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Urban Fire Risk Hot Spot Assessment and Green Spaces: A Geospatial Analysis of Fire Risk Mitigation in Nagpur

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Abstract

This study explores the interrelationship between urban configurations, fire risks, and green spaces within Nagpur, utilizing GIS and satellite remote sensing technologies to evaluate how urban greenery contributes to fire hazard mitigation. Our analysis focuses on the detailed examination of the city's five zones, assessing the distribution of green spaces against fire risk hotspots. The research employs Pearson's correlation coefficient to quantify the relationship between urban property types and greenery, indicating a strong positive correlation ($r = 0.771$), suggesting that an increase in built-up areas correlates with an increase in green spaces. The results reveal that greener zones correlate with fewer fire incidents, emphasizing the critical role of urban green spaces in fire risk mitigation. These areas not only enhance urban aesthetics and environmental health but also function effectively as natural firebreaks. The study advocates for the integration of green spaces in urban design, promoting them as essential components in achieving sustainable urban development and enhancing city resilience against fire incidents.

Categories: Urban Planning and Development, Environmental Engineering and Sustainability
Keywords: urban planning, fire risk hotspots, green spaces, gis, satellite data

Introduction

Urban environments and green spaces significantly influence fire risk, especially in wildland-urban interfaces (WUIs), where urban development meets wild vegetation. The presence of WUIs is linked to increased fire risks due to the interaction between human activities and natural environments. The type and management of vegetation, or land use/land cover (LULC), play crucial roles in fire ignition risks, with forestry plantations in WUIs showing higher risks than native forests and agricultural lands. These findings suggest that managing low-risk land covers could offer cost-effective fire prevention alternatives to traditional strategies focusing on reducing fuel loads [1].

Advancements in satellite remote sensing and GIS technologies are crucial for assessing and managing urban fire risks and green spaces. Satellite remote sensing provides systematic, near-real-time data on fires, aiding in detection, prioritization, and understanding of their socioeconomic impacts [2,3]. GIS technology enhances fire risk assessment by integrating various factors, such as vegetation type, topography, and human activities into comprehensive risk zone maps, vital for planning and mitigation efforts [4-6]. The combination of GIS, remote sensing, and Global Positioning System (GPS) technologies forms an effective framework for urban fire management, supporting emergency response with real-time data and spatial analysis capabilities [7,8]. These geospatial tools also support the development of decision-support systems for fire risk management, offering dynamic, integrated approaches for operational management and public safety in urban areas [9].

This study is centered on investigating the interrelations among urban configurations, fire risk areas, and green zones within Nagpur's initial five zones, with the aim of delivering practical insights for urban planners and decision-makers [10,11]. The primary objective is to utilize this thorough analysis to shape strategies that bolster urban fire safety and enhance the efficacy of green spaces in reducing fire hazards, ultimately fostering Nagpur's sustainable growth. Such an investigation is driven by the imperative to understand the dynamics between urban infrastructure, fire-prone areas, and green spaces in Nagpur, a city characterized by distinct urban and ecological features that pose both challenges and opportunities for innovative urban planning and effective fire risk management approaches.

Materials And Methods

Study Area

Nagpur, situated at 21.90° N and 79.50° E in Maharashtra, India, is home to approximately 2.45 million individuals as per the 2011 census. This positions it as the third-largest city in Maharashtra and the thirteenth in India, encompassing an area of 225.08 square kilometers with a notable population density of

10,873 individuals per square kilometer [12]. Managed by the Nagpur Municipal Corporation (NMC), the city is divided into 10 zones, including Laxmi Nagar, Dharampeth, Hanuman Nagar, Dhantoli, and Nehru Nagar, each characterized by distinct demographics and urban layouts [12].

The city's climate is classified as 'Aw' under the Köppen climate classification, experiencing extreme temperatures up to 47.8°C during summers and moderate winters with temperatures ranging between 10°C and 12°C. Annually, Nagpur receives an average rainfall of 1161.54 mm [12]. An analysis of fire incident data from 2011 to 2020, sourced from the NMC Fire Service Department, indicates an upward trend in fire occurrences, with a significant peak in May. This peak is underscored by a *z*-score exceeding 2.01, highlighting a significant correlation between climatic conditions and fire incidents, thus providing a basis for in-depth analysis to identify and assess fire hotspots [12,13].

