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URBAN RIVERINE FLOOD RISK & VULNERABILITY ANALYSIS FOR GANGA BASIN IN UTTAR PRADESH

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Abstract - *This study investigates urban riverine flooding in the Ganga Basin, Uttar Pradesh, emphasizing the region's vulnerability due to rapid urbanization, inadequate drainage, and recurring monsoon floods. Using the Analytical Hierarchy Process (AHP), the study systematically assesses flood risk by evaluating hydrological, topographical, urban development, socio-economic, and environmental factors. AHP enables the prioritization of mitigation measures by structuring complex variables into a hierarchical model. The research advocates for integrating AHP to enhance flood risk analysis and urban planning. Findings highlight the significant influence of socio-economic and environmental conditions on flood impacts and underscore the need for targeted, data-driven interventions. The study offers a valuable framework for urban planners and policymakers to identify vulnerable zones and implement effective, sustainable flood management strategies. Its insights contribute to global discussions on disaster resilience and urban sustainability, with potential applicability to other flood-prone urban regions.*

Key Words: Urban riverine flooding, Vulnerability, Risk, Flood susceptibility, Analytical Hierarchy Process (AHP), Flood vulnerability, Flood risk assessment, Geographic Information System (GIS), Remote Sensing (RS)

1. INTRODUCTION

Urban flooding is an increasingly critical environmental and economic issue, especially in rapidly urbanizing regions. It occurs when intense rainfall or coastal overflow overwhelms drainage systems, leading to widespread inundation. Factors such as unplanned urbanization, climate change, and natural erosion exacerbate the problem. Urban areas, with their high population density, poor infrastructure, and limited drainage capacity, are particularly vulnerable. The Ganges River, stretching over 2,500 miles from the Himalayas to the Bay of Bengal, sustains millions of people but also poses a major flood risk. Among the states in the basin, Uttar Pradesh faces some of the most severe impacts on health, safety, and livelihoods.

The Ganges Basin, one of the world's largest, spans about 984,076 square kilometres across India, Nepal, China, and Bangladesh. In India, it covers several flood-prone states, including Uttar Pradesh, Bihar, and West Bengal. Traditional flood management approaches are often inadequate for dealing with the complexity of modern urban environments. The Analytical Hierarchy Process (AHP) provides a robust decision-making framework by integrating hydrological, topographical, socio-economic, and land use parameters. By structuring these factors hierarchically and assigning them relative weights, AHP allows for effective prioritization of risk mitigation efforts. It offers a data-driven, adaptable approach for developing resilient urban flood management strategies.

1.1 Urban Riverine Flooding in India

India is vulnerable to urban riverine flooding due to its extensive network of rivers. During the monsoon season, the country gets over 75% of its annual rain in a short period of time. This causes the rivers to overflow their banks and cause flooding. There are additional challenges for urban centers located near rivers.

The Ganga, Brahmaputra, and Godavari are some of the major river basins in India. Billions of dollars are lost annually when floods affect millions of people. Despite significant investments in flood control infrastructure, the problem persists due to poor maintenance, encroachments, and a lack of integrated water management.

1.2 Uttar Pradesh: The Heart of the Ganga Basin

Uttar Pradesh holds a central position in the Ganga Basin, intersected by major rivers like the Ganga, Yamuna, Ghaghara, Rapti, and Gandak. Its fertile Indo-Gangetic Plain supports dense populations and intensive agriculture, but also heightens flood vulnerability. The state faces recurrent monsoon floods, with the 2022 events devastating districts like Gorakhpur, Balrampur, and Siddharthnagar. These floods were intensified by heavy rainfall, inadequate drainage, and unplanned urban expansion. Uttar Pradesh is the second-most flood-affected state in the Ganges Basin, with sub-basins like the Ghagra and Middle Ganges significantly contributing to its flood risk. Approximately 17.3 million people are exposed to flooding in a two-year return period event, and the state suffers substantial Average Annual Losses (AAL). Both urban centers and rural areas are at risk, with high-priority intervention needed in districts such as Varanasi, Prayagraj, Mirzapur, Kanpur, and Ballia. This underscores the urgent need for localized and data-driven flood risk mitigation strategies.

