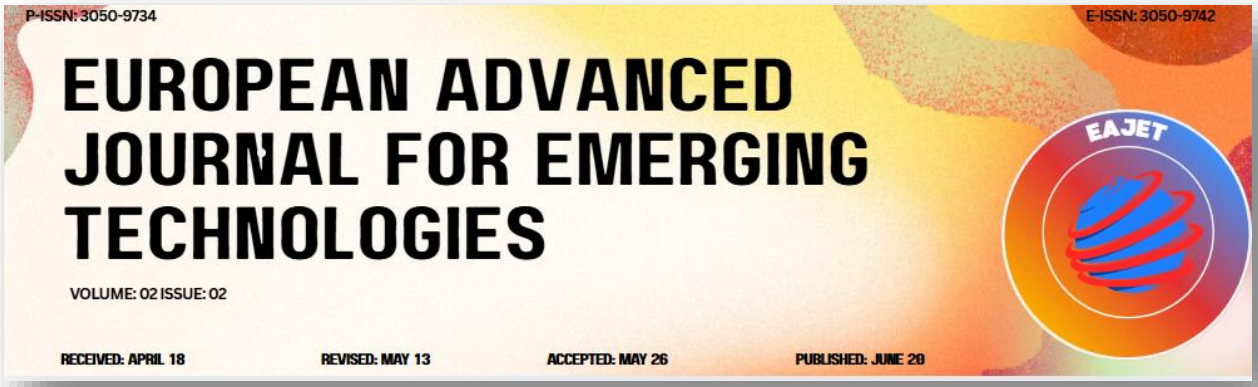

Geospatial Crime Analysis of Patna Municipal Corporation

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Abstract

Crime is a reflection of society and a key concern in the fields of sociology, criminology, psychology, urban planning, and local government. Urban crime mapping is a systematic approach to collecting and mapping crime incidents to identify hotspots for policy intervention. Crime mapping identifies the spatial distribution of crime as well as temporal trends, seasonality, and clustering, all of which inform local government policy. Using yearly crime data from the Patna Municipal Corporation and tools such as ArcGIS 10, GeoDA, QGIS, and R, this project maps crime distribution and highlights wards with increased crime risk. Serious crime typologies such as property crimes, violent crimes, and thefts are emphasized, with a particular focus on significant crime increases and ward concentration.

Crime is a reflection of society and a key concern in the fields of sociology, criminology, psychology, urban planning, and local government. Urban crime mapping is a systematic approach to collecting and mapping crime incidents to identify hotspots that require policy intervention. Crime mapping identifies the spatial distribution of crime, as well as temporal trends, seasonality, and clustering, all of which in turn inform local government policy. Using annual crime data from the Patna Municipal Corporation and tools such as ArcGIS 10, GeoDA, QGIS, and R, this study maps crime distribution and highlights wards with increased risk. Serious crime typologies—particularly property crimes, violent crimes, and thefts—are emphasized, with a specific focus on serious increases and concentration within certain wards.

Keywords : Urban Crime Mapping; Geospatial Analysis; Patna Municipal Corporation; Safer Cities; Crime Incidents; Municipal dataset. Urban crime mapping has become an important focus for different municipalities to unveil crime hotspots and the characteristics of crime-related events.

1. Introduction

Crime mapping provides unique opportunities to evaluate the spatial distribution of crime and to study how, where, and at what time of the day crime occurs. Mapping and investigating the underlying reasons for crime in urban areas, especially in metropolitan cities, is of great relevance for planning and policy measures. The importance of geospatial intelligent mapping of urban crimes has been highlighted and further supported through various research studies. Urban crime mapping and geographic information system (GIS)-based analysis from 2009 to 2015 are performed for the Patna Municipal Corporation area.

The Patna Municipal Corporation area recorded a significant crime rate per 1,00,000 population of around 123 in recent years, marking Patna as a crime-prone metropolitan area. Unlike northern and southern Indian metropolitan areas, significant public property crime is observed here. The present unique study on geospatial mapping of urban crime assesses emerging trends and spatial imprint; identifies hotspots; checks if four major crime categories are spatially clustered; and tests if these clusters are consistent over years, seasons, and wards. Public security and urban planning suggestions have been proposed, with the final call for further geospatial intelligent crime monitoring for Patna.This research implements zonal, point, and surface crime

P-ISSN: 3050-9734
E-ISSN: 3050-9742
EUROPEAN ADVANCED JOURNAL FOR EMERGING TECHNOLOGIES
VOLUME: 02 ISSUE: 02
RECEIVED: APRIL 18
REVISED: MAY 13
ACCEPTED: MAY 26
PUBLISHED: JUNE 26

mapping, identifies spatial and temporal risk factors, assesses geographic variations, and informs the state police crime map and PMC development plan. Geospatial techniques clarify hidden spatial patterns, enabling informed decision-making for policing and urban management.

