CHAPTER 125

Spatio-Temporal Analysis of Urban Flooding in Industrial Towns: A Case Study of Gurugram

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ABSTRACT

Urban flooding has become a major environmental and economic problem in industrial cities, facing rapid urbanisation and land use changes. Gurugram, being one of the top industrial and commercial hubs of India, has seen a rise in the number of floods mainly due to uncontrolled urbanisation, inadequate drainage systems and environmental degradation. This research does a spatio-temporal analysis of urban flooding in Gurugram to identify the main contributing factors, community perception of flood risk and the existing flood management strategies. Data was collected through a structured survey of residents from different sectors and industrial areas of Gurugram. The total sample size is 193. The survey asked about public perception of urban flooding, its impact on daily life and the perceived effectiveness of planning and infrastructure in reducing or increasing flood risk. Results show that most of the respondents viewed urban flooding as a big issue, especially during the monsoon months of July and August. Respondents identified inadequate drainage systems, encroachment on water bodies, deforestation and unplanned urbanisation as the top three factors contributing to the frequency and severity of floods. Apart from environmental and infrastructural concerns, respondents reported significant socio-economic impacts like property damage, mobility disruption, loss of work hours and vulnerability to waterborne diseases. Results also show a gap between community needs and existing mitigation strategies. Most of the respondents rated maintenance of drainage systems, emergency response services and enforcement of land use regulations as inadequate. While some initiatives, like awareness campaigns and the creation of green spaces, got more positive responses, they are not enough to address the scale of the issue. The study suggests the need for comprehensive urban flood management strategies that integrate infrastructure improvement, enforcement of land use regulations and active community engagement.

Keywords: Urban flooding; Spatio-temporal analysis; Industrial towns; Gurugram; drainage infrastructure.

1.0 Introduction

Urban flooding is a serious concern in industrialised areas where urbanization, climate

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variability and poor infrastructure collide to create regular disasters (Gupta & Nair, 2021; Yasmin & Das, 2019). Gurugram, one of India's fastest industrial and commercial hubs in NCR, has been experiencing urban flooding for the last two decades (NIDM & Amity University, 2021). The city has transformed from a small town to an industrial and IT centre, which has resulted in significant land use changes, shrinkage of water bodies and an overloaded drainage network (Gupta & Nair, 2021; Suriya & Mudgal, 2012). Monsoon floods have become a regular phenomenon, causing economic loss, public health concerns and severe disruption in business, transportation and residential life (Sahana *et al.*, 2019).

The motivation behind this study is to address Gurugram's increasing vulnerability to urban flooding; despite being an industrial hub, it lacks robust and adaptive flood management systems (Lavanya, 2012). While efforts are being made to modernise infrastructure, the combination of rapid industrialization and limited green infrastructure has made the city more flood-prone (Harsha & Sridharan, 2020). Since Gurugram is a model for other emerging industrial towns, a spatio-temporal analysis of its flooding pattern is needed to understand how urbanization and climate factors interact to increase flood risk (Patra & Kant, 2014). This study aims to investigate the spatial and temporal dynamics of urban flooding in Gurugram, identifying key factors like land use and land cover (LULC) changes, drainage network efficiency and socio-economic vulnerabilities. This study will use GIS and remote sensing to map flood-prone areas, identify infrastructure gaps and evaluate existing flood mitigation measures (Wang & Zhang, 2018).

This research will look into Ward 32 of Gurugram, a flood prone area which is a microcosm of the city's overall urban flooding problem. The study will look into historical flood data, LULC trends and performance of natural and man-made drainage systems over a defined period. It will also explore the scope of nature based solutions and integrated urban planning frameworks to enhance flood resilience. The limitations of this study are that it is limited to one industrial city (Gurugram) and may not apply to other urban contexts with different geography and socio-political conditions. Also, the study is based on secondary data and community level surveys, which may have data gaps or response bias. However, the study will give insight into the evolving problem of urban flooding in industrial areas.

