment and traffic exposure affect hotspot discovery.

6.3.2.4 Land-use factors, driving habits, road geometry, and weather conditions may all have an impact on hotspot detection, which merits their inclusion in future researches.

6.4 Way Ahead

The following actions are planned to be done in the study setting, consequent to the inferences derived from the study:-

6.4.1 Hand over the populated final master data sheet (developed using data extraction template) used for present study, to Puducherry traffic police authorities. This sheet contains data of 2016-2018 period, from all four traffic police zones.

6.4.2 Also hand over the blank data frame template for capturing road crash data, to the authorities. This blank data frame can be populated with past data, and also can be used for future periods. It will enable capturing wholesome data on all important variables of individuals involved in road crashes, while also ensuring that geo-coordinates (Latitude-Longitude) of the crash spot is accurately mapped.

6.4.3 Share the 'R'code and entire data flow algorithm for seamless analysis of the data thus captured using the above-mentioned process.

6.4.4 Train the stake-holders on the nuances of data management process, the forms/ formats involved, and the input-process-output cycle. Traffic police personnel involved in data handling, at all echelons/ levels of the structure, will be trained. Necessary clearance and approval will be taken from appropriate authorities.

6.4.5 Review the outcomes on a regular basis through periodic interactions, obtain feedback and refine the schema/ mechanism to achieve optimal gains.

6.4.6 Based on the outcomes and experience gained through the aforesaid process, explore the feasibility of expanding this experiment to other similar settings in India, as a step towards optimizing road safety in a holistic manner.

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LIST OF PUBLICATIONS FROM THESIS: DR ANAND N

1. Anand N, Soman B, Prakash M. Epidemiological profiling of fatal road crashes in Puducherry, South Coastal India. Indian J Public Health. 2021 Apr-Jun;65(2):203-205. doi: 10.4103/ijph.IJPH_1436_20. PMID: 34135193.

   Remarks: *Published*

2. Anand N, Soman B, Kumar S. Identification and analysis of fatal road crash black spot clusters in an urban setting in south coastal India. Med J DY Patil Vidyapeeth 2021;XX:XX-XX. **doi:** 10.4103/mjdrdypu.mjdrdypu_344_21.

   Remarks: *Accepted for Publication*

CURRICULUM VITAE: DR ANAND N

Name	Dr. Anand N
Age; **Date of Birth**	47 years; 20/11/1975
Gender	Male
Residence Address	C-4, Anandham Apartments, Gangai Amman Koil Street, Opposite Bharathi Nagar, Karuvadikuppam, Puducherry- 605008
Contact details	Mobile No.: 9315039969e- mail Ids . : anandn@sctimst.in, 2n2nd.n@gmail.com
Academic Qualifications	MBBS (1993-1999) • Calicut Medical College, Calicut University
	MD: Community Medicine (2007-2010) • AFMC, Pune; Maharashtra University of Health Sciences
	DNB: Preventive and Social Medicine (2010) • National Board of Examinations (NBE)

CURRICULUM VITAE: DR ANAND N

Awards and Achievements	• Recipient: Lieutenant General JC Chatterjee (Retd) silver medal for securing first position in Basic Medical Sciences capsule • Recipient: Merit Certificate for third rank overall in MD Community Medicine University exam by Maharashtra University of Health Sciences • Cleared-passed DNB (PSM) examination in first attempt • Contributor: 'Standard Treatment Guidelines (STG)' and 'Textbook of Public Health and Preventive Medicine' developed by AFMC Pune in collaboration with MoHFW, GoI & WHO Country Office-India. • Recipient: Best Meritorious research paper award in Community Medicine and allied subjects: by Armed Forces Medical Research Committee (AFMRC) under aegis of DRDO • Recipient: Commendation by Vice Chief of NavalStaff • Recipient: Commendation by Chief of Naval Staff • Nodal Officer: Telemedicine Project Indian Navy • Team Leader: Indian Navy Medical Assistance Team (INMAT) for Covid control in Comoros, an island nation in Indian Ocean Region • Member: WHO Legal Development Programme (LDP) for formulating legal framework for road safety
PhD Programme: The Journey	• June 2016: Initially Registered for PhD in Health Sciences at National Institute of Epidemiology • March 2018: Re-registered and joined at AMCHSS, SCTIMST

CURRICULUM VITAE: DR ANAND N

Publications	• A total of 21 publications in indexed journals • Original articles related to topic of road safety are as follows (publications based on doctoral research work are indicated in italics):- • ***Anand N**, Soman B, Prakash M. Epidemiological profiling of fatal road crashes in Puducherry, South Coastal India. Indian J Public Health. 2021 Apr-Jun;65(2):203-205. doi: 10.4103/ijph.IJPH_1436_20. PMID: 34135193.* • ***Anand N**, Soman B, Kumar S. Identification and analysis of fatal road crash black spot clusters in an urban setting in south coastal India. Med J DY Patil Vidyapeeth 2021;XX:XX-XX.* ***doi:*** *10.4103/mjdrdypu.mjdrdypu_344_21 (accepted for publication)..* • **Anand N**, Kotwal BA, Ilankumaran M. Determinants of injuries and Road Traffic Accidents amongst service personnel in a large Defence station. Medical Journal Armed Forces India [Internet]. 2017 Jul;73(3):216–21. Available from: http://dx.doi.org/10.1016/j.mjafi.2016.08.002.