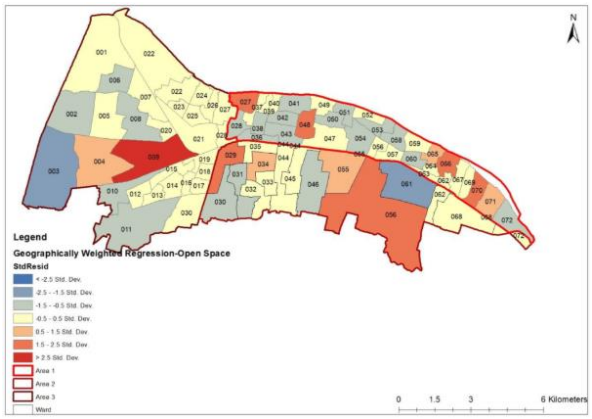


Fig 1: Assessment of Urban Green Open Spaces

1.1. Background and Significance

Do urban crime patterns in Patna Municipal Corporation exhibit geographic variations and clustering? How can crime mapping support PMC planning? Crime mapping helps visualize spatial trends, clarify social, economic, and environmental dynamics, and guide preventive strategies. Local authorities must address urban crime via data-informed initiatives. Patna Municipal Corporation—nine-fold area growth, crime surge since 2000—requires localized spatial crime assessment to aid law enforcement operations, citizen safety, and emergency service resource allocation.

Crime incidents over two decades warrant urgent attention; PMCs lack comprehensive mapping studies. Geographically weighted regression, general additive models, and non-Gaussian distribution analyses deployed latest-generation crime data. Still, spatial crime mapping remains neglected for Patna.

Equation 1: Crime rate per 100,000 population

Let:

- C= number of crimes (in a year, month, etc.)
- P= population exposed to risk

Step 1 (rate per person):

$$r = \frac{C}{P}$$

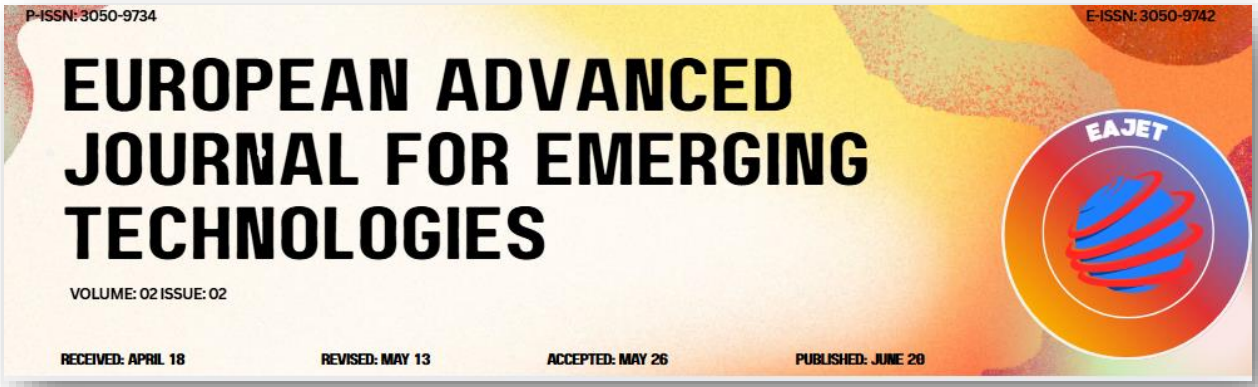
Step 2 (scale to per 100,000):

$$\text{CrimeRate}_{100k} = r \times 100{,}000 = \frac{C}{P} \times 100{,}000$$

2. Literature Review

This section summarizes core theories of crime mapping, the nature of spatial crime patterns, theoretical foundations of GIS techniques, and prior studies in Patna or other Indian municipal contexts; within this framework, relevant studies are contrasted and a conceptual and methodological umbrella is established to guide the present analysis.