This review aims to critically analyse the spatio-temporal methods used to assess urban flooding in industrial towns with special reference to Gurugram. Through this review, the gaps in research, methodologies and findings will be highlighted, which will contribute to our understanding of urban flood risk in industrial areas. Urban flooding is a growing phenomenon in cities the world over due to rapid urbanization and climate change (Suriya & Mudgal, 2012; Gupta & Nair, 2021). Industrial towns like Gurugram have multiple challenges due to haphazard growth, conversion of natural landscape to impervious surfaces and inadequate stormwater management (Patra *et al.*, 2018). This chapter will review the literature on urban flooding with special reference to industrial cities, spatio-temporal analysis and sustainable flood management. A systematic review of 150 articles was done, out of which 30 articles were

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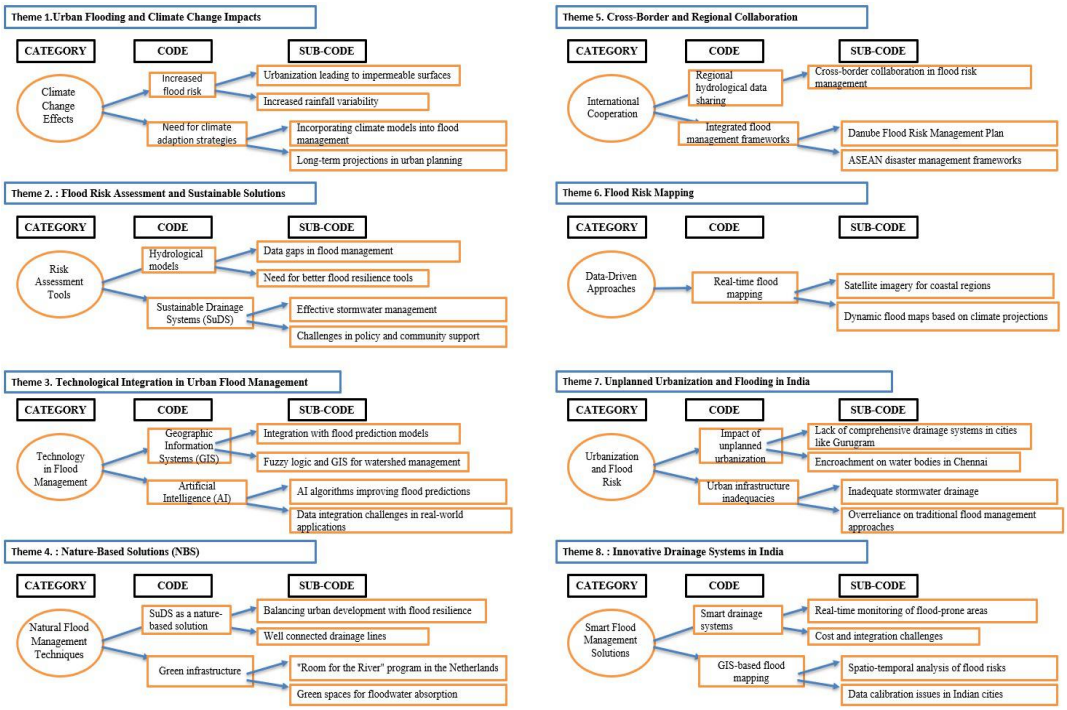
selected for the review. The themes determined by the systematic literature review are showcased in Figure 1. The themes are Urban flooding and Climate change impacts, Flood risk assessment and Sustainable Solutions, Technological Integration in urban flood management, NBS etc.

Figure 1: Themes Identified through Systematic Literature Review



Source: By authors

Globally, urban flooding is linked to increased rainfall variability, sea level rise and land use change. Cities like Rotterdam, New York and Copenhagen have seen major pluvial and fluvial flooding due to these changes (Schreider *et al.*, 2000; Sandink, 2013). It's made worse by the increase in impervious surfaces and ageing or poorly designed drainage infrastructure (Miller, 2018). To tackle these, cities have adopted Sustainable Drainage Systems (SuDS) and green infrastructure to be more resilient (Guptha, 2020). For instance, Rotterdam's water squares and Copenhagen's cloudburst management plan combine grey and green infrastructure to reduce flood impact (Armenakis, 2019).

Technological advancements like artificial intelligence (AI) and Geographic Information Systems (GIS) have enabled flood prediction and early warning systems globally (Chew Ze, 2021; Wang, 2012). AI models have improved flood forecasting in urban Malaysia,

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while fuzzy logic combined with GIS has improved urban watershed management in other areas (Wang, 2012). In India, cities like Mumbai, Chennai and Gurugram have faced repeated urban flooding due to unplanned urbanisation, encroachment of natural floodplains and poor stormwater infrastructure (Sahana *et al.*, 2019). The problem is further compounded by high population density and a lack of coordination between municipal bodies and environmental agencies (Yasmoon & Saud, 2016). For instance, Gurugram has lost its water bodies and wetlands and has reduced its natural stormwater absorption capacity (Guhathakurta & Marathe, 2022). NIDM and Amity University (2021) say urban flooding in India has socio-economic impacts like disruption to transportation, damage to property and health impacts.