The examination of 570 fire events during May from 2011 to 2020 revealed that residential fires accounted for 48% of these incidents, followed by mercantile fires at 32%. These incidents were classified according to the occupancy types outlined in the National Building Code of India (NBCI), 2016, indicating a predominant risk within residential and commercial settings [13,14].

Fire causes in Nagpur have been classified into five main categories: gas cylinder leakages (14%), electrical short circuits (31%), nearby garbage fires (2%), and other causes (6%), with a notable 48% of fires remaining unspecified. These data suggest that electrical short circuits, common in May due to increased use of electrical appliances, indicate a weather-related pattern in fire incidents [13].

Methodology

The methodology implemented for this study is intricately designed to examine the interaction between urban structures, fire risk hotspots, and green spaces within five specified zones of Nagpur. By delving into each zone's unique blend of built environment and vegetative areas, the study aims to uncover the nuanced dynamics affecting urban fire safety and green space distribution.

Data collection techniques: The data collection strategy employed a detailed, two-fold approach focusing on the characteristics of urban structures and the extent of green spaces, enhanced by ground-level data gathering and subsequent GIS processing.

1) Urban structures: Data collection for urban structures involved site-specific visits within each zone to gather comprehensive information on various building types, including residential, industrial, and commercial entities. Essential data such as geospatial coordinates, the number of stories, and the total floor area were meticulously recorded. This information was then compiled and converted into a CSV format, streamlining the process for detailed analysis and ensuring the precision of urban density and complexity assessments.

2) Greenery analysis: The analysis of green spaces was conducted through the examination of high-resolution satellite imagery, coupled with on-site data verification. This dual approach allowed for the accurate identification and mapping of green areas, encompassing everything from expansive parks to smaller green elements like street trees and gardens. The spatial distribution and characteristics of these green spaces were meticulously catalogued, providing critical insights into their role within the urban ecosystem.

Analysis methods: Analytical efforts were centered on two principal areas: pinpointing fire risk hotspots and discerning the mitigative impact of green spaces on urban fire risks.

1) Fire risk hotspot identification: Leveraging GIS technology, the study overlayed detailed urban structural data. This spatial analysis facilitated the precise identification of fire risk hotspots, correlating specific fire incidents with their immediate urban and green surroundings.

2) Greenery's role in fire risk mitigation: Further analysis was devoted to evaluating how green spaces influence urban fire risks. By examining the relationship between identified fire hotspots and surrounding greenery, the study aimed to understand the potential of green spaces as natural barriers, contributing to fire risk reduction and urban resilience.

Data processing and validation: Post-collection, the data underwent a thorough review process to ensure its accuracy and completeness. Any detected inadequacies prompted additional data collection efforts to address gaps, followed by a rigorous quality check to validate the dataset's integrity. Subsequently, the validated data were processed using GIS software, enabling comprehensive spatial analysis to identify potential fire hotspots, evaluate current fire prevention measures, and guide the development of enhanced urban planning strategies. This methodical approach ensures a robust analytical foundation, paving the way for informed decision-making in urban fire risk management and sustainable urban development.

Calculation of correlation coefficient (*r*): To analyze the relationship between the distribution of urban property types and greenery percentages within Nagpur's zones, Pearson's correlation coefficient is employed. This statistical measure was chosen for its effectiveness in quantifying the linear correlation between two continuous variables, providing insights into the strength and direction of their relationship.

The rationale behind using Pearson's correlation coefficient lies in its ability to offer a clear, numerical value that represents the degree to which two variables are linearly related. This measure is crucial for understanding the dynamics between urban development and the preservation of green spaces within the city, as it helps in identifying potential trends or patterns that could inform urban planning and fire risk mitigation strategies [15,16].

The calculation of Pearson's correlation coefficient (*r*) follows the formula:

$$r = \frac{\sum (X - \bar{X})\,(Y - \bar{Y})}{\sqrt{\sum (X - \bar{X})^2 \sum (Y - \bar{Y})^2}}$$

Where:

X constituted the average percentage area of various urban property types within each zone, calculated as the mean of percentages across all identified property categories (industries, high rises, commercial, etc.).