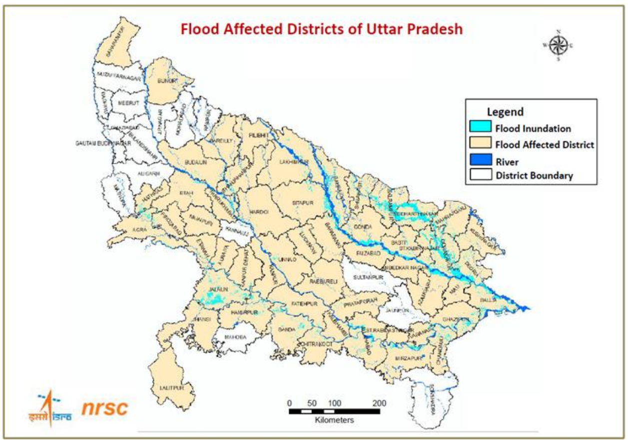

Fig -1: Map of flood affected District in Uttar Pradesh

2. VULNERABILITY AND RISK IN FLOOD MANAGEMENT

Vulnerability and risk are fundamental concepts in disaster management, environmental studies, and urban planning, particularly in flood-prone regions. While closely related, they serve distinct purposes in assessing the potential impact of natural hazards such as urban flooding.

2.1 Vulnerability

Vulnerability refers to the susceptibility of a system, community, or area to harm when exposed to a hazard like flooding. It encompasses multiple dimensions:

Physical Vulnerability: Involves physical characteristics such as elevation, infrastructure quality, proximity to water bodies, and drainage capacity. Low-lying areas or poorly constructed settlements are more physically vulnerable.

Social Vulnerability: Relates to the demographic and socio-economic characteristics of a population. Groups such as the elderly, children, low-income households, and those in informal settlements are more socially vulnerable.

Economic Vulnerability: Refers to potential economic losses from flood events—damage to homes, businesses, jobs, and infrastructure.

Environmental Vulnerability: Considers the susceptibility of ecosystems and natural resources, such as wetlands and forests, to flood damage, often with long-term ecological consequences.

Contributing Factors to Vulnerability:

Urbanization: Unplanned growth increases impermeable surfaces, encroachment on floodplains, and weak drainage infrastructure.

Hydrology: River behavior, rainfall patterns, and water discharge determine flood dynamics.

Topography: Flat or low-lying regions are naturally more prone to water accumulation and flood events.

2.2 Risk

Risk is the potential for loss or damage resulting from a hazard. It combines the likelihood of a hazard (such as flooding) with the level of vulnerability and exposure of the affected area.

Risk Formula:

Risk = Hazard × Vulnerability
Risk = Hazard × Exposure × Vulnerability

Components of Risk:

Hazard Frequency/Probability: The recurrence of floods in a specific area (e.g., annual monsoons).

Exposure: The presence of people, assets, and infrastructure in flood-prone zones.

Vulnerability: The degree to which the exposed systems or communities can be harmed.

3. CAUSES, IMPACTS AND RISKS OF URBAN FLOODS

Understanding the key factors driving urban flooding is crucial to mitigating its widespread impacts on society. Urban floods cause significant socio-economic disruptions, affecting essential services like transportation, power, sewage, and communication, while damaging infrastructure. The risk of flooding is expected to intensify, particularly in densely populated cities with high-value assets. Two major contributors to this rising threat are climate change and urbanization. Climate change alters the global water cycle, leading to more intense and unpredictable rainfall events. Meanwhile, urbanization—driven by population growth and economic expansion—leads to increased impervious surfaces like roads and buildings, reducing natural water infiltration. This not only amplifies surface runoff but also increases the vulnerability of urban populations and infrastructure. Together, these factors strain existing flood management systems and pose challenges for future planning, highlighting the urgent need for adaptive, integrated, and forward-looking flood mitigation strategies in urban environments.