Lavanya (2012) also says there is no policy integration between urban planners and the environment department, hence poor implementation of land use regulation and increased vulnerability to flooding. Gurugram is an industrial and commercial hub of Haryana and is a perfect example of the challenges faced by Indian industrial towns on urban flooding. The city has been facing frequent and severe flooding, especially in sectors like Ward 32, NH-8 and Golf Course Road (Patra *et al.*, 2018). The rapid transformation of Gurugram into an economic centre has resulted in widespread land cover changes, notably the conversion of agricultural and open spaces into built-up areas (Gupta & Nair, 2021). Suriya and Mudgal (2012) report that Gurugram's stormwater drainage system is inadequate for its current rate of urbanization, with many natural drains encroached upon or completely obstructed. This leads to frequent waterlogging, traffic congestion, and economic losses during the monsoon season. While infrastructural upgrades have been initiated, they have been largely fragmented and insufficiently integrated with environmental planning efforts (NIDM & Amity University, 2021). The global discourse on urban flood management is increasingly advocating for Nature-Based Solutions (NBS) as a complementary or alternative strategy to traditional grey infrastructure (Guptha, 2020).

Green infrastructure elements such as bioswales, rain gardens, green roofs, and permeable pavements have been successfully implemented in cities like Singapore and Amsterdam (Armenakis, 2019; IPCC, 2021). These interventions enhance water infiltration, reduce surface runoff, and restore ecological functions within urban settings. In India, Harahap *et al.* (2021) show that combining traditional practices like rainwater harvesting with modern technology can create cost-effective and community-driven flood mitigation measures. Given Gurugram's wetland heritage, there is a huge scope to integrate NBS, like wetland restoration and green-blue corridors, in its flood management plans. Though there is a lot of research on urban flooding globally and in India, research on industrial towns like Gurugram is limited.

Most available research tends to either focus narrowly on hydrological modelling or socio-economic vulnerabilities (Sahana *et al.*, 2019). There is a lack of comprehensive studies that integrate spatio-temporal data with community-based insights to analyse urban flooding holistically. Furthermore, while the role of NBS in flood mitigation has been studied extensively

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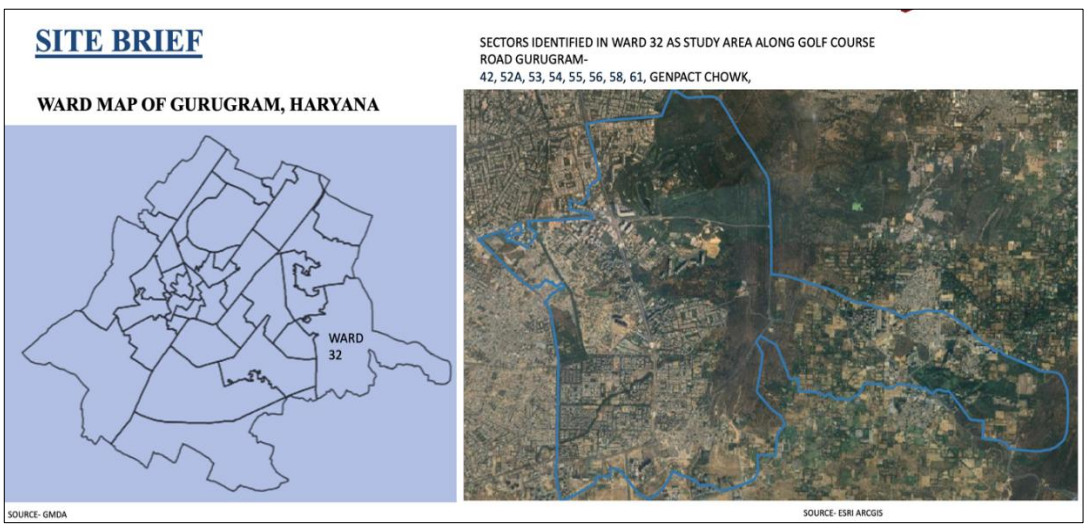
in global north contexts, its application and effectiveness in fast-growing Indian industrial towns are yet to be fully explored.

2.0 Methodology

This research employs a mixed-methods approach to comprehensively investigate the spatio-temporal dynamics of urban flooding in Gurugram, with a particular focus on Ward 32, a flood-prone area within the city. The methodology is designed to integrate both geospatial analysis and field-based qualitative insights, ensuring that both the physical patterns of flooding and the socio-economic dimensions of vulnerability are adequately addressed.