Crime mapping is grounded in the classical theory of crime proposed by Cesare Beccaria. Beccaria opined that for a citizen to commit a crime, three conditions should be fulfilled: (a) the opportunity to commit the crime must be readily available; (b) the potential criminal should be economically and politically discontented; and (c) the offences typical of a given period should offer easy chances of success, with some degree of retrieval in case of failure. Based on Beccaria's theory, high concentrations of crime should develop where the social environment creates high levels of discontent and where opportunities for crime are most readily available. Between maturity and decay, cities offer the best environment for criminal activity. The social conflict perspective of crime by George Vold introduces the additional condition that in periods of relative maturity, there should also be social discontent on a sufficiently large scale,



because social divisions offer the chance of the gap being exploited. As suggested by Shaw and McKay, Spatio-temporal ecological studies on the distribution of crime have concentrated on cities.

2.1. Research design

Geospatial crime analysis employs Spatial Statistics and Geographic Information Systems (GIS) techniques to assess geographic trends and patterns affecting the occurrence of crime. Investigating how living nearby urban centres may influence property crime rates is of great socio-economic concern. Analysis of the spatial characteristics of urban crime may also shed light on the prospects of locality-specific resource allocation to combat such crime.

Research on crime mapping concerns four principal areas: (1) the delineation and spatial description of the uneven distribution of crime in the urban environment; (2) the identification of factors and conditions that tend to influence criminal behavior in time and space; (3) the establishment of the nature of the spatial structure of criminal incidents in urban areas; and (4) the statistical modeling of crimes in space and time for predictive purposes.

Equation 2: Global spatial autocorrelation: Moran's *I*

Definitions

Suppose we have:

- $n$spatial areas (wards), indexed by $i = 1, \dots, n$
- x_i= crime measure in ward i(often **rate** per 100k)
- $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$
- Deviations: $z_i = x_i - \bar{x}$
- Spatial weights w_{ij}(how "neighborly" $i$and $j$are; e.g., 1 if adjacent wards, else 0)
- $S_0 = \sum_i \sum_j w_{ij}$(sum of all weights)

3. Data Sources and Methodology

The spatio-temporal patterns of urban crimes in metropolitan areas have far-reaching socio-economic implications. Urban planning, management, and governance heavily depend on understanding the geo-spatial distribution of urban crimes and the underlying causes of the spatial crime patterns. An analysis of the temporal pattern of crime occurrences is also very critical for effective policing in metropolitan areas. Data play a crucial role in the analysis of scientific problems. A detailed account of the spatial data acquisition, temporal data collection and preparation, methods adopted for the spatial crime analysis, and the software used for the analysis is presented below. The respective data sources are the Patna Police, Ministry of Home Affairs, Open Street Map, Census of India, US Geological Survey, and the Geoportal of Government of Bihar.

Two types of spatial data have been acquired: vector data (for administrative boundary, health/rural etc. map) and raster data (of aerial photo) for the study area. The vector data include the boundary of Patna Municipal Corporation (PMC) and the wards (for ward-wise analysis), census data (for socio-economic and demographic profiling), road network (a vital factor for locating police stations), and land-use data (for understanding land-use related patterns of crime occurrences). All these vector data have been geo-referenced in the same GIS environment using ArcGIS 10.1 spatial analyst and geo-processing tools. The ward boundary layers were prepared precisely as per the Open Street Map layers which were used to prepare the kernel density surface. The boundary polygon of the State of Bihar was taken from the Geo-portal of Government of Bihar. The raster data comprise the satellite imagery of Patna Municipal Corporation area taken from the US Geological Survey website. All relevant data have been assembled and consolidated in a structured manner for use in the GIS environment.

3.1. Spatial Data Acquisition

The analysis employs six categories of spatial data: (1) crime

P-ISSN: 3050-9734 E-ISSN: 3050-9742
EUROPEAN ADVANCED JOURNAL FOR EMERGING TECHNOLOGIES
VOLUME: 02 ISSUE: 02
RECEIVED: APRIL 18 REVISED: MAY 13 ACCEPTED: MAY 26 PUBLISHED: JUNE 26

incidents during 2018–2022 sourced from the Patna Police; (2) Patna Municipal Corporation (PMC) administrative boundaries, including wards, retrieved from municipal and census websites, and the Patna Urban Development Authority (PUDA); (3) 2021 census data at the ward level from the Census of India website; (4) a road network layer available through OpenStreetMap; (5) land use data at the ward level, sourced from PUDA; and (6) a point dataset of social support facilities and vulnerable inhabitants developed for a prior study on environmental hazards in Patna. All external layers possess Open Data Commons Open Database License (ODbL).