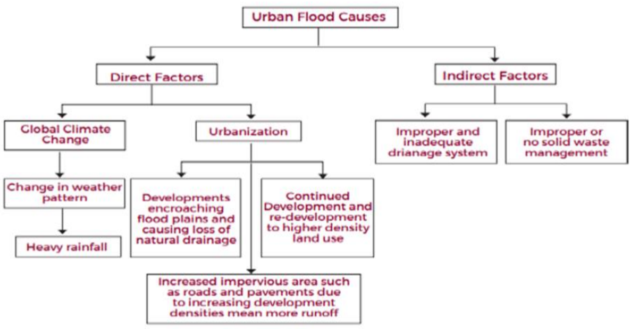

Fig -2: Urban Flood Causes

Urban flooding in India arises from a blend of natural and human-induced factors, with anthropogenic influences becoming increasingly significant. Key contributors include rapid urbanization, unplanned development in low-lying and hilly areas, and encroachment on natural drainage systems. Impervious surfaces and poor waste management overwhelm drainage infrastructure, leading to frequent flooding. Climate change has intensified extreme rainfall events, and the urban heat island effect further increases precipitation in cities. Additionally, the absence of a centralized flood management authority and fragmented policy implementation hinder effective flood mitigation, making urban areas more vulnerable to recurrent and severe flooding events.

3.1 Direct Factors

Climate change and urbanization are key direct factors contributing to urban flooding. Global climate models predict a significant rise in global temperatures by the end of the 21st century, with India already experiencing a warming trend of 0.62°C per century. Rising temperatures increase atmospheric moisture, resulting in heavier rainfall and more frequent extreme weather events, such as storms and cyclones.

Urbanization exacerbates flooding by increasing impervious surfaces like roads and pavements, which prevent water infiltration and accelerate surface runoff. The removal of vegetation and natural absorption areas during development, combined with dense construction, further intensifies the impact. Additionally, urban growth disrupts natural drainage systems, heightening flood risks.

Encroachments on river floodplains pose a major challenge. Despite devastating floods in India—such as those in Mumbai (2005), Kedarnath (2013), and Chennai (2015)—there remains no strict legal protection for floodplains. These areas naturally allow rivers to disperse excess water, but illegal settlements restrict river expansion, leading to severe flooding. Government inaction has worsened this issue, as highlighted by reports showing widespread encroachment of urban water bodies and poor enforcement against violators. Collectively, these human-induced factors significantly elevate the frequency and severity of urban floods.

3.2 Indirect Factors

Poor urban planning is a major indirect factor contributing to flooding in India. Inadequate drainage systems, rapid urban growth, and unregulated development have intensified vulnerabilities. Expanding impervious surfaces disrupt natural ecosystems, reduce water absorption, and increase flood risks, especially in low-lying areas. Despite government efforts, urban planning lacks cohesion, leading to hazardous settlements and environmental degradation. From 1915 to 2015, India faced 649 major disasters—47% of them floods—impacting over 40 million hectares of flood-prone land across the country.

3.3 Impacts and Risks Due to Urban Floods

Urban floods pose serious threats to cities, affecting lives, infrastructure, and economic activity. Flooding can range from local disruption to widespread inundation, causing fatalities, property damage, and health risks. Losses are categorized as tangible and intangible. Tangible losses include direct structural damage and indirect economic disruptions. Intangible losses involve life loss, health issues, environmental harm, and post-flood psychological trauma. The cascading effects of floods strain emergency services, hinder recovery efforts, and highlight the urgent need for resilient urban planning.