Y represented the percentage of greenery within the same zones. The calculation was performed on a dataset comprising these values for each of the five zones under study.

$\bar{X}$ and $\bar{Y}$ are the means of X and Y, respectively.

Results

The integration of GIS and satellite data has significantly enhanced the analysis of fire risk within the urban landscape of Nagpur, resulting in a nuanced understanding of the spatial distribution of urban properties, green spaces, and fire risk hotspots. Utilizing high-resolution satellite imagery and sophisticated ArcGIS software, the study has successfully mapped out detailed urban and green structures, corroborating the findings with site-collected data for authenticity and precision.

Property Type Distribution

The distribution of urban properties was meticulously evaluated, revealing the complex interplay of various structures within the five zones of Nagpur. This comprehensive analysis, presented in Table I, highlights the proportional makeup of property types such as high-rise buildings, industries, and commercial spaces that form the core of the urban fabric.

Property Type	Laxmi Nagar	Dharampeth	Hanuman Nagar	Dhantoli	Nehru Nagar
Industries	0.01990	0.00734	-	-	0.00629
High Rises	0.01478	0.00779	0.00399	0.01905	0.00023
Commercial	0.01349	0.01862	0.01845	0.03554	0.00600
Educational	0.02026	0.05603	0.01885	0.08430	0.04027
Petrol Pumps	0.00126	0.00081	0.00207	0.00341	0.00075
Gas Godowns	0.00017	0.00004	-	0.00065	-
Hospitals	0.01215	0.00417	0.00839	0.03474	0.00794
Restaurants	0.00563	0.00425	0.00168	0.00329	0.00401
Shops	0.00413	0.00411	0.00512	0.01197	0.00574

TABLE 1: Area Percentage Distribution of Urban Properties Across Nagpur’s Five Zones (2023)

Greenery Distribution

The strategic placement of green spaces within each zone has been identified as a significant factor in urban fire risk mitigation. Satellite and GIS analysis provided precise mapping of vegetative areas, as depicted in the attached imagery, and their quantification is showcased in Table II.

Zone	Percentage of Greenery (%)	Area of Greenery (sq km)
Laxmi Nagar Zone	21	8.589
Dharampeth Zone	19	7.049
Hanuman Nagar Zone	13.7	1.507
Dhantoli Zone	23.6	3.1624
Nehru Nagar Zone	9.4	1.9458

TABLE 2: Greenery Coverage in Nagpur’s Zones (2023)

Geo-spatial Visualization of Fire Risk Hot Spots and Green Spaces

The geo-spatial analysis has not only pinpointed potential fire risk hot spots but has also delineated the green spaces within Nagpur’s urban landscape. This dual-focus mapping provides a holistic view of the zones, where the color-coded areas represent both the identified risk areas and the crucial green spaces that contribute to the urban ecology and fire mitigation. The mapping combines high-resolution satellite imagery and GIS technology to reveal the multifaceted urban landscape, encompassing both the built environment and vegetative areas.