CURRICULUM VITAE: DR ANAND N

Special Skills Related to RoadSafety	**Key Expert Resource Person : World Health Organization (WHO) Legal Development Road Safety Programme (LDP)** * Was selected as a member of World Health Organisation's Legal Development Programme (LDP) on Road Safety–Phase II, after a rigorous and competitive selection process. The LDP is a global program that focuses on developing legal and policy expertise among professionals with an aim to strengthen road safety legislation. * LDP in India started in 2017 and are presently working with various lawyers, academicians, journalists, policy professionals and road safety experts to strengthenroad safety legislation, both at the central and state level. As part of the LDP in India, the Ph D scho la r was trained for drafting policy papers and guidelines on various subjects connected to road safety. * He also actively participated in the following technical sessions of Phase II of the program held in New Delhi: Induction Workshop: July 28, 2018, Technical Workshop I: Oct 5-6, 2018. Technical Workshop II: Nov 30 – Dec 1, 2018. * Considering the valuable contribution made and active participation of the PhD scholar as a key resource person in the series conducted in phase II of the program in 2018, WHO- LDP selected him to participate in the induction and technical workshops as part of phase III of the program which was held in 2019. He attended the induction workshop held in New Delhi from 19-21 July 2019. * Thus, the PhD student acquired and built comprehensive capability in the sphere of road safety by interacting with experts in multifarious related fields, like lawyers, policy makers and implementers, in the spheres of public health, engineering, insurance etc.,.He g ained valuable knowledge and insights on multifarious aspects of road safety, which enabled higher quality o u t c o m e s of research on road safety, undertaken as part of the PhD program. * Was part of team which drafted White Paper on the topic of `Designing safer roads through a lead agency'. The white paper has been submitted to WHO for perusal and publication thereon.

CURRICULUM VITAE: DR ANAND N

Conferences/ Workshops/ CME/ Presentations	Participated/ presented in many conferences/ CMEs/ workshops. Those related to topic of road safety are as follows (ones based on doctoral research work are indicated in italics):- ▪ *Delivered e-Poster Presentation titled 'Application of Safe Systems Approach for Fatal Road Crash Prevention : A Public Health Perspective' in the 65th Annual National Conference of Indian Public Health Association – IPHACON 2021 held in hybridmode from 23-26 September 2021 at JIPMER, Puducherry.* ▪ Delivered Poster Presentation titled 'User awareness and perception as key to optimising road safety: A primordial preventive approach' in the 14th World Congress on Public Health held at Kolkata from 11- 15 February 2015.
Miscellaneous Points Related to PhD programme	• Popularized the scientific topic of 'Road safety' was amongst school children by conducting two interactive sessions for class XI students of Higher Secondary School (Navy Children School) Kochi on 06 Oct 21. • Successfully completed the 'Road Safety Legislation Course' (online) conducted jointly by WHO and John Hopkins International Injury Research Unit (WHO Collaborating Center for Injuries, Violence and Accident Prevention) on 23 September 2018.

श्री चित्रा तिरुनाल आयुर्विज्ञान और प्रौद्योगिकी संस्थान, तिरुवनंतपुरम - 695 011, केरल, भारत
SREE CHITRA TIRUNAL INSTITUTE FOR MEDICAL SCIENCES AND TECHNOLOGY
TRIVANDRUM - 695 011, KERALA, INDIA
(एक राष्ट्रीय महत्व का संस्थान, विज्ञान एवं प्रौद्योगिकी विभाग, भारत सरकार)
(An Institution of National Importance, Department of Science and Technology, Government of India)
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Institutional Ethics Committee

(IEC Regn No. ECR/189/Inst/KL/2013/RR-16)

SCT/IEC/IEC-1655/DECEMBER-2020 19.12.2020

Dr Anand N
MD DNB (Community Medicine) A7-4 Jalvayu Vihar Shihab Thangal Road Panampilly Nagar Kochi -682036

Dear Dr Anand N ,
Thank you for submitting documents related to your proposal titled "**"An Epidemiological Study of Road Traffic Accidents in an Urban Setting in South India"** (IEC/IEC-1655)" to the IEC for review.
The following documents were reviewed:

1. Checklist
2. Covering letter addressed to the Chairperson, IEC, SCTIMST dated 03.11.2020 recommended by guide
3. TAC Approval
4. IEC Application Form
5. Full proposal
6. CV of Dr. Anand with TCMC registration number
7. CV of Dr. Biju Soman with TCMC registration number

IEC Recommendations

1. Please define the outcome measures for phase III of the study.
2. Explain how the output generated will be of practical use in different geo-spatial patterns.
3. Lighting of roads at night time and presence of traffic boards are important factors affecting road traffic accidents. Please mention if these are being captured in Phase III. If it not, mention it as a limitation.
4. As the data is being collected from one city only, please ensure that it is not generalised to the rest of the country by mentioning it in the limitations of the study section.

The following members of the Institutional Ethics Committee participated in the discussions held virtually on Dec 18 2020, at the offices and residences of the members

SL. No.	Member Name	Highest Degree	Gender	Scientific /Non Scientific	Affiliation with Institution(s)
1.	Dr. R V G Menon	M Tech, PhD	Male	Lay Person(Chairman)	No
2.	Dr. Rema M. N	MD	Female	Basic Medical Scientist	No
3.	Dr. Kala Kesavan. P	MBBS, MD	Female	Basic Medical Scientist	No
4.	Dr. K R S Krishnan	M.E., Ph.D.	Male	Medical Technology	No
5.	Dr. Harikrishna Varma PR	Ph.D(Materials Science)	Male	Medical Technology	Yes
6.	Dr. S S Giri Sankar	LL.M. Ph.D.	Male	Legal Expert	No
7.	Dr. Anand Kumar A	MD, DM	Male	Clinician	No
8.	Dr. Aneesh V Pillai	BA. LLB (Hons.), LLM, Ph. D, SET (Law)	Male	Legal Expert	No
9.	Smt. Sathi Nair	MA (English Literature)	Female	Lay Person	No
10.	Dr. P. Manickam	BSMS, MSc (Epid).,PhD	Male	Health Science Expert/ Social Scientist	No
11	Dr.Raman Kutty V	MD (Padiatrics), Mphil, MPH	Male	Health Science Expert/Clinician	No
12.	Dr. Harikrishnan S	MD, DM (Cardiology) DNB (Cardiology)	Male	Clinician	Yes
13.	Dr. Christina George	MD Psychiatry	Female	Clinician	No
14.	Mr. Satheesh Chandran	MSW, PGDPM	Male	Lay person/ NGO/ Social Scientist	No
15.	Dr. Mala Ramanathan	PhD	Female	Social Scientist (Member Secretary)	Yes

IEC Decision
The IEC approved the conduct of the study with the conditions listed under IEC Recommendations.