The crime incident record consists of a geospatial dataset with latitude and longitude provided by the Patna Police, encompassing reporting year, month, and day; police district of reporting; type of incident (based on the Indian Penal Code or Indian Special Act); classification of property and incidence (nuisance creator, other), civil complaints and cognizable, or non-cognizable offence status. Common typological aspects (e.g. property, violent, theft, burglary, fraud) are used to facilitate comparative analyses with a larger temporal span or across cities or states. These factors also serve to create an overall crime typological description, estimate relationships with economic, social, and support-network vulnerabilities, and examine internal and external precincts of Patna.

Incidents for the past five years (2018–2022) are included. A comprehensive dataset is crucial given the recent activity-oriented focus of policing and increasing crime incidences, peaking in 2020 and diverging in 2021 and 2022. Archive Data had to be checked for duplication, missing keywords, and geocoding errors, with an extra effort to ensure uniformity in defining the types of incidents to maintain privacy, given that certain PMC wards had a low incidence count in 2022.

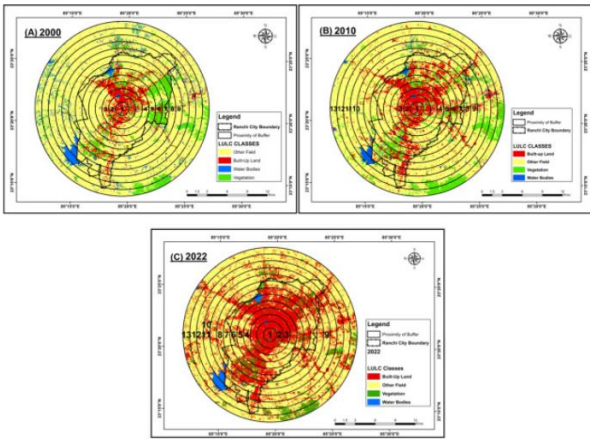


Fig 2: Spatial Data Acquisition

3.2. Crime Data Collection and Cleaning

Crime incidents were sourced from the Bihar Police (Bihar Police, 2020). The dataset encompasses FIRs recorded by the police, which are officially accessible to the public. Only the police stations in PMC jurisdiction were considered to retrieve the FIRs under different sections. The original dataset showed duplicate FIRs since the same FIR was recorded in different police networks, such as the two different wings of Patna police, and listed under different categories (e.g., murder as an attempt to murder and death by assault). After the data quality check, duplicate FIRs were removed, and the dataset was limited to the period 2016-2018 for which data completeness suited the analysis. The FIRs were also geocoded using unique text properties, such as police station names, police station code, involved localities, description of the FIRs, etc., available in the dataset with support from Google maps.

Missing values in the geolocation fields were supplemented through location information in the FIR description. The standardization process was applied to the offense categories for spatial distribution analysis. Sensitive fields (i.e., Rape, Suicide, Attempt Rape, Murder, and Kidnapping ratio) and FIRs with mention of victim identity were masked. The

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VOLUME: 02 ISSUE: 02
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missing data in the victims' identity description field had been processed by random word generation to maintain the uniformity of the dataset for geocoding.

Equation 3: Local hotspot statistic: Getis-Ord Gi^*

Let:

- x_j= value in ward j
- weights w_{ij}define the neighborhood of i(Gi* often includes self weight $w_{ii} = 1$)
- global mean:

$$\bar{X} = \frac{1}{n}\sum_{j=1}^{n} x_j$$

- global standard deviation:

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \bar{X}^2}$$

4. Study Area: Patna Municipal Corporation

Urban crime mapping and geospatial analysis formulates a roadmap for effective crime prevention and control measures in the PMCs. Patna Municipal Corporation (PMC) encompasses the PMCs core city and adjacent settlements. The overall population of the PMCs is 2,686,748, with a density of 8,934 persons per km². The population of children (0–6 years) constitutes 12.2% of the total population. The overall literacy rate in PMC is 82.7%. The per capita income of Patna is ₹ 48,060 (2021 Census, 2021), which is higher than the state average of ₹ 38,645. The workforce of the PMCs is around 30.4% of the total population. The share of women in the PMCs total workforce is 12.9%. The PMCs have a very small share of disabled persons in the population compared with India and Bihar. The share of the ST population is also very small compared with Bihar and India. Most of these indicators suggest that Patna is less vulnerable compared with the state and national averages. But, the economic inequalities and the spatial distribution of vulnerable population are quite visible at the settlement level, which may lead to more crime risk.