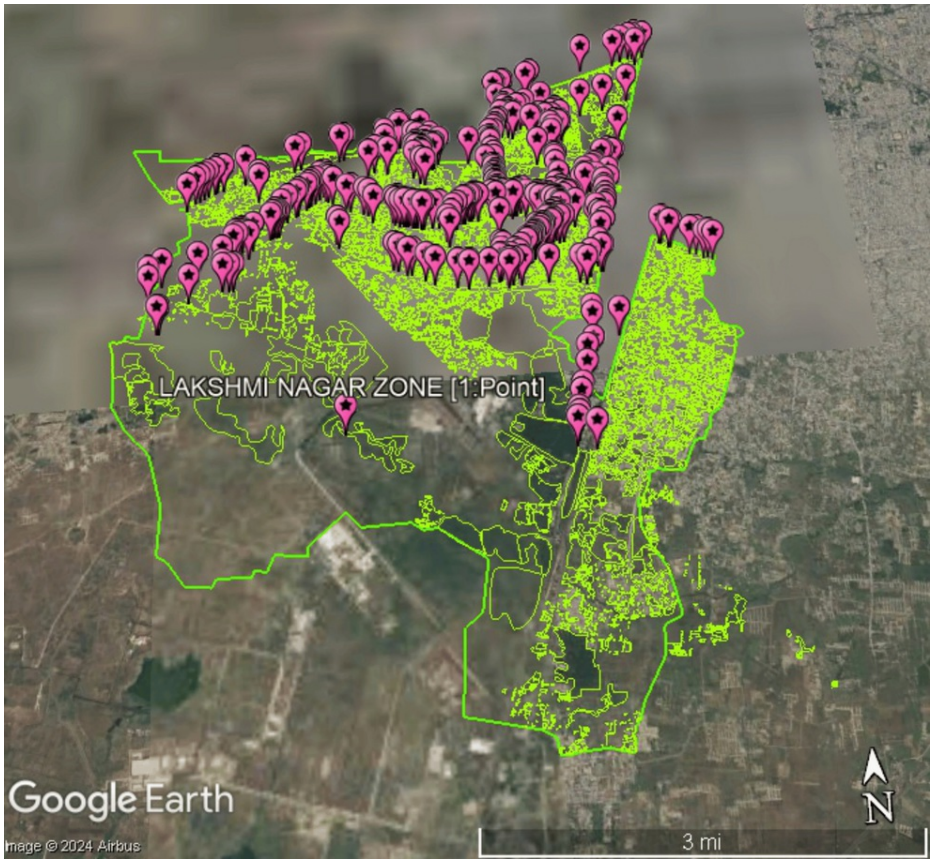

FIGURE 1: Laxmi Nagar Zone—Urban Landscape and Greenery

In Figure *1*, a vivid display of Laxmi Nagar's fire zones, with green highlighting green spaces and pink icons representing different properties, providing insight into fire risk distribution against an urban backdrop.

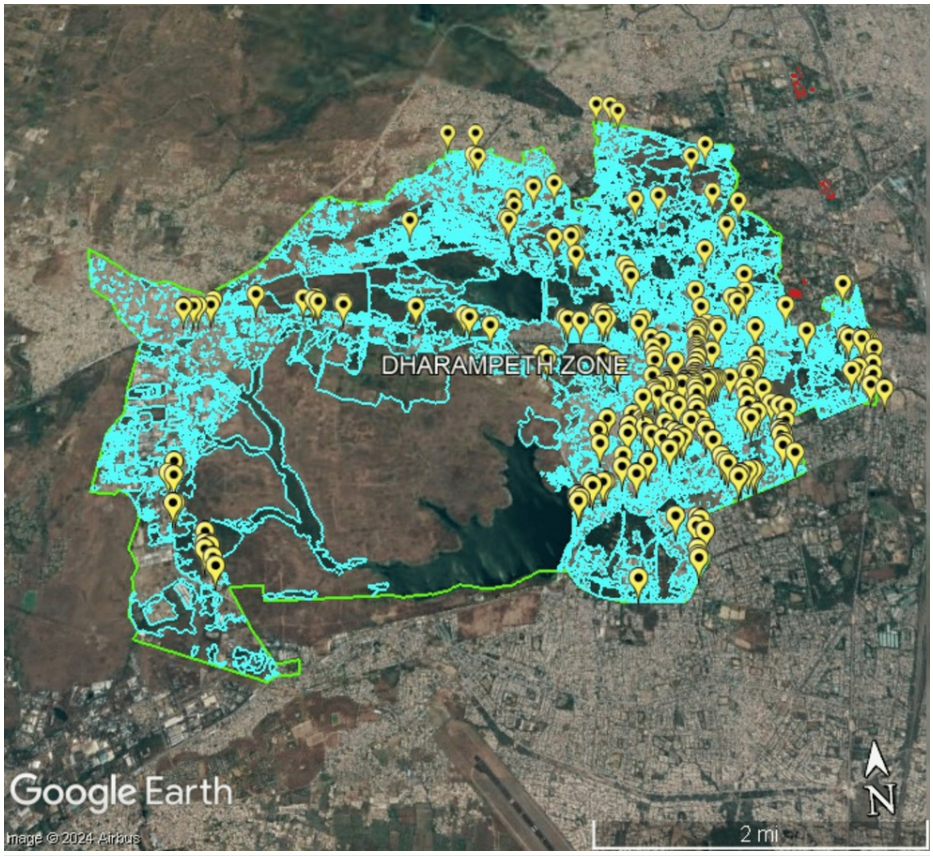

FIGURE 2: Dharampeth Zone—Urban Landscape and Greenery

Figure *2* shows the map of Dharampeth depicts fire zones with turquoise for green spaces and yellow icons for properties, illustrating the urban and natural interplay.