Remarks:

1. **The PI is required to self-certify that all the conditions required by the IEC have been fully and fairly met with. The declaration should include the listed IEC suggestions and the revisions made. A revised copy of the complete submission including the self-declaration should be submitted as a single pdf file to the email id of the Member Secretary – iec.mem.sec@sctimst.ac.in/iec@sctimst.ac.in**
   The study shall be commenced only after the submission of the revised protocols with the self-declaration.
2. 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.
3. There was no member of the study team 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,

Mala Ramanathan
Member Secretary, IEC

Brief Research Article

Epidemiological Profiling of Fatal Road Crashes in Puducherry, South Coastal India

Anand N[1], Biju Soman[2], Manivel Prakash[3]

[1]PhD Scholar (Health Sciences), [2]Professor and Associate Dean (Health Sciences), Achutha Menon Centre for Health Sciences Studies, Sree Chitra Tirunal Institute for Medical Sciences and Technology, Thiruvananthapuram, Kerala, [3]Assistant Professor, Department of Community Medicine, Indira Gandhi Medical College and Research Institute, Puducherry, India

Summary

Road crash fatalities form leading cause of deaths in India. Streamlining road crash data systems are essential for building robust prevention strategies. This study explores epidemiological profile of fatal road crashes in a south Indian urban setting. Between April and June 2019, secondary data on fatal road crashes in Puducherry district for 3-year period (2016, 2017, and 2018) were accessed from traffic police records and analyzed. Raw data accessed in descriptive format was converted to analyzable objective format by self-developed data extraction template. 154 fatal crashes happened in Puducherry during this period. Most victims were males (85.7%), in productive age group (41.5%), with higher rates in monsoon and winter seasons (35.1% each), during evening-to-night hours (41.6%), and during weekends (42%). Most offenders (91.2%) were men, elder than victims, with heavy motor vehicles (91.2%) being the culprit vehicle. Rash driving led to most deaths (53.2%).

Key words: Epidemiology, fatal crashes, profile, road traffic

Road crashes are a significant public health problem, causing 1.5 million deaths and 5 million injuries annually worldwide. In spite of many control measures adopted, fatalities continue to rise, especially in low- and medium-income countries which account for 90% of all road traffic casualties.[1] Road crash fatalities, presently the seventh leading cause of mortality worldwide, are expected to become the third leading cause by 2030, if present trends continue. Approximately 1.5 lakh deaths and 4.5 lakh injuries annually result from road crashes in India. "Vulnerable road users," i.e., pedestrians, cyclists, and two-wheeler users, bear the brunt of fatalities.[2] This calls for radical change in preventive strategies.

The focus of road safety strategies is changing from Haddon's matrix, to "Safe Systems Approach," which considers people's vulnerability to serious injuries in road crashes. Therefore, systems and processes must be designed to be forgiving of human error. While crashes cannot be completely eradicated, postcrash deaths are preventable. In this approach, data system management is oriented around objective, action-oriented models for operational and translational usage.[3] Studies exploring the major epidemiological features of road crashes under a single gamut will enrich road safety data systems.

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This study aimed to create epidemiological profile of fatal road crashes in an urban south Indian setting. Fatal road crash was defined as "Any road traffic crash resulting in a person killed immediately or dying within 30 days as a result of the crash." Epidemiological profile was defined as "outline description of epidemiological facets (frequency, distribution, determinants, and preventive modalities) of a public health problem, to aid in prioritization of interventions and provide policy guidance for stakeholders."

A cross-sectional study was carried out between April and June 2019, wherein traffic police records of all fatal road crashes under South Traffic Police Station, Puducherry, over 3-year period (2016, 2017, and 2018) were analyzed. These raw data were mainly in alpha-numeric format/descriptive terms and

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had many variables related to road crash epidemiology. Data extraction template was applied onto these data, wherein it was converted into analyzable/objective format. Epidemiological profile of fatal road crashes in the setting was analyzed subsequently using this objective format.

Ethical clearance from the Institutional Ethics Committee of research institute and administrative approval for access to records from concerned authorities in study setting were obtained. Confidentiality of study participants was maintained, since only anonymized records were analyzed. Data were entered in MS Excel and analyzed using R software.

A total of 154 fatal road crashes occurred under jurisdiction of South Traffic Police station from 2016 to 2018. Maximum deaths (56) took place in 2017. Most victims were males (85.7%). Predominant proportion of deaths (41.5%) was in productive age group (16–45 years), while children and adolescents <15 years formed the smallest age group (4.5%) of victims. Mean age of alleged offenders (32.6 years, standard deviation [SD]: 9.9 years) was less than that of victims (48.3 years, SD: 18.2 years). Age of victims ranged from 7 years (youngest) to 80 years (eldest) while that of alleged offenders ranged from 17 to 56 years.

Monsoon and winter seasons witnessed equal share of fatalities (35.1% each). Most fatal crashes happened in evening-to-night hours (41.6%), with least in morning hours. Most fatal crashes (42.3%) took place in weekends, followed by week beginning (30.6%); middle days of a week (Wednesday, Thursday, and Friday) witnessed 27.1% of all fatal crashes.

Most victims (98.7%) were vulnerable road users, i.e., pedestrians and two and three-wheeler users. Pillion riders (85.6%) formed the largest group of victims as per vehicle occupancy distribution. 91.2% of alleged offenders were men (91.2%). Offending vehicle data were available for 126 fatal road crashes; of which nearly two-fifths (39.7%) were due to heavy motor vehicles, while more than one-third (34.1%) were caused by two wheelers. Nearly, two-fifths (40.3%) of offenders were in middle age group (31–45 years) while under one-third (31.2%) proportion were in 16–30-year age group. Tables 1 and 2 depict epidemiological profile of fatal road crashes both of victims and alleged offenders.