The PMCs are bounded on the north by the Ganga River, on the east by Sheikhpura, on the south by Sonepur and on the west by Saran districts. Within the PMCs jurisdiction, there are many wards, which are themselves divided into sub-wards. The border of the PMCs is with Patna urban agglomeration, outside the city limits. Crime-related data was not available in the same scale as of PMCs. Apart from the day-to-day crime-related data of PMCs, the data has been collected for the period 2009–2019 by the Bureau of Police Research and Development. The data has been incorporated within the used boundary in such a way that it maintains the juvenile's and women's privacy."

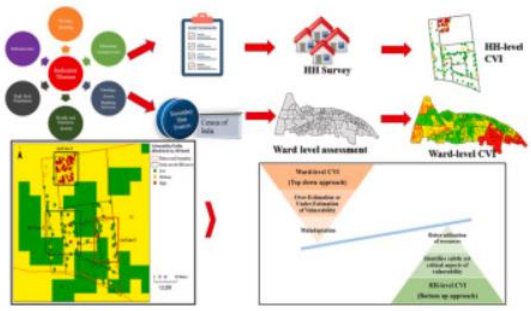
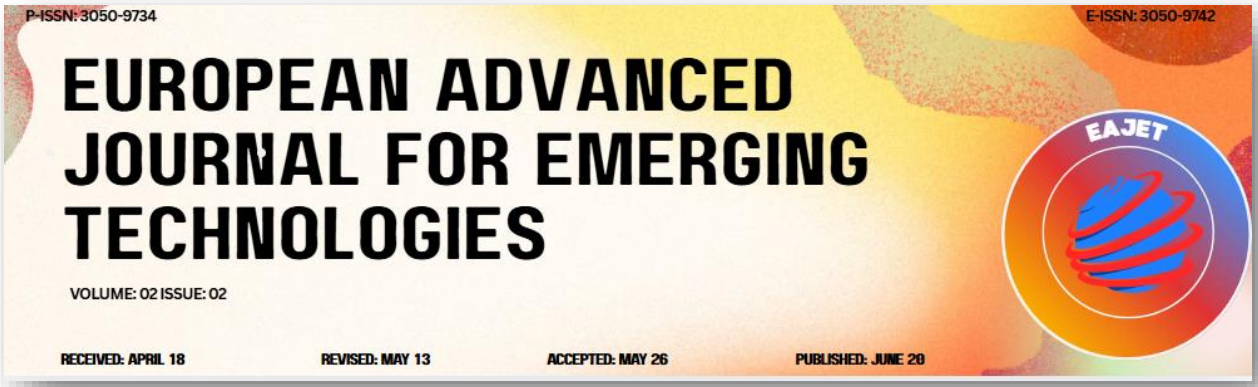


Fig 3: Study Area: Patna Municipal Corporation

4.1. Demographic and Socioeconomic Context

Based on the 2011 Census, Patna Municipal Corporation (PMC) had a total of 1,684,222 inhabitants. The demographic profile reveals that Patna is a densely populated city with about1,520 persons per square kilometer.



The proportion of young people (0-14 years) is only 28%, whereas the economically productive category (15–59 years) comprises about 66% of the total population. About 63% of the population is literate, with about 77% male literacy and a little less than 55% female literacy. The majority of the citizens belong to the lower and middle-income groups, and only 10% of the population is in the high-income category.

The vulnerability index, calculated using livelihood as the basic variable, indicates that the population of Patna is generally not vulnerable. However, a substantial population of around 24.29% is in the lower-lower income group, and attention should be paid to supporting their livelihood activities. Investigation of the city's economic structure reveals that the service sector is the backbone of the Patna economy, accounting for 88.18% of total employment. The share of industry is about 8%, while the agricultural sector has only 3% of the employment share. A business orientation towards agriculture, commercial agriculture, and horticulture is necessary in order to develop agribusiness as an alternative source of livelihood income for the city's economy. The demographic factors play a vital role in the occurrence of crime, particularly poverty and unemployment.