Figure 2: Site Brief of the Study Area



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The study area, Ward 32, was selected due to its recurring history of urban flooding, rapid land use transitions, and its representation of the broader infrastructural and environmental challenges faced by Gurugram (see Figure 2). The research combines primary data collection through field surveys and interviews with secondary data analysis derived from satellite imagery, municipal records, and census data. This combination ensures a holistic understanding of flood risk patterns and their underlying drivers. The primary data component includes household surveys conducted with 50 residents in Ward 32 (see Figure 3). The surveys were structured to gather information on residents' experiences with flooding, perceptions of the adequacy of drainage systems, awareness of government interventions, and coping mechanisms during flood events.

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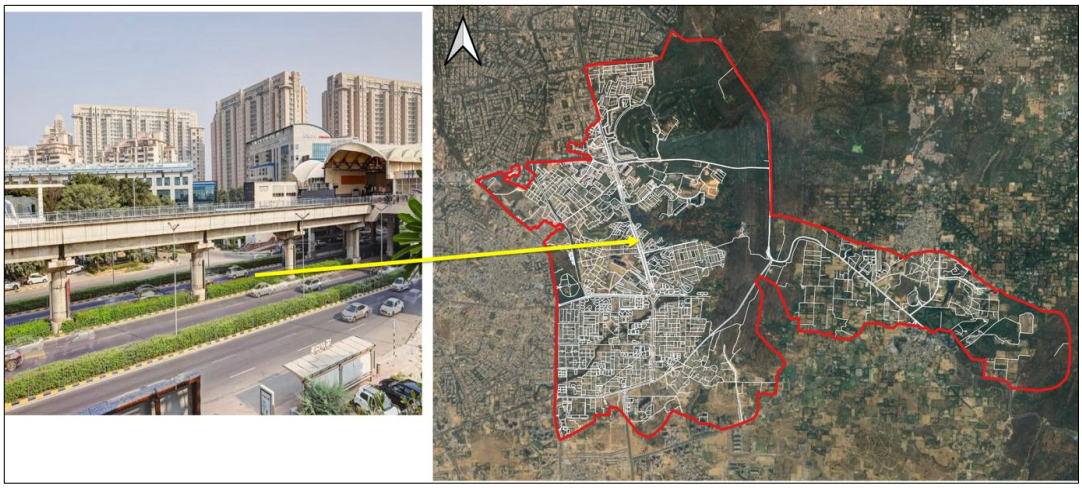
Figure 3: Ward Boundary of the Selected Study Area Ward -32



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The survey responses provide critical insights into the socio-economic impacts of urban flooding at the community level. In addition to household surveys, key informant interviews were conducted with officials from the Municipal Corporation of Gurugram (MCG) and the Haryana Urban Development Authority (HUDA). These interviews were instrumental in understanding institutional efforts, planning gaps, and challenges related to flood management within Gurugram. The secondary data includes a multi-temporal dataset of Landsat 8 (30-meter resolution) and Sentinel-2 (10-meter resolution) satellite images for the years 2010, 2015, and 2023, which were used to perform land use/land cover (LULC) change detection. The study area has witnessed extensive land conversion, particularly from open spaces and agricultural land to built-up areas, which has altered its hydrological behaviour and drainage patterns. helping to identify natural flow patterns and low-lying areas prone to waterlogging. For the assessment of community-level vulnerabilities and responses, survey data was processed using Microsoft Excel and SPSS.

Descriptive statistics such as frequencies and percentages were used to interpret patterns in household perceptions regarding the frequency, causes, and impacts of flooding in Ward 32. These insights were further corroborated with flood incident reports and municipal data sourced from the MCG and the Indian Meteorological Department (IMD). Despite the comprehensive nature of the methodology, the research does acknowledge certain limitations. The use of medium-resolution satellite data restricts the fine-scale detection of micro-level urban features such as narrow drains or small green spaces that could influence localized flooding patterns. Additionally, the household survey sample size is relatively modest due to time and logistical constraints, which may affect the generalizability of socio-economic findings beyond Ward 32. Finally, while the study provides a detailed assessment of Gurugram, it is