Rash driving was the most important risk factor, being the cause in 82 out of 154 fatal crashes. More than three-fourths (79.0%) of this subgroup were due to rashness on part of the victims themselves. Overspeeding (43.3%) and negligent driving, i.e., not following rules (25.2%), were subdeterminants among this factor that led to most deaths. Nearly, one-third (32.2%) of fatalities resulted from victims not wearing helmet at the time of crash. Minor risk factors included no streetlight and speed breaker (1% each). 3% of road crash deaths were due to combination of rash driving while not wearing helmet.

Puducherry district, located in South coastal India, with a total population of nearly 9.5 lakhs is the largest of the four districts of Puducherry (union territory). Its traffic jurisdiction is divided into four zones: North, East, South, and West. We analyzed data from South Traffic PS as a representative sample. Study finding of male preponderance in fatal crashes is substantiated by many official reports and earlier studies on the participant, with males comprising 74.4%–90% of accident victims. On an average, males were 5.7 times more commonly involved than females in such fatal crashes. This could be due to more outdoor activity practices of males as compared to females.

Table 1: Epidemiological profile: Fatal road crash victims

Variable	No.s	Percentage
Gender		
Male	132	85.7
Female	22	14.3
Age (Yrs)		
<15	07	4.5
16-40	64	41.5
41-65	73	47.5
>66	10	6.5
Season		
Summer (including spring)	46	29.8
Winter (including autumn)	54	35.1
Rainy season	54	35.1
Time of day (Hrs)		
0001-0800	52	33.8
0801-1600	38	24.6
1601-0000	64	41.6
Vehicle type/Transport mode		
Vulnerable road user (Pedestrian/Bicycle/2-wheeler/3-wheeler)	152	98.7
>4 wheeler	02	1.3
Victim occupancy in vehicle		
Passenger (3 or 4 wheeler)	71	46.1
Other (Pillion rider/Driver (2 wheeler)	83	53.9
Total (for each variable)	154	100

Table 2: Epidemiological profile of alleged offenders in fatal road crashes

Variable	Numbers	Percentage
Gender		
Male	125	81.2
Female	12	7.8
Data not available	17	11.0
Vehicle		
2-wheeler	43	27.9
3 and 4-wheelers	38	24.7
>4 wheeler (heavy vehicle)	45	29.2
Data not available	28	18.2
Age (Yrs)		
<15	0	0
16-45	110	71.5
46-60	34	22.1
>60	2	1.2
Data not available	8	5.2
Total (For each variable)	154	100

Mean age of the victims in the present study was 32.6 years, a finding broadly validated by official reports.[4] However, few studies pegged the mean age of victim either higher[5] or lower.[6] Younger age has the risk-taking tendency which could be the probable explanation for this.

The present study found pillion riders formed the largest group of victims as per vehicle occupancy distribution, with 85.6% fatalities. Few studies support these findings,[5,7] whereas other studies have found that drivers are more affected as compared to pillion riders.[6,7] The current study observed that nearly two-fifths (39.7%) of the offending vehicle were due to heavy motor vehicles, which is similar to other study findings.[5,7,8] Misra *et al*. found that majority of the victims' vehicle was motorized 2 wheeler (53.4%) and the offending vehicle was four wheeler (39.3%).[7] This finding is very important as such impact could be very fatal.

Studies in variegated settings such as New Delhi, Himachal Pradesh, and Andhra Pradesh found results similar to this study, with respect to both timings and days of fatal road crashes, i.e., between late afternoon and evening until night, and more on weekends, respectively.[6,8,9] This is the time when vehicular congestion would be high in the city. This may also be expected since Puducherry is one of the popular tourist destination sites, especially for people from neighboring districts and states of Tamil Nadu, Kerala, Karnataka, and Andhra Pradesh, especially in weekends.

Overspeeding and rash driving, risk factors identified by this study, are also flagged as prime determinants by other reports.[2,4] Helmet use and seat belt use were found to be low in several studies.[5,8,9] Human factor as the most significant determinant (74.2%) in road crashes and injuries thereof (both fatal and nonfatal) is a finding supported by many reports and independent studies on the participant.[4,6,9]

The findings indicate need for proper implementation of road traffic regulations and creating awareness among drivers and pillion riders. Two features are unique to this study. They are: Firstly, comparison of age profile of victim with offender. Secondly, comparison of transport mode (vehicle) of victim with that of alleged offender. Limitations of this study were access/analysis of data from only traffic police one zone and the lack of a proper denominator in the form of data on nonfatal road crashes. Only traffic police records were analyzed, whereas that from other stakeholders (such as health department, insurance companies, and transport department) were not explored.

Lower age of offender compared to victims, and more heavy motor vehicles involved in crashes as culprit vehicle indicates that preventive modalities need to be focused around such findings, by analyzing minor variables of fatal crash epidemiological profile in such settings.

Raw data on fatal road crashes need to be captured in a standardized and readily analyzable format. Data processing cycle through the stages of raw data capture, collation, entry into software, analysis, computation of results and interpretation thereof, merits smoothening out, and streamlining between individual components and compartments. Deeper studies encompassing sociodemographic and clinical aspects of fatal road crashes under a single ambit will enable more robust road crash data systems, toward optimization of road safety in developing countries.

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Conflicts of interest

There are no conflicts of interest.