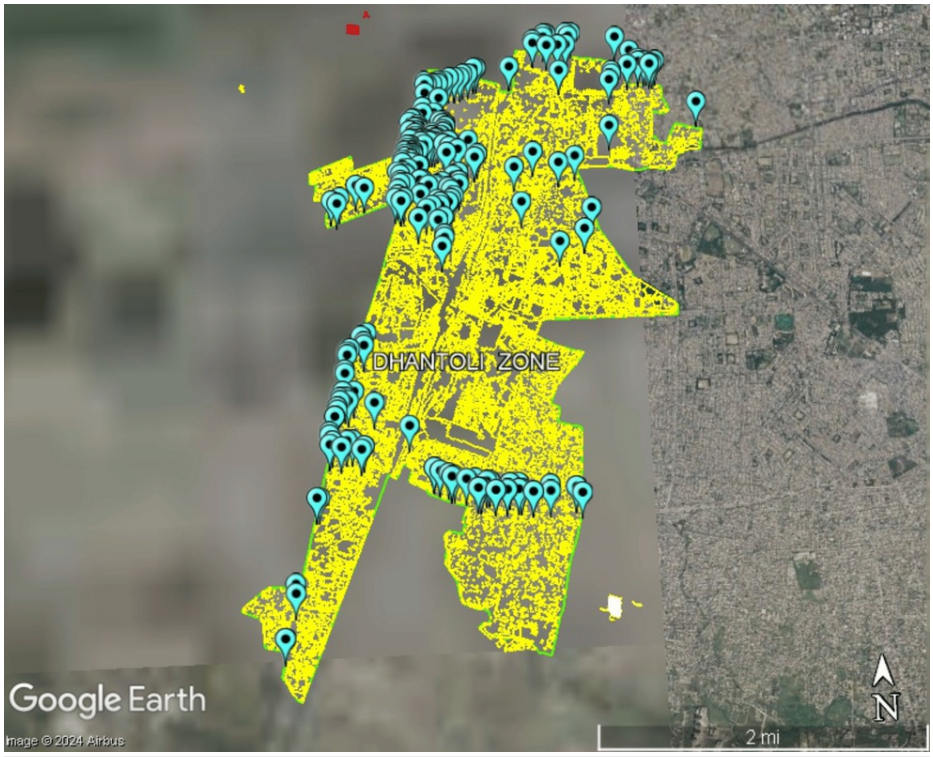

FIGURE 3: Dhantoli Zone—Urban Landscape and Greenery

Figure *3* shows that the Dhantoli's urban density is depicted in yellow color, with cyan icons representing properties within fire zones, juxtaposed with patches of green spaces.