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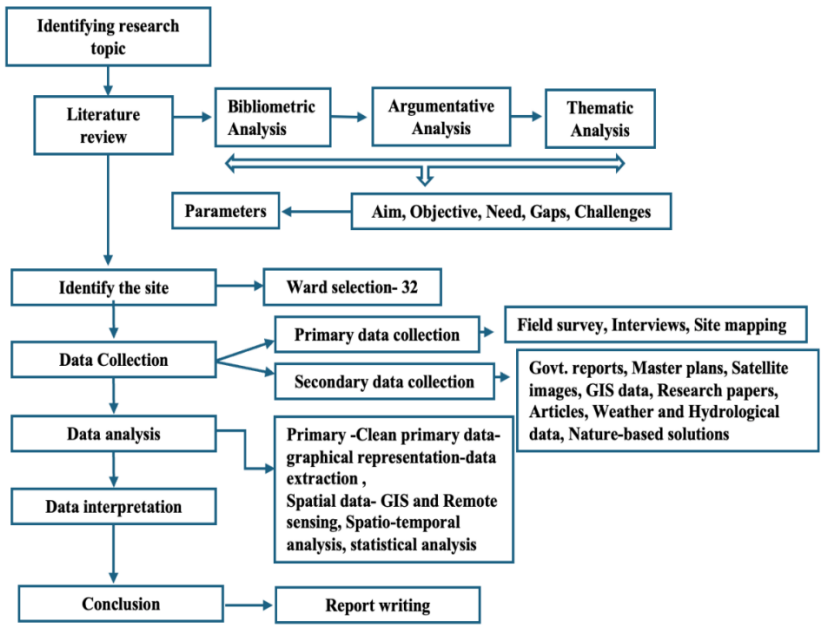
context-specific and may not fully capture the complexities of urban flooding in cities with significantly different geomorphological or institutional frameworks.

Figure 4: Methodology of the Study



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To understand the causes and impacts of urban flooding in Gurgaon, a total of 193 surveys were conducted with residents of Ward 32. The survey aimed to capture the public's perception of flooding-related issues, its frequency, and its consequences. Respondents highlighted urban flooding as a critical problem, exacerbated during the monsoon season, with 90% agreeing that it disrupts daily activities such as commuting, work, and accessing basic services. A significant number reported property damage and financial loss caused by waterlogging, emphasizing the role of inadequate drainage infrastructure and rapid urbanization. Additionally, the responses shed light on the community's preference for nature-based solutions, including the creation of green spaces, water retention areas, and improved urban planning practices, as effective mitigation strategies. These insights underscore the urgent need for implementing a Sponge Park in low-lying areas of Ward 32 to manage stormwater, reduce runoff, and enhance resilience against flooding. Overall, the methodology offers an integrated lens to understand both the physical landscape transformations and the lived experiences of urban residents in Gurugram, providing a solid foundation for developing targeted recommendations for flood risk reduction (see Figure 4).

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3.0 Results and Discussion

The following section outlines the key findings from the survey conducted to assess urban flooding issues in Gurugram. The survey focused on understanding the public's perception of urban flooding as a major issue, the contributing factors, the socio-economic and health impacts, and the effectiveness of flood management measures implemented in the area. The responses were gathered from a sample representing both residential and industrial areas of Gurugram, reflecting the broader challenges faced in an industrial town undergoing rapid urbanisation. The data indicates that a significant portion of respondents perceive urban flooding as a severe issue in Gurugram. Specifically, 78 participants strongly agreed that urban flooding is a major problem, while 54 participants rated it as a significant concern (scale 4 out of 5).

A similar trend emerged regarding seasonal flooding, where 78 respondents reported frequent occurrences of urban flooding during the monsoon season. The pie chart depicting the months most associated with waterlogging issues highlights that July is the most critical period, with 102 responses identifying it as the peak month for waterlogging, followed by August (44 responses) and June (38 responses). The data suggests a clear monsoon-related vulnerability to urban flooding, which coincides with heavy rainfall months typical of the region's climate pattern. Urban flooding has had significant socio-economic and health-related impacts on the surveyed population. A majority of respondents (78) strongly agreed that urban flooding disrupts their daily activities such as commuting, attending work, and accessing basic services. Moreover, 82 respondents strongly believed that flooding poses serious health risks, particularly in the form of waterborne diseases such as cholera and diarrhoea, which are prevalent during the flood season. Financial repercussions were also prominent, with 112 respondents confirming that either they or someone in their family had experienced property damage or financial losses as a direct consequence of urban flooding. This highlights the urgent need for improved urban flood management strategies in Gurugram (Figure 4).

The survey also evaluated public perceptions of the factors contributing to urban flooding. Poor drainage infrastructure was identified as the leading contributor, with 68 respondents strongly agreeing and 40 moderately agreeing (scale 5 and 4 respectively) that inadequate drainage exacerbates flood risks in the city. Encroachment on natural water bodies ranked second, with 64 respondents moderately agreeing and another 40 strongly agreeing that it has significantly contributed to flooding.