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AQ1 **Original Article**

Identification and Analysis of fatal Road Crash Black spot Clusters in an Urban Setting in South Coastal India

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ABSTRACT

Introduction: Deaths from road crashes form the leading cause of mortality in India. Streamlining road crash data systems are essential for building robust prevention strategies. This study explores objectivisation of fatal road crash data by spatiotemporal analysis (geographical information system [GIS] technology) in an urban setting in South India. **Aim:** To identify clusters of fatal road crash black spot clusters in an urban setting and to analyze crash-related variables in clusters. **Settings and Design:** Secondary data analysis of fatal road crashes in Puducherry. **Methods:** Fatal road crash data from 2016 to 2018 were collected from South Traffic Police records. Spatiotemporal analysis was done using GIS to map high-density locations (black spots); these were further grouped into clusters. Crash-related variables in each cluster were studied to identify profiles of crash victims, alleged offenders, and risk factors. **Results:** Raw data accessed in descriptive format were converted to analyzable objective format using a self-developed data extraction template. A total of 154 fatal road crashes occurred in Puducherry South during the study period. Total 11 black spots and 3 clusters were mapped. One particular stretch of National Highway witnessed maximum (59%) black spots. Clusters differed from each other for variables such as age (of both victims and causing persons), time of the crash, and causing vehicle type. Intercluster similarities were observed in the preponderance of males (82.3%), youth (mean age: 28.9 years), vulnerable road users (92.6%), rainy season (43.4%), and weekends (46.7%) witnessing most fatal crashes. **Conclusion-Recommendations:** Standardized, objective format for data capturing, and seamless mechanism for data processing are essential. The crash location is a key index variable for data systems, with the feasibility to superimpose other data layers. AQ4

Keywords: *Black spot, clusters, fatal crashes, road traffic*

AQ5 Introduction

Road "crashes" are no longer called "accidents" because they are neither "accidental" nor inevitable but result from preventable shortcomings, either by crash victim or road or vehicle.[1] The number of road crashes, consequent injuries, and deaths are on the rise, especially in developing countries. Nearly 1.5 million deaths and 10 million injuries result from road crashes worldwide. Deaths from road crashes, which presently form the seventh leading cause of mortality from all causes worldwide, are expected to become the third leading cause by 2030 if present trends continue.[2]

This problem is more severe in Low and Middle-Income Countries, which account for two-thirds of all road crash-related deaths the world over.[3] About 10% of all road crash deaths occur in India, with 1.5 lakh dead and 1 million injured annually. The younger age group form predominant victims (40% of deaths). Vulnerable road users, i.e., pedestrians, bicycle, and two-wheeler users,

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are the most victims (65%–70%).[4] It is a serious public health challenge due to rising deaths, injuries, and loss to gross domestic product (lost man-days and premature deaths).[5] In spite of multiple measures to stem the tide, road crashes and resultant morbidity-mortality continue unabated.[6]

There is a paradigm shift in prevention strategies for road safety. Earlier, Haddon's matrix (precrash, during-crash, and postcrash features) was used as a template to analyze factors responsible and to derive mitigation measures thereon.[7] Human factor, i.e., road user, was pivotal to analysis and primary to control plans. This strategy has been replaced by the "Safe systems approach," which recognizes the innate propensity of humans to commit errors on the road. It also acknowledges the frailty/vulnerability of the human body that leads to serious injury or even death when meeting with a seemingly trivial crash.[7,8]

The safe system approach aims to reduce deaths and severe injuries by focusing on nonhuman elements involved in road safety, such as road network, vehicle design, and traffic management.[9] Streamlining of road safety data is a vital element in this approach. Making road safety data system robust and objective is essential to render research operational and translational. To achieve this aim, the system calls for harnessing newer technology such as geographical information system (GIS). Marking the exact location and time of the crash as geocoordinates (latitude-longitude) using GIS is a good starting point in this direction. Such geospatially and temporally robust data make it possible to correctly pinpoint black spots (grouping of crashes). Consequently, mitigation measures can be focused on this specific density cluster area, thus optimizing available resources and enhancing the success of control measures.[10,11]

The present study aimed to map density clusters of fatal road crash black spots in an urban South Indian setting. It also aimed to analyze the characteristics/profile of crash-related variables in each cluster, to derive actionable inferences.

Methods

Selection of traffic zone for study

From a total of four traffic police zones in Puducherry (South, East, North, and West), data on road crash fatalities in Puducherry over a 3-year period (2016–2018) were accessed from traffic police department records of South traffic Police zone; this zone was selected as sample area for the study, because it was the most representative, being the largest in terms of both road network density and vehicle traffic density. These facts emerged from preliminary discussions with traffic police authorities and on scrutiny of department records.

Creation of fatal crash inventory

Since the raw dataset was available in the descriptive format, a data extraction template was used to convert it into a dataset for carrying out spatiotemporal analysis. From this raw dataset, variables relevant to the geospatial and temporal analysis of fatal road crashes were extracted using a data extraction template and GIS-based software. For instance, the crash date in raw dataset was mentioned in the alpha-numeric format as "30th of November 2017," which was not readily suitable for geospatial analysis. Therefore, it was first converted into a standard objective format (i.e., November 30, 2017). Similarly, the fatal crash location was observed to be not amenable to analysis as such, so the details were entered into open street map plug-in of QGIS software and converted into corresponding geographic coordinates. Finally, all fatal crash location and time details were manually verified and entered into the QGIS software program using the above-mentioned method. This created a vector (geospatial) dataset in GIS, wherein each point represented one crash location. This enabled a snapshot view of the distribution of fatal crashes in that area.

Construction of heat raster image

Subsequently, from this vector dataset, a heat raster image was developed using Kernel Density Estimation (KDE) method, wherein fatal crash location data were depicted as grid matrices. KDE is a nonparametric method of data analysis using a continuous probability density in one or more dimensions.[6] The heat-map appearance depends on the density of dots/points, with each raster cell having a particular density value. The radius around a given dot determines the distance around that point where the influence of the point will be felt. Thus, the density spread of fatal road crashes from geospatial and temporal perspectives (over a period of time in that particular area) could be assessed and captured pictorially. Further, a KDE plot was used for the graphical depiction of spatiotemporal distribution of fatal crash locations. The KDE plot is a method for visualizing the distribution of observations in a dataset analogous to a histogram.

Generation of fatal road crash black spots

Thereafter, fatal road crash black spots were identified from locations mapped on the heat-map raster grid image. Based on their density, such black spots were further grouped into clusters. Black spots were coded as B1, B2, B3 and clusters as C1, C2, C3, and so on. The code for the first black spot in cluster 3 was C3B1 and for the second black spot of cluster 2 was C2B2, and so on. The schema of the method adopted is shown in Figure 1.