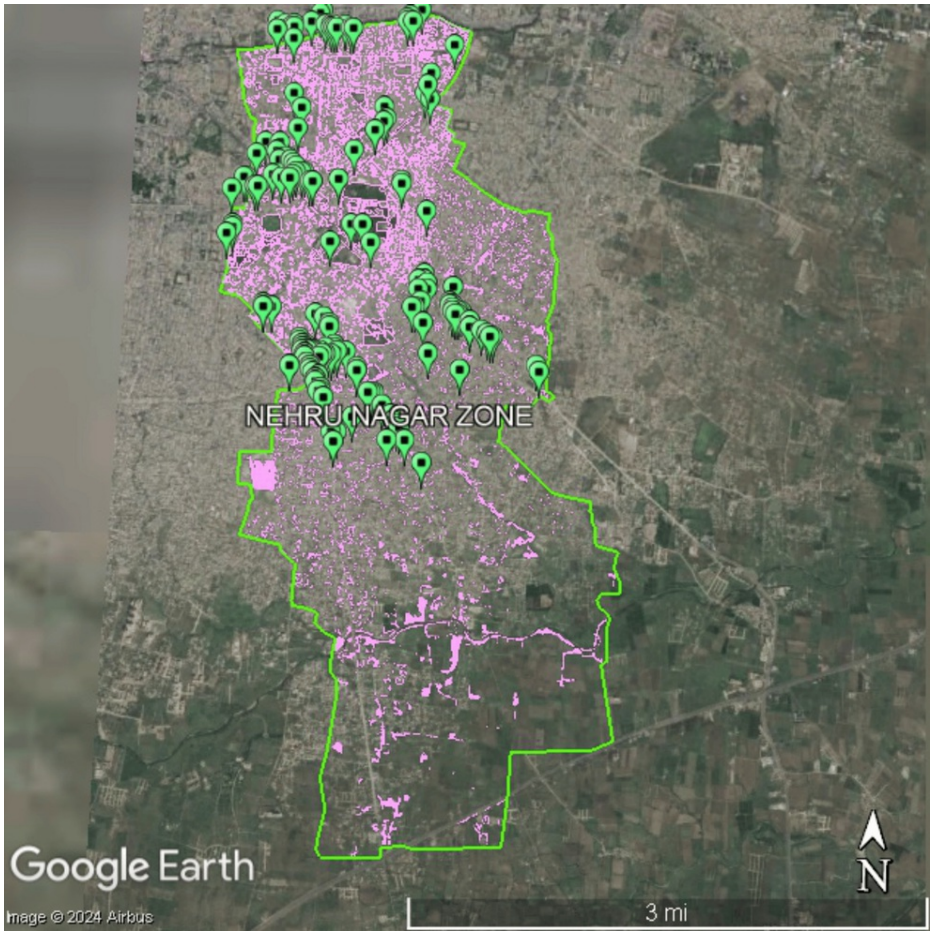

FIGURE 4: Nehru Nagar Zone—Urban Landscape and Greenery

Figure *4* shows the map presenting Nehru Nagar with purple indicating residential areas and green spaces, and green icons for properties, indicating potential fire risk areas within a predominantly residential zone.