Rapid and unplanned urbanization was another major concern, as 56 respondents strongly agreed that unregulated growth has worsened flooding conditions. Additionally, deforestation and reduced green cover were also seen as contributing factors, with 50 respondents strongly agreeing that the loss of natural vegetation has increased surface runoff and waterlogging incidents. Climate change, specifically the increased intensity and frequency of rainfall, was acknowledged by 60 respondents who strongly agreed that it plays a role in the rising urban flood risk (as seen in Figure 5).

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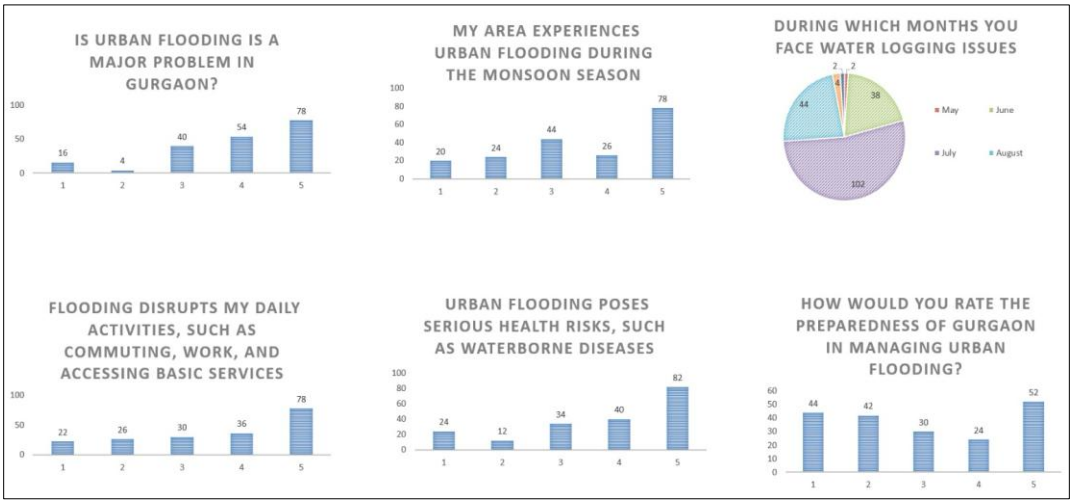
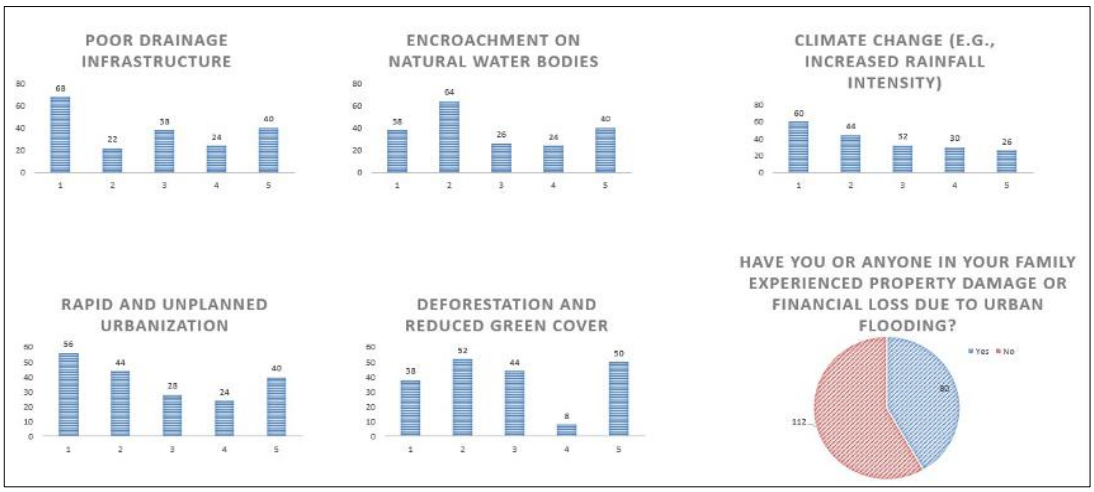
Figure 5: Respondents Perception about Urban Flooding in Study Area



Source: By authors

Figure 6: Factors Contributing to Urban Flooding in the Study Area



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Respondents were asked to evaluate the effectiveness of existing flood management measures in their local areas on a scale from 1 (very ineffective) to 5 (very effective). The results reveal a general dissatisfaction with current interventions. For instance, maintenance of drainage systems was rated as very ineffective by 90 respondents, highlighting major issues in