3. LITERATURE STUDY REVIEWS

3.1 "Flood Vulnerability Analysis and Risk Assessment Using Analytical Hierarchy Process (AHP)"

The study focuses on flood vulnerability and risk assessment in Paschim Medinipur, a district in West Bengal, India, particularly prone to flooding due to the presence of four major river basins—Kangsabati, Kaliaghai, Silabati, and Subarnarekha. Among these, the first three basins are notably more vulnerable to flooding. The district experiences frequent flood events between July and October, largely driven by monsoonal rains. In this context, the study employs the Analytical Hierarchy Process (AHP) to perform a multi-criteria decision analysis, combining physical, social, and coping capacity indicators to assess flood risk and prioritize intervention areas.

The primary objective of the research is to systematically identify, classify, and quantify the elements at risk, focusing on the population's vulnerability and coping mechanisms in floodplain areas. The study incorporates the concept of vulnerability as the potential for loss or damage due to exposure to hazards, while risk is defined as the likelihood of such loss occurring in a given hazard scenario.

The methodology involves collecting data across three main dimensions—physical, social, and coping capacity factors. These include topographical data (elevation, land use, geology, proximity to rivers), demographic data (population density, age distribution, poverty, housing types, literacy), and disaster preparedness metrics (awareness, shelter and hospital availability). Each factor is assigned a weight using AHP through systematic pairwise comparisons, ensuring consistency and accuracy in decision-making. The weighted factors are integrated into three separate indices—Physical Vulnerability Index (PVI), Social Vulnerability Index (SVI), and Coping Capacity Index (CCI)—which are then combined using a Weighted Linear Combination (WLC) technique to produce the Composite Vulnerability Index (CVI).

Geographic Information System (GIS) tools are used throughout to visualize spatial distribution and produce flood risk maps at community levels.

Physical vulnerability factors reveal that areas below 30 meters in elevation are highly susceptible to flooding. Land use data show that cultivated lands are at significant risk, as flood-induced agricultural loss directly affects rural livelihoods. Proximity to active river channels increases flood exposure—areas within 0.5 km of rivers are most at risk. Geological features are also examined: floodplain deposits are the most flood-prone, followed by areas with sandy and clayey soils.

The study places significant emphasis on population density, identifying densely populated areas as more vulnerable due to evacuation challenges and greater potential impact. Vulnerable groups include children (especially the 0–4 age group) and the elderly (above 60 years), who face heightened risks during emergencies. Economic vulnerability is reflected in poverty levels, with poorer communities having fewer resources to respond to and recover from floods. Housing types also play a crucial role—katcha (temporary) structures located near water bodies are particularly susceptible to damage. Furthermore, illiteracy correlates with reduced disaster preparedness, and poor sanitation increases health risks post-flooding.

The study develops flood risk maps that help visualize high-risk zones and support targeted disaster mitigation strategies. Approximately 24.25% of the population in Paschim Medinipur is found to reside in high to very high flood-risk zones, predominantly located in the southern and southeastern parts, especially the Ghatal sub-division. This region's vulnerability is attributed to its low elevation, proximity to rivers, high population density, and concentration of economically and educationally disadvantaged groups. The key vulnerable demographics include individuals living in poverty, those with low literacy levels, and residents of non-durable mud houses.

The study demonstrates the effectiveness of AHP in integrating multiple layers of vulnerability and risk data into a coherent, actionable framework. By combining spatial, physical, and socio-economic indicators, the analysis offers a nuanced understanding of flood vulnerability in Paschim Medinipur. The resulting Composite Vulnerability Index and flood risk maps serve as essential tools for urban planners, policymakers, and disaster management authorities. These tools enable the identification of the most at-risk areas and populations, guiding resource allocation, emergency response, and long-term flood mitigation planning. The methodology is replicable and can be adapted for use in other flood-prone regions, making it a valuable contribution to disaster risk reduction strategies.