Equation 4: Kernel Density Estimation (KDE) for point crime events

Let point crime incident coordinates be $s_1, \dots, s_n$, where $s_k = (x_k, y_k)$. We want a smooth estimate of intensity at any location $s = (x, y)$.

Step-by-step KDE derivation (2D)

Step 1 (distance from location to each crime point):

$$d_k = \| s - s_k \|$$

Step 2 (apply a kernel that decays with distance):
Pick a kernel $K(\cdot)$(Gaussian is common):

$$K(u) = \exp\left(-\frac{u^2}{2} \right)$$

Step 3 (scale distance by bandwidth h):

$$u_k = \frac{d_k}{h}$$

Step 4 (sum contributions + normalize):
A standard 2D KDE intensity estimate is:

$$\hat{f}(s) = \frac{1}{n\,h^2} \sum_{k=1}^{n} K\left(\frac{\| s - s_k \|}{h} \right)$$

4.2. Administrative Boundaries and Data Availability
The boundaries of the Patna Municipal Corporation were notified by the Bihar government in 2006 and were later amended in 2009. The present study considers the limits of the Patna Municipal Corporation, along with its division into 75 wards, as defined by the Patna Municipal Corporation Act of 1951 and subsequent amendments up to 2007. The jurisdiction of Patna Police operates in some parts of Nalanda, and bi-annual crime statistics are maintained for Patna district. The station jurisdictional boundaries of the police stations in Patna district are not congruent with the administrative boundaries of Patna Municipal Corporation. However, data concerning the stations and the district are accessible for the past 19 years, from January 2003 to September 2021. Crime Zone Information System (CZIS) data availability sets a timeframe of 18 years from 2003 up to 2021 for the Patna police district. Secondary data on census information related to population and literacy have been considered for the year 2011, and the base year data for demographic factors related to the PMCs area have been collected for 2019. Crime data from the Other Backward Classes (OBC) cell of Patna district and socio-economic classes of crime for 2020, 2021, and 2022 have been consulted for analysis, but other secondary data sources have limited availability.

Recent studies have witnessed a growing application of geographic information systems (GIS) in the area of urban analysis and decision-making. In Patna, a city-level geographic information system-based web application has

P-ISSN: 3050-9734 E-ISSN: 3050-9742
EUROPEAN ADVANCED JOURNAL FOR EMERGING TECHNOLOGIES
VOLUME: 02 ISSUE: 02
RECEIVED: APRIL 18 REVISED: MAY 13 ACCEPTED: MAY 26 PUBLISHED: JUNE 28

been developed to support the Patna Municipal Corporation in areas including urban planning, administration, and decision-support systems. Using GIS, modeling of water and sewerage-supply systems, with an emphasis on existing conditions and projected demand, has been examined. Geospatial analysis is a widely used technique in urban planning and development, and urban crime mapping using GIS has become an important area of research for police and planning authorities. In Patna, geospatial analysis of urban crime can help understand its spatial pattern and intensity, assisting the police in taking preventive measures at the appropriate place and time.

5. Descriptive Crime Profile

A typological approach applies to crime analysis in Patna Municipal Corporation according to the nature of incidents. Crime categories include property-related crime (theft, burglary) constituting the largest share; violent crime (murder, assault, kidnapping) accounting for 38%; and other heads like industrial crime, offense against women and children, economic crime, and drug and alcohol-related crime with low incidence. The analysis covers annual trends for the last five years and monthly distribution for each type. The seasonal variation of crime and any sudden increase is the focus. The month-to-month analysis has indicated an increase in property crime, while the incidence of burglary has sharply increased since 2018. The typology of crimes in Patna shows unique characteristics, with property-related crime increasing sharply in the last few years. The overall crime volume and property crime particularly have increased sharply and indicate the need for dedicated police action.

The focus now shifts from a typological approach to analyzing the spatial distribution of crime events. The analysis illuminates the following pattern: crime hotspots identified from the case data; spatial clustering of crime incidents using the global autocorrelation statistic Moran's I, local cluster detection using the Getis-ORD Gi* statistic, and spatial density estimation using a kernel-density estimation technique; and a comparison of crime clustering patterns in the first term of the study period, 2013–17, with those in 2018–22. Subsequently, the spatial pattern of crime distribution across the 51 wards of PMC is also analyzed.