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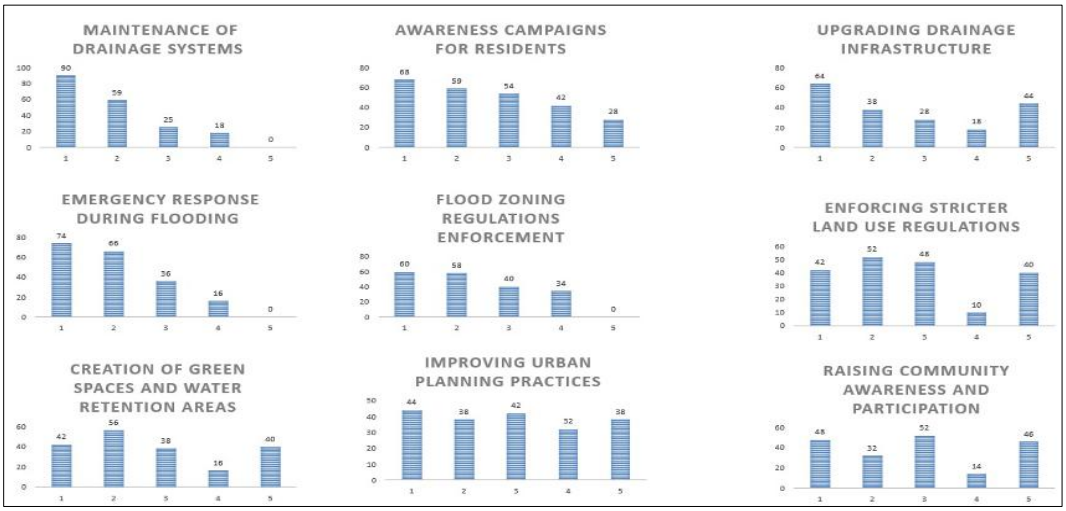
the upkeep and capacity of existing infrastructure. Similarly, emergency response during flooding was deemed ineffective, with 74 respondents giving it the lowest possible rating. The awareness campaigns for residents were slightly better rated but still concerning, with 68 participants marking them as largely ineffective. Flood zoning regulations and land use regulations enforcement also received mixed feedback, with a noticeable number of respondents rating them as moderately ineffective (60 and 58 respondents, respectively).

Figure 7: Effective Measures Implemented in the Study Area as per Respondents' Perception



Source: By authors

However, some positive feedback was recorded for upgrading drainage infrastructure and the creation of green spaces and water retention areas**,** where a segment of respondents (44 and 40 respectively) rated these measures as effective. Notably, raising community awareness and participation and improving urban planning practices showed relatively balanced opinions. Around 46 respondents viewed community participation as effective, whereas urban planning improvements were seen as moderately effective by 38 respondents. Lastly, when asked to rate the overall preparedness of Gurugram in managing urban flooding, the responses were divided. While 52 respondents rated the preparedness as effective (score of 5), a substantial portion—44 and 42 respondents—rated it as poor (scores of 1 and 2). This polarization reflects the inconsistency in the implementation and perceived success of urban flood management strategies across different parts of the city. The major parameters emerging from this analysis include the lack of proper drainage infrastructure**,** encroachment on water bodies**,** unplanned urban growth, and weak enforcement of planning regulations. Additionally, health risks,

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economic damages, and disruptions to daily life were consistently reported as critical consequences of urban flooding. While some measures such as the creation of green spaces show moderate success, there remains a critical gap in community preparedness and systemic responses to urban flood risks in Gurugram (as seen in Figure 7).

Interviews with key informants, including officials from MCG, the Haryana Urban Development Authority (HUDA), and local elected representatives, provided critical institutional perspectives on urban flood management challenges in Ward 32. Officials acknowledged that while the city's Drainage Master Plan exists, ward-level implementation is fragmented due to budgetary limitations, bureaucratic delays, and the lack of an integrated drainage and land-use plan. There was also recognition of the difficulties posed by rampant encroachment on natural water bodies and drains, which has disrupted the natural flow of stormwater. While some short-term measures have been initiated, such as localized drain cleaning and the raising of road levels in selected streets, there has been limited movement toward systemic and sustainable solutions. Officials cited limited land availability, legal disputes over land ownership, and a lack of technical expertise in green infrastructure as major barriers to implementing large-scale Nature-Based Solutions in Gurugram. Nevertheless, municipal officials expressed interest in piloting NBS projects, including sponge parks and bioswales, particularly in flood-prone areas where conventional infrastructure has failed to address the problem adequately. However, there is currently no formal mechanism in place for engaging the community in these efforts.