Analysis of variables in each cluster

Finally, characteristics of each cluster (profile) were analyzed using MS Excel, wherein variables pertinent to fatal road crash (such as age, gender, the vehicle of both victims and alleged offenders) were studied.

Operational definitions

For the purpose of this study, a fatal road crash was defined as "Any road traffic crash resulting in a person killed immediately or dying within 30 days as a result of the crash."[12] The black spot was defined as "road stretch of about 500 m in length in which either five accidents involving any fatalities took place during last three calendar years, or ten fatalities took place during last three calendar years."[13] Spatiotemporal analysis was defined as "collation, input, processing, and output of data to derive inferences regarding their spread/distribution over prespecified space and time framework."[14] A cluster was defined as a group of events (fatal crashes, in this case) that are positioned or occur closely together.[15] Vector images are "lines, shapes, and other graphic image components stored in a format incorporating geometric formulas for rendering the image elements." Raster (or bitmap) is an array or map of bits within a rectangular grid of pixels or dots.[16] The heat map represents data in the form of a map or diagram in which data values are represented as colors in incremental terms of color intensity.[17]

Results

In the 3-year period (2016–2018), 154 fatal road crashes took place in the South traffic police area. By following the clustering process, 11 black spots and 3 clusters emerged. Cluster 1 had four black spots; cluster 2 had three, and cluster 3 had four black spots. One particular stretch of road (National Highway) running in a South-South Westerly direction from Puducherry to Cuddalore accounted for most black spots (59%) and resultant clusters. There was a slight variation in the distribution of black spots, both within clusters and between clusters. The location of most dense clusters also varied from year to year. In 2016, cluster 3 (in the South-Eastern part of the whole grid) had a maximum number of black spots. However, in 2017, cluster 2 at the East Central part of the grid was the densest in black spots. In 2018, cluster 1 at North-Eastern part of the grid reported maximum black spots. Timeline distribution of fatal road crash black spot clusters in South Traffic Police Station (PS) jurisdiction from 2016 to 2018, both year-wise and consolidated, is shown in Figure 2.

Heat-map images of black spots and resultant clusters (developed using the KDE method) revealed a more objective estimate of crash density and black spot cluster distribution. It helped validate the findings previously arrived at, in that the densest cluster in 2016 was in the South-Eastern part of the grid, while in 2017, the East Central part of the grid formed the densest

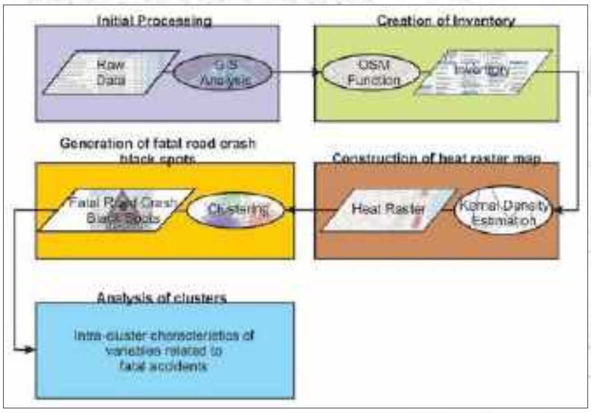

Figure 1: Schema of methodology adopted in the present study

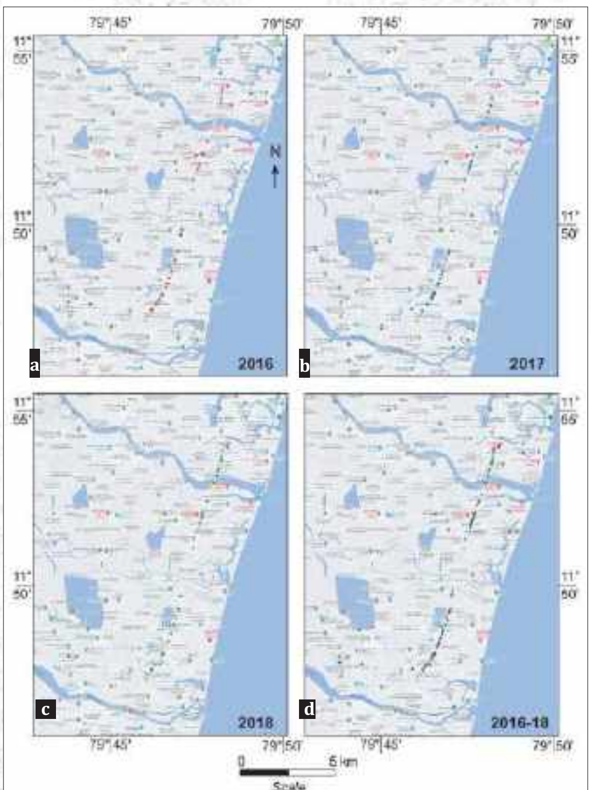

Figure 2: Fatal road crash black spots under Puducherry south traffic police station limits (a) 2016, (b) 2017, (c) 2018, (d) 2016–2018

cluster, and in 2018, North-Eastern part of the grid witnessed most black spot clusters. Other roads in the South PS area were the least affected, with around 2.5% of fatal road crashes. Heat-map image of fatal crash black spot clusters, depicting density distribution for the 3-year study period (both year-wise and consolidated), is shown in Figure 3. The geocoordinates (latitude and longitude) of individual clusters that accounted for densest black spots in each study year and those of all clusters composite are shown in Table 1.

Black spot clusters differed from each other with respect to certain fatal crash variables while being similar in regard to certain other variables. Cluster 3 (densest in 2016) and cluster 1 (densest in 2018) had predominantly young victims (mean age: 24.6 years, standard deviation [SD]: 2.1 years), with alleged offenders being even younger aged (mean age: 21.7 years, SD: 1.9 years). Cluster 2 was characterized by slightly older age victims (mean age: 31.1 years, SD: 3.9 years) as well as alleged offenders (mean age: 24.8 years, SD: 3.0 years). While heavy motor vehicles (such as lorry and truck) were main causing vehicles in clusters 1 and 3, light-and-medium motor vehicles such as car, jeep, van, and minibus formed the single largest proportion (43.2%) of deaths in Cluster 2.