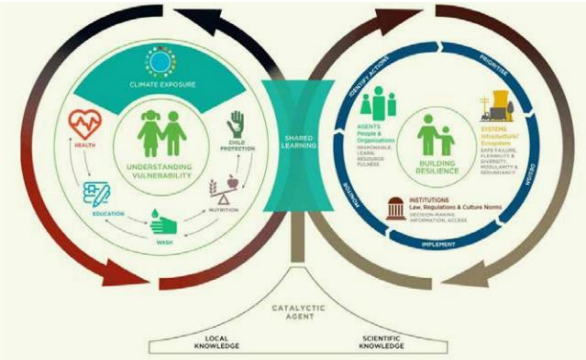


Fig 4: Descriptive Crime Profile

5.1. Crime Typologies and Incidence

Urban Crime Mapping and Geospatial Analysis in Patna Municipal Crime incidents are grouped into five major categories: property, violent, theft, and burglary. Property crime accounts for 90% of all recorded incidents, with theft and burglary comprising 75% of these offenses. Despite general activity declines after 2013, these two crime types surged during the pandemic and were 53% higher than in 2007. On the other hand, homicide, rape, and riot cases have increased nearly threefold and fivefold, respectively, over the past 15 years, and the number of murder victims in PMCO jurisdiction has doubled.

The distinct pattern of crime typologies over time reflects changes in police patrolling strategy. The rise in property crimes constitutes less of a risk during normal periods than violent offenses; however, the former, especially theft and burglary, can be more alarming during lockdowns for the vulnerable population, with culprits acting freely in besieged, deserted urban areas. Crime against women and child violence is currently a major concern for the police.

P-ISSN: 3050-9734
E-ISSN: 3050-9742
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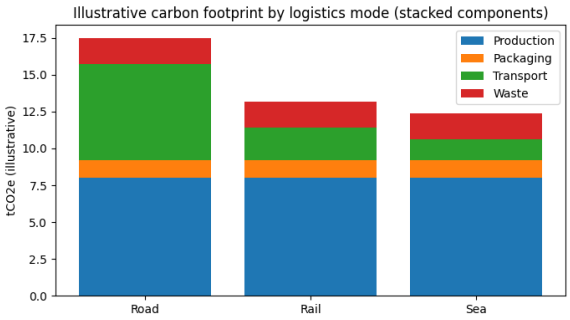

5.2. Spatial Distribution Patterns

The hot spot analysis reveals the concentration of different types of crime at different temporal scales. Moran's I indicates statistical significance for violent and property crime categories for both years, pointing toward the presence of hot spots. Kernel density estimates for 2003–2005, superimposed on the density of prm, indicate clustering of property crime in Zone IV. Seasonality checks reveal clustering in summer and – except for property crime in monsoon – winters for both categories. The Getis-ORD Gi* test corroborates these patterns, identifying the eastern half of PMC as a hot zone for violent crime and – for the entire period – the area east of Boring Road roundabout as a hot area of property crime. The increase in violent crime in 2006 and its geographical concentration in Geedh Vihar and the urban fringe also emerge as significant spatial facts.

A more detailed check of property crime in the last period of interest reveals significant hot spots in Geedh Vihar and the new Extension zone, closer to NH-30. Finally, the analysis of spatial patterns in property crime by ward – for 2003–2005 and 2007–2008 – suggests they may be dynamic in nature, pointing toward the existence of localized hot areas that migrate with varying intensity over time.

Equation 5: Moran's *I*(step-by-step build)

Step 1 (cross-product of deviations):
For each pair (i, j), compute $z_i z_j$. If nearby wards both have high (or both low) values, $z_i z_j$ is positive.

Step 2 (keep only neighbors via weights):

$$\sum_i \sum_j w_{ij}\, z_i z_j$$

Step 3 (normalize by overall variance):
Total "energy" in deviations is:

$$\sum_i z_i^2$$

Step 4 (scale for number of areas and total weights):

$$I = \frac{n}{S_0} \cdot \frac{\sum_i \sum_j w_{ij}\, z_i z_j}{\sum_i z_i^2}$$

7. Conclusions

Patterns of urban crime in Patna Municipal Corporation are determined by indicators of disadvantage and vulnerability, while mappable trends show increasing risk for property crimes, especially burglaries, thefts, and assaults. Geospatial police data establishes incidents and distributions, enables digitization of offences by class, and facilitates Crime Mapping Analysis Procedure reports. However, the datasets in open-source format are inherently limited, identifying only the patrolling police jurisdictions and crime types.