Figure 8: Classification of Nature-Based Solutions and their Usage in Gurugram

Name of NBS	Case Study	Where It Can Be Used in Gurgaon Ward 32	
Sponge Parks	**Qunli National Urban Wetland Park** in Harbin, China: Restored wetlands to mitigate flooding and improve biodiversity.	Designating low-lying open spaces near **NH-48** and residential areas in Ward 32 as sponge parks to capture and store stormwater.	
Rain Gardens	**Diverse projects in Portland, USA**: Small-scale green spaces used to absorb and filter stormwater.	Installing **rain gardens** along sidewalks and medians of **MG Road and Galleria Market area** to slow down runoff and reduce waterlogging.	
Urban Wetlands	**East Kolkata Wetlands, India**: A natural wetland system treating wastewater while reducing flood risks.	Restoring natural depressions and low-lying areas near **Wazirabad Drain**, converting them into wetlands to manage flood overflow.	
Green Roofs	**Singapore's Green Roof Program**: Rooftop vegetation to reduce runoff and urban heat.	Encouraging commercial and residential buildings near **DLF Phase IV** to install **green roofs** to manage rainwater at its source.	
Permeable Pavements	**Palava Smart City, Mumbai**: Introduced permeable concrete for sidewalks and parking areas.	Replacing impervious concrete in **residential lanes** and parking spaces in Ward 32 with permeable pavements to reduce surface runoff.	
Bioswales	**High Line, New York**: Vegetated channels designed to manage stormwater runoff.	Creating **bioswales** along internal roads in Ward 32, particularly near schools and community centers, to filter and channel water.	
Retention Ponds	**Bhopal's Upper Lake Revitalization**: Used as a stormwater reservoir to	Building small **retention ponds** in underutilized parks or open areas near Ward 32 to temporarily store stormwater during peak rainfall.	

Source: By authors

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Nature-based solutions (NBS) offer a promising alternative to traditional flood control infrastructure. By working with natural processes, NBS can help mitigate flood risks, enhance urban resilience, and provide co-benefits such as improved biodiversity, air quality, and recreational spaces for residents. Some of the most relevant NBS types for Ward 32 include Permeable pavements, Bioswales, Rain Gardens, Green Roofs, Sponge Parks etc. (as mentioned in Figure 8). The survey revealed that while direct knowledge of these solutions was low, there is broad support for the idea of green infrastructure if framed as a way to reduce flooding and improve local living conditions. 84% of respondents expressed that they would support or help maintain green spaces that could also serve to manage stormwater effectively. Based on both community feedback and physical site observations, Saraswati Kunj has been identified as a potential site for developing a Sponge Park (see Figure 9). This study area was consistently mentioned by respondents during the survey as an area prone to chronic waterlogging during monsoons. The selected site is strategically located at a topographic low point within Ward 32, making it ideal for intercepting and storing runoff during heavy rain events. The site, currently covered with degraded grass and informal dumping of solid waste, presents an opportunity to be transformed into a multi-functional green space.

Figure 9: Site Selected for NBS (Sponge Park) to Mitigate Urban flooding

Source: By authors

A well-designed sponge park here could achieve several objectives, such as Retention of stormwater (reducing flood peaks), Groundwater recharge (supporting local water security),

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Provision of recreational space (contributing to community well-being), and Improvement of local biodiversity by introducing native vegetation. Community feedback indicated that 55% of residents would be willing to participate in tree planting, park maintenance, and other related activities that could help in mitigating the issue, provided that the initiative is championed by the municipal authorities and supported with basic resources. The combined results of the community survey and key informant interviews highlight a clear need for integrated flood management strategies in Ward 32 that go beyond conventional infrastructure solutions. The lack of awareness about NBS among residents contrasts with their strong willingness to engage in community-based projects if properly mobilized. Institutional gaps, particularly in terms of cross-agency coordination and public participation, continue to hinder progress. However, the identification of a viable sponge park site near the Saraswati Kunj presents a concrete opportunity to pilot nature-based interventions within a highly vulnerable urban area.

4.0 Conclusion

Based on the survey findings, it is evident that urban flooding poses a persistent and severe challenge for Gurugram, particularly during the monsoon season, leading to significant disruptions in daily life, health risks, and financial losses for residents. The study highlights key contributing factors such as poor drainage infrastructure, rapid and unplanned urbanization, encroachment on natural water bodies, and reduced green cover, all of which are exacerbated by climate change-induced rainfall variability. While some flood mitigation efforts, including awareness campaigns and the creation of green spaces, show marginal effectiveness, the overall perception of Gurugram's flood preparedness remains low.

These findings underscore the urgent need for integrated urban planning strategies, stricter land use enforcement, and enhanced community participation to build resilience against urban flooding in this rapidly industrializing city.

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