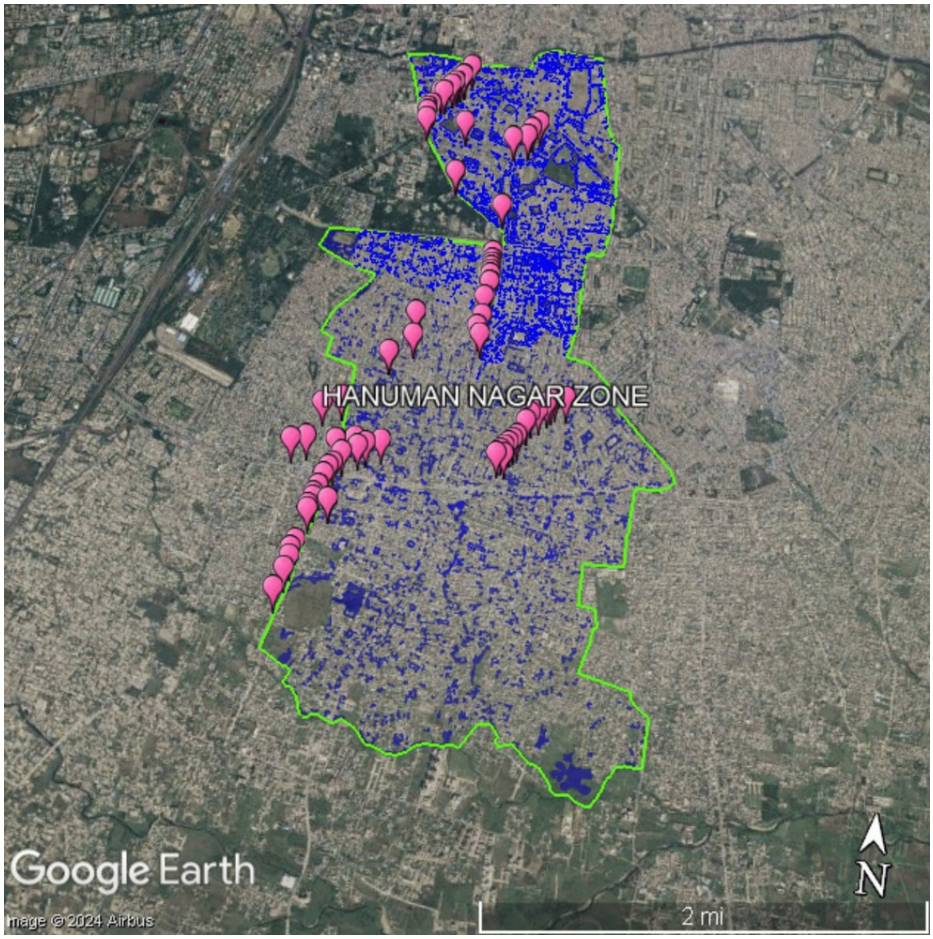

FIGURE 5: Hanuman Nagar Zone—Urban Landscape and Greenery

Figure *5* shows the geo map of Hanuman Nagar's blend of urban development and green belts depicted in blue, with pink icons for properties, providing a perspective on fire risks in relation to the green urban matrix.

Discussion

Correlation Coefficient (r)

The correlation coefficient between the average percentage of different property types and the percentage of greenery across the five zones is approximately 0.771. This positive correlation suggests that as the average percentage of property increases, the percentage of greenery also tends to increase. However, it is important to note that correlation does not imply causation, and other factors may influence the presence of green spaces in relation to the distribution of urban properties.

Our investigation of Nagpur's cityscape, leveraging GIS and satellite data, has rendered a precise understanding of the nexus between urban structures and fire risks. This utilization of state of the art geospatial technology has been instrumental in the accurate mapping of zones at heightened risk for fires and the identification of vegetative areas, underlining the significant spatial dynamics at play.

The research underscores the indispensable role of green spaces within the city matrix, evidenced by a substantial correlation (approximately 0.771) between the proportion of urban properties and the extent of greenery. This relationship intimates that the incorporation of green areas is a strategic urban planning choice, aimed at mitigating fire risks. Beyond their aesthetic and environmental significance, these spaces function as critical firebreaks, contributing to fire containment by modulating the urban micro climate.

Corroborating our findings, the literature acknowledges the essential nature of urban green spaces for ecological balance and as pivotal elements in disaster prevention frameworks [17]. The contributions of such green infrastructures to disaster risk reduction, notably in fire mitigation, resonate with global studies and recommended practices emphasizing the conservation of urban natural diversity and enhancement of ecosystem services [18-20].

In conclusion, the insights derived advocate for the strategic application of GIS and satellite technologies by urban planners and developers. The aim is to sculpt urban landscapes that are not only resilient but also in synergy with the natural environment. A planning ethos that integrates green spaces into the urban fabric is envisaged to significantly elevate fire risk mitigation efforts, in alignment with established global research and best practices.

Conclusions

This study underscores the essential role of urban green spaces, as revealed through GIS and satellite technologies, in mitigating fire risks. Analysis within Nagpur indicates a clear correlation between green space incorporation and urban planning, with greener zones experiencing fewer fire incidents. This is a valuable insight for urban planners prioritizing environmental integration in city development.

Further research could explore this phenomenon across diverse urban climates to assess the global applicability of these findings. Long-term studies could track the sustained impact of urban greenery on fire safety and city resilience. Additionally, assessing the broader socioeconomic effects of urban green spaces on community health, property values, and overall well-being could offer a holistic view of their benefits.

Innovations in urban greening, such as vertical and rooftop gardens, particularly in dense urban areas, present a new frontier for research. Investigating these methods could significantly advance our understanding of urban design in relation to fire risk mitigation and environmental sustainability.

The study promotes the adoption of GIS and remote sensing in urban planning, suggesting that an integrated, data-driven approach can lead to effective strategies for fire prevention, sustainable urban development, and improved quality of urban life.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Kirti V. Thakare Ms., Kiran M. Tajne Dr.

Acquisition, analysis, or interpretation of data: Kirti V. Thakare Ms.

Drafting of the manuscript: Kirti V. Thakare Ms.

Critical review of the manuscript for important intellectual content: Kirti V. Thakare Ms., Kiran M. Tajne Dr.

Supervision: Kiran M. Tajne Dr.

Disclosures

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References

1. Calviño-Cancela M, Chas-Amil M, García-Martínez E, et al.: Wildfire risk associated with different vegetation types within and outside wildland-urban interfaces. Forest Ecol Manage. 2016, 372:1-9. 10.1016/J.FORECO.2016.04.002
2. Tralli D, Blom R, Zlotnicki V, et al.: Satellite remote sensing of earthquake, volcano, flood, landslide and

coastal inundation hazards. ISPRS J Photogramm Remote Sens. 2005, 59:185-98. 10.1016/J.ISPRSJPRS.2005.02.002.