3.2 "Flood hazard risk zoning through AHP, GIS, and RS: A case study of Ramganga River Basin (India)"

The study titled "Flood Hazard Risk Zoning through AHP, GIS, and RS: A Case Study of Ramganga River Basin (India)" presents an integrated approach to identifying and assessing flood hazard zones using Analytical Hierarchy Process (AHP), Geographic Information System (GIS), and Remote Sensing (RS) tools. Focusing on the Ramganga River Basin, which stretches across parts of Uttarakhand and Uttar Pradesh, the research addresses the increasing threat of floods in the region—aggravated by natural conditions and anthropogenic influences such as rapid urbanization and deforestation.

A combination of spatial and non-spatial data forms the foundation of the study. Non-spatial data were sourced from the Census of India (2011), while spatial data included Sentinel satellite imagery, SRTM DEM, soil maps, geomorphological and geological data from GSI, and climatic records from World Climate. These datasets were processed and analyzed using ArcGIS.

The primary objective of the research is to delineate flood hazard zones within the basin using a multi-criteria decision-making framework. Fourteen parameters were identified as critical to flood vulnerability, encompassing physical (elevation, slope, drainage density, land use, soil), environmental (precipitation, climate variability), and social indicators (population density, infrastructure, accessibility). The AHP method was employed to assign weights to each criterion through pairwise comparisons, ensuring a structured and objective prioritization of factors. These weights were then integrated with spatial data through a GIS-based Weighted Overlay Analysis, leading to the generation of a Flood Hazard Risk Map.

The study area exhibits complex geomorphological and geological features, including structural hills, valleys, and alluvial plains, shaped by tectonic activity, erosion, and sediment deposition. Geological structures such as the Himalayan Frontal Fault and Main Boundary Thrust further influence hydrological patterns. Land use and land cover (LULC) changes—particularly deforestation and urban expansion—play a crucial role in exacerbating flood risks by reducing infiltration and increasing runoff. Similarly, soil types—ranging from mountain soils in high-altitude zones to alluvial soils in the plains—affect water retention and erosion susceptibility.

Accessibility and population distribution were also assessed, using models like Access Mod 5, to understand the ease with which communities can evacuate or access flood relief during emergencies. High population densities and poorly developed infrastructure increase both exposure and vulnerability. Hydrological and topographic parameters such as drainage density, surface slope, elevation, aspect, planform curvature, Slope Position Index (SPI), and

Topographic Wetness Index (TWI) were meticulously analyzed to understand water flow, accumulation potential, and runoff dynamics.

Key findings of the study include the successful zoning of the basin into five flood risk categories: Very High, High, Moderate, Low, and Very Low. Approximately 10.2% of the region falls under "Very High Risk," and 17.8% under "High Risk," highlighting areas that need urgent flood management interventions. The study illustrates the effectiveness of combining AHP for decision support, GIS for spatial visualization, and RS for accurate terrain mapping. The resulting flood hazard maps serve as crucial tools for policymakers, planners, and disaster management authorities in devising evacuation plans, infrastructure design, and land-use regulations.

In conclusion, the study demonstrates that AHP-GIS-RS integration provides a scientifically robust and scalable methodology for flood hazard assessment. It supports proactive risk mitigation, especially in ecologically sensitive and densely populated regions like the Ramganga River Basin. By combining multi-dimensional criteria—physical, social, and environmental—the framework ensures a holistic understanding of flood risks, thus promoting sustainable regional planning and disaster resilience.

3.3 "Flood Vulnerability Assessment Using AHP and Frequency Ratio Techniques"

The study titled "Flood Vulnerability Assessment Using AHP and Frequency Ratio Techniques" explores the complex dynamics of flood risk in the Torsa-Raidak River Basin, located in northeastern West Bengal, India. With floods being one of the most destructive hydro-meteorological hazards globally—affecting around 170 million people annually—the research aims to develop a robust, geospatially driven model for flood vulnerability assessment. Using a combination of the Analytical Hierarchy Process (AHP) and Frequency Ratio (FR) techniques, supported by Geographic Information System (GIS) and Remote Sensing (RS) tools, the study identifies key flood-contributing factors and quantifies their spatial influence on flood-prone zones.