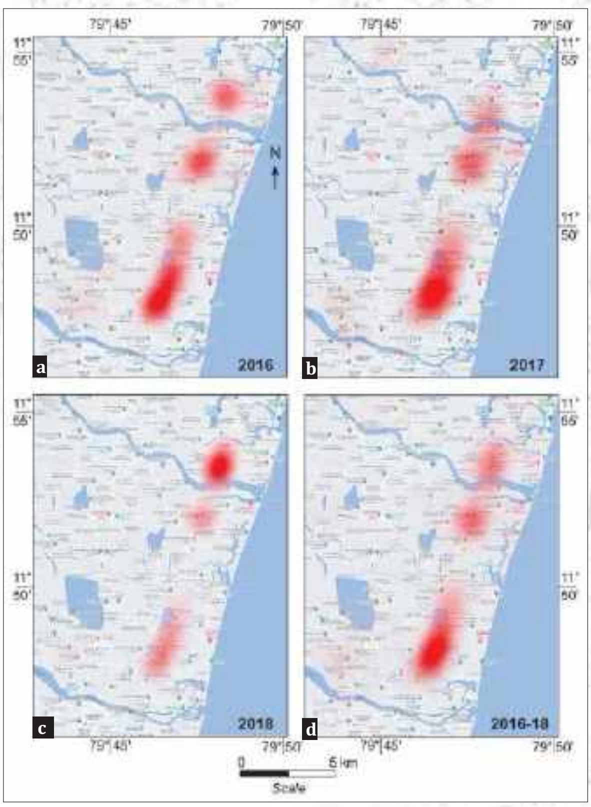

Figure 3: Black spot heat-map cluster of areas within Puducherry south traffic police station limits (a) 2016, (b) 2017, (c) 2018, (d) 2016–2018

Certain fatal crash variables exhibited a uniform pattern across all three clusters. Males were the predominant victims (range: 78.5%–85.4%) and most common alleged offenders (range: 90.0%–92.3%) in all clusters. Vulnerable road users formed a predominant subgroup (92.6%) of victims across clusters. Rash driving formed the most critical risk factor (range: 46.7% in cluster 2 of 2017%–60.7% in cluster 3 of 2016) for fatal road crashes. In all 3 clusters, most fatal crashes happened in the rainy season (range: 39.2% in cluster 3, 47.7% in cluster 1). Most crashes occurred only at weekends, irrespective of which cluster they occurred (range: 44.3% in cluster 3, 48.5% in cluster 1). Characteristics of individual black spot clusters are exhibited in Table 2.

DISCUSSION

Puducherry is the capital and largest city in the union territory of Puducherry. The area is divided into four traffic zones, namely North, South, East, and West, for road safety and traffic control. The number of road crashes in Puducherry was 1766 in 2016, 1693 in 2017, and 1597 in 2018. The corresponding number of deaths for these three years was 216, 208, and 204, respectively.[18] While both the number of crashes and deaths show a slight downward trend, there is much scope for further reduction in these incidences. Most common reasons enlisted by Puducherry police for road crashes, and resultant deaths in this setting include (a) over speeding, (b) drunken driving, (c) distractions to driver, (d) red light jumping (Signal violation), (e) avoiding safety gears such as seat belts and helmets, and (f) nonadherence to lane driving and overtaking in the wrong manner.[19]

The need for more profound research on road safety in developing countries has been highlighted by the World Health Organization, based on bibliometric analysis

Table 1: Geo-coordinates boundaries of fatal black spot clusters

Boundaries of Fatal Blackspot Clusters : Year-wise and composite			
Year	Boundary Direction	Latitude (North)	Longitude (East)
2016	South	11°.79'	79°.78'
	North	11°.83'	79°.78'
2017	South	11°.85'	79°.78'
	North	11°.88'	79°.79'
2018	South	11°.80'	79°.79'
	North	11°.90'	79°.80'
All 3 years (2016-2018)	South	11°.79'	79°.78'
	North	11°.91'	79°.80'

AQ13 **~~Table 2a: Characteristics of (fatal road crash) black spot~~ clusters - time-trend analysis**

YEAR		2016	2017	2018
Densest Cluster		CLUSTER 3	CLUSTER 2	CLUSTER 1
Cause/ Risk factor (%)	Rash driving (incl overspeeding)	**60.7**	**48.7**	**53.5**
	Drunken driving	11.2	23.5	20.6
	Not wearing helmet	20.4	23.1	19.8
	Not wearing seatbelt	2.5	1.5	1.6
	Road factor	3.6	3.4	3.7
	Vehicle factor	1.6	2.0	1.8
Day (%)	Week start	27.1	26.1	26.6
	Week Middle	28.6	27.6	25.0
	Week End	**44.3**	**45.1**	**48.5**
Time of Day(%)	0001h-0800h	32.7	**46.8**	24.5
	0801h-1600h	22.3	21.1	**45.7**
	1601h-0000h	**45.0**	32.3	29.9
Season (%)	Summer	21.8	25.9	30.1
	Rainy Season	**39.2**	**45.6**	**47.7**
	Winter	**39.2**	29.0	22.2

of injury in the South-East Asia Region. This region, home to over one-fourth of the total world population, accounted for <1% of global research in the sphere of injury (including those due to road crashes), as revealed by situation analysis of the current status of violence and injury. Subtopics of "safer vehicles" and "postcrash response" documented very limited research.[20]

Traditional research on road safety has focused on road users as the primary unit of analysis, wherein age, gender, behavior, and other characteristics of victims have been scrutinized for drawing inferences. Road factors and vehicle determinants have been taken as secondary variables in research.[21] However, in recent years, there is a marked shift in the focus of road safety research. System analysis (road network, traffic management, and vehicle features) has taken precedence, mainly because of two reasons. First, due to the realization, humans are naturally prone to commit errors while on the road. Second, the innate fragility of the human body renders it vulnerable to serious injury/death even when it meets a seemingly normal/innocuous crash.[22]

A robust road crash data framework mechanism is an integral part of the systems approach to road safety. Objectification of road crash data by collecting quantitative variables amenable to analysis is the way ahead. Replacing individual road users, whose data were collected primarily earlier, now the emphasis is on crash location data as the primary variable. Date-time and crash location give a bird's eye snapshot view of density, distribution, and time-trend of crashes.[23] Harnessing newer technology of capturing geospatial data in a GIS environment is an invaluable tool in this context.