3. Mazzeo G, De Santis F, Falconieri A, et al.: Integrated satellite system for fire detection and prioritization. Remote Sens. 2022, 14:335. 10.3390/rs14020335.
4. Jaiswal RK, Mukherjee S, Raju K, et al.: Forest fire risk zone mapping from satellite imagery and GIS. Int J Appl Earth Obs Geoinf. 2002, 4:1-10. 10.1016/S0303-2434(02)00006-5.
5. Chuvieco E, Salas J: Mapping the spatial distribution of forest fire danger using GIS. Int J Geogr Inf Syst. 1996, 10:333-45,. 10.1080/02693799608902082.
6. Petrakis M, Psiloglou B, Lianou M, et al.: Evaluation of forest fire risk and fire extinction difficulty at the mountainous park of Vikos-Aoos, Northern Greece: use of remote sensing and GIS techniques. Int J Risk Assess Manage. 2005, 5:50. 10.1504/IJRAM.2005.006612.
7. Chrysoulakis N: Integration of Earth observation and in-situ spatial data for the development of a decision support tool for technological risk management. Proc SPIE. 2003, 4886:10.1117/12.463236.
8. Zhong Z, Jing N, Wu Q: Integration of GIS/RS/GPS for urban fire response. 2012 International Conference on Computer Vision in Remote Sensing. 2012, 311-16. 10.1109/CVRS.2012.6421281.
9. Chrysoulakis N, Prastacos P, Cartalis C: Development of a Decision Support Tool for Technological Risk Management with Remote Sensing and GIS. 2004. 10.4018/978-1-59140-342-5.CH022.
10. Gltié J: GIS-supported modelling and diagnosis of fire risk at the wildland urban interface: A methodological approach for operational management. Modelling Environmental Dynamics: Advances in Geomatic Solutions, Environmental Science and Engineering. Martin Paegelow, Camacho Olmedo, Maria Teresa (ed): Springer, Berlin Heidelberg; 2008. 169-97,. 10.1007/978-3-540-68498-5_6.
11. Zhao M, Liu X: Regional risk assessment for urban major hazards based on GIS geoprocessing to improve public safety. Safety Sci. 2016, 87:18-24. 10.1016/J.SSCI.2016.03.016.
12. Singh PP, Sabnani CS, Kapse VS.: Hotspot analysis of structure fires in urban agglomeration: A case of Nagpur City, India. Fire. 2021, 4:38-38. 10.3390/fire4030038
13. India Meteorological Department (IMD): Ministry of Earth Sciences; Climate Application and User Interface; Climatology of Smart Cities, Climate Smart City-Nagpur (Sonegaon). 2022-03-23.
14. Bureau of Indian Standards (BIS): National Building Code of India. New Delhi, India; 2005.
15. Blyth S: Karl Pearson and the correlation curve. Int Stat Rev. 1994, 62:393-403. 10.2307/1403769
16. Šverko Z, Vrankic M, Vlahinić S, et al.: Complex Pearson correlation coefficient for EEG connectivity analysis. Sensors. 2022. 22:10.3390/s22041477
17. Liu Y, Zhang S, Wang T: Analysis of influence factors of disaster prevention capacity in urban green space based on analytic hierarchy process. Energy Procedia. 2018, 153:370-75. 10.1016/j.egypro.2018.10.076
18. Govindarajulu D: Urban green space planning for climate adaptation in Indian cities. Urban Climate. 2014, 10:35-41. 10.1016/j.uclim.2014.09.006
19. Duan J, Wang Y, Fan C, et al.: Perception of urban environmental risks and the effects of Urban Green Infrastructures (UGIs) on human well-being in four public green spaces of Guangzhou, China. Environ Manage. 2018, 62:500-17. 10.1007/s00267-018-1068-8
20. Swart R, Timmermans W, Jonkhof J, et al.: From urban façade to Green Foundation: Re-imagining the Garden City to manage climate risks. Urban Plann. 2021. 10.17645/up.v6i4.4360