In Patna, a city of 1.72 million inhabitants and an area of 102.41 square-kilometre, where centre and periphery are so sharply contrasted that the Patna Informatics Infrastructure Plan has recommended a restricted construction policy, there is an emergent risk of open-enterprise housing, which is practically impossible for the police administration to monitor properly. Disturbingly, residential burglaries and thefts from houses by unknown persons have become the

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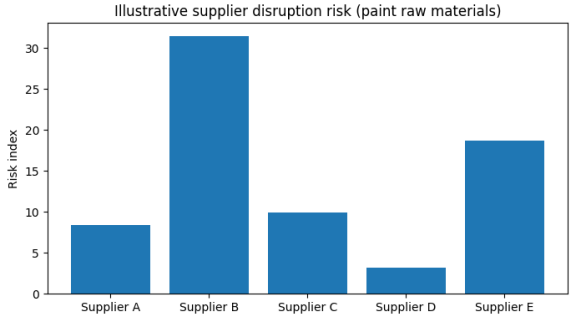
most common forms of property crime. To manage such issues well, potential areas of crime need to be known in advance, and risks and vulnerabilities to certain crime types need to be established. These factors, coupled with an analysis of the geographic concentration of crimes (indicators of clustering), help in assessing the response and the effectiveness of the police administration.



7.1. Emerging Trends

A detailed crime typology for the PMCs, which includes information about the total number of offences per category between 2014 and 2020, reveals that property crimes account for approximately 78.41% of all recorded offences. This category is then followed by violent crimes (approximately 18.46%), with theft and burglary the most frequently occurring offences in each of the aforementioned categories. The temporal crime series (indicator frequency of crime in Patna Municipal Corporation) highlights two notable features: a marked increase in recorded offences between 2015 and 2016 and a major decrease between 2016 and 2017, also visible in the hot spot maps. The semi-annually aggregated series suggests a peak during the hot months (April to June) and a subsequent decline during the monsoon.

Hot spot maps combined with the spatial clustering statistic's results suggest that considering a longer period would eliminate the detection of the 2015 and 2016 clusters, while analysis at the ward level indicates that the spatio-temporal pattern has remained consistent across the different years. The spatio-temporal evolution of crime distribution in certain wards has also remained stable, but at different periods and with a different clustering power. A first clustering period unanimously affecting almost all methods and time windows, with a relatively small Gi* value, is visible in the warden chain between the northeastern and the southwestern parts (ward limits visible in figure 2), together with the highest kernel density.

Metric	Value in paper	Where mentioned
Property crimes share (2014–2020)	≈78.41%	Emerging trends
Violent crimes share (2014–2020)	≈18.46%	Emerging trends
Property share of incidents (alt. statement)	≈90%	Crime typologies
Theft+burglary share of property (alt. statement)	≈75% of property	Crime typologies

Table: Key quantitative statements extracted

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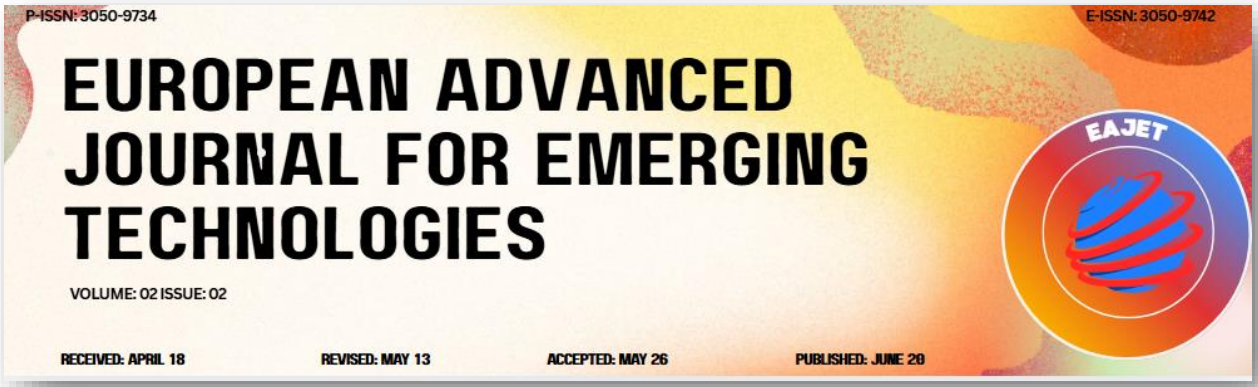

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