GIS framework mechanism offers collecting, collating, and analyzing data. Rooted in principles of geography, it can integrate multiple yet diverse data and provides the capability to connect previously unrelated information through a common platform, namely location as "key index variable."[24] Locations and extents, called geographic coordinates, of Earth, captured in terms of date-time in x, y, and z coordinates, are the main parameters utilized in this study.[25] Alam and Ahsan observed that GIS is a valuable tool to generate maps that give clear, quick impression of crash distribution in the road network, thus identifying areas with high concentrations.[26] Rodrigues *et al*. developed a model for the classification of road traffic networks based on their indexation and classification in a GIS environment.[27] Two independent studies, by Turton and Openshaw[28] on the one hand and by Pino-Díaz *et al*.,[29] validated/reaffirmed the potential of GIS in facilitating pattern discovery of geospatial clusters of road crashes.

Many studies have concluded that KDE is the most reassuring among numerous tools available for incorporating changing geographic point pattern in determining road crash black spots.[30,31] Its main benefit over other methods is that it defines risk of crash extent, rather than crash location only *per se*. Sun *et al*. mention that KDE procedure involves placing asymmetrical area (kernel) over each crash point and calculating distance between this point and a reference location based on mathematical function. Subsequently, similar values computed for all areas in a particular grid are summed up. The process is repeated for successive points. Finally, the total of individual kernels gives an estimate of road crash distribution.[32]

The most critical parameters for KDE are bandwidth and cell size. This study arrived at a bandwidth value of 500 m and a cell size of 500 m, based on many sequential tests on point density using geospatial analyst tools.[33] In her study on KDE and K-means clustering to profile road accident hotspots, Anderson TK had employed similar methodologies to classify crashes into black spots, then into clusters, and finally into groups.[34]

Studies in different settings have reported results similar to this study regarding more crashes on weekends.[35-37] This is the time when vehicular congestion would be dense in the city. This may also be expected since Puducherry is one of the popular tourist destination sites, especially for people from neighboring

~~Table 2b: Characteristics of (fatal road crash) black spot~~ clusters - time-trend analysis

BLACKSPOT CLUSTERS AND THEIR CHARACTERISTICS: 2016-2018
TRAFFIC PS SOUTH, PUDUCHERRY

YEAR		2016	2017	2018
Densest Cluster		Cluster 3	Cluster 2	Cluster 1
Victim Age (%)	<25 yrs	43.7	32.6	48.1
	26-50 yrs	34.7	45.6	30.9
	>50 yrs	21.6	21.8	21.0
Offender Age (%)	<25 yrs	56.8	43.5	55.6
	26-50 yrs	33.2	40.4	38.7
	>50 yrs	10.0	16.1	5.7
Victim gender (%)	Male	78.5	81.2	85.4
	Female	21.5	18.8	14.6
Offender Gender (%)	Male	91.3	92.3	90.0
	Female	8.7	7.7	10.0
Victim vehicle /transport mode	Pedestrian	36.1	38.9	29.2
	Bicycle	26.2	27.6	37.9
	Motorised 2-wheeler	26.3	28.0	19.6
	3-wheeler	2.2	1.8	4.5
	4-wheeler (Light/Medium Vehicle)	6.5	3.7	6.6
	> 4-wheeler (Heavy vehicle)	2.7	1.1	2.2
Offending Vehicle (%)	2-wheeler	10.0	19.9	17.6
	3-wheeler	22.6	12.2	21.9
	4-wheeler (LMV-MMV)	33.2	43.2	21.9
	> 4-wheeler (MMV-HMV)	34.4	25.7	38.6

districts of Tamil Nadu and other states of South India. Overspeeding and rash driving as risk factors identified by this study are also flagged as prime determinants by findings of epidemiological studies done by Radjou *et al.* in a regional trauma center at Puducherry and by Misra *et al.* in patients attending Emergency Departments of a Trauma Centre in New Delhi. Helmet use and seat belt use were found to be less in several studies.[38,39] Human factor as the most significant determinant in road crashes and injuries thereof (both fatal and nonfatal) is a finding supported by many reports and independent studies on the subject.[40,41]

Raw data for this study were available in descriptive (alpha-numeric) format. Developing an extraction template to convert this data type into an objective format is a unique feature of this study. However, the lack of data on other layers (such as the location of schools, liquor shops, hoardings, speed breakers, and potholes) related to road crashes is a limitation of the study. Nonavailability of data on nonfatal injuries (simple and grievous) is a limitation in interpreting findings, for want of a valid denominator. Only traffic police records were analyzed, whereas that from other stakeholders in road crash data systems (such as the health department, insurance companies, transport department) could not be analyzed.

Conclusion-Recommendations

Findings indicate the need to have a standardized, objective format for data capturing, and a seamless mechanism for data processing. The crash location needs to be kept as a key index variable for data systems, with the feasibility to superimpose other data layers (such as the location of schools, liquor shops, and markets) on top of this primary layer. Traffic police data need to be synced with data from other stakeholders in road safety (such as insurance agencies, transport department, health, and legal). Heavy vehicles are the main culprits, and alleged offenders of crashes are younger than victims. Therefore, the focus of preventive strategies can be revolved around such findings. Existing resources for fatal road crash prevention can be concentrated on black spots and clusters to derive optimal outcomes.

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Conflicts of interest

There are no conflicts of interest.

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1 INTRODUCTION