The Torsa-Raidak integrated basin spans approximately 12,316 km^2, encompassing parts of Bhutan and India, including the districts of Alipurduar and Cooch Behar. The region is geographically characterized by a north-south slope gradient, transitioning from high elevations in Tibet and Bhutan to flat plains in West Bengal. The basin experiences heavy monsoonal rainfall, making it highly susceptible to recurrent flooding. For this study, six critical parameters were selected to model flood risk: elevation, slope gradient, topographic wetness index (TWI), rainfall, land use/land cover (LULC), and proximity to rivers. These factors were analyzed using geospatial data to generate thematic maps that informed the vulnerability analysis.

To prioritize the influence of each factor, the AHP method was used to assign relative weights through a structured pairwise comparison matrix, followed by consistency ratio checks to validate the weighting scheme. Concurrently, the FR model was employed to establish the statistical relationship between historical flood occurrence and each contributing factor. Historical flood data—sourced from the National Remote Sensing Centre—identified 156 flood-affected locations, of which 75% were used for training the model and the remaining for validation. The Area Under the Curve (AUC) method was applied to evaluate the model's predictive accuracy, confirming the reliability of the derived flood susceptibility maps.

The analysis revealed that rainfall is the most influential factor in flood generation, with more than 90% of annual precipitation occurring during the monsoon season. Flood-prone zones were strongly associated with areas of low elevation, gentle slopes, and close proximity to rivers. Furthermore, land use changes—particularly the presence of agricultural lands and sandbars—were found to exacerbate flood risks due to reduced infiltration and increased surface runoff. The combined AHP and FR approach produced a Flood Vulnerability Index (FVI) that categorized the basin into various risk levels, identifying approximately 27.84% of the total area as being under high to very high flood risk. The districts of Alipurduar and Cooch Behar were found to be the most vulnerable, with recurring flood events causing widespread socioeconomic disruption.

Beyond rural implications, the study offers significant insights for urban flood management. The AHP model proved effective in integrating diverse environmental and anthropogenic variables, allowing for informed prioritization of flood risk factors—a critical need in urban planning where infrastructure decisions must balance development and hazard mitigation. The study highlights how land use changes, especially urban expansion with impervious surfaces, intensify flood vulnerability. The inclusion of LULC and proximity to rivers aligns closely with urban flood studies, where land transformation and river encroachment are major risk amplifiers.

Moreover, the integration of high-resolution spatial data through GIS and RS provided a scalable and replicable approach for urban flood vulnerability mapping. The topographical analysis underscored that flat terrains and low-lying areas are inherently more susceptible to inundation, emphasizing the need for elevation-based zoning and effective storm water drainage design in urban settings. The study also brought attention to socioeconomic vulnerability, noting that low-income groups are disproportionately affected by floods due to their settlement in high-risk areas and limited access to resources for recovery.

In conclusion, this study demonstrates the effectiveness of combining AHP and FR models within a geospatial framework to assess flood vulnerability. The methodology successfully integrates physical, climatic, and human-induced factors, offering a holistic understanding of flood risk. The findings provide a valuable foundation for disaster risk reduction strategies, urban resilience planning, and policy development. Most importantly, the approach underscores the need for multi-criteria decision-making, high-resolution data, and equity-focused planning in managing the growing challenges of flood risk in both rural and urban riverine environments.

4. ANALYTICAL HIERARCHY PROCESS (AHP) TOOL

The Analytic Hierarchy Process (AHP) is a structured decision-making methodology that helps in comparing and evaluating complicated options by way of breaking down a trouble right into a hierarchy of sub-troubles or standards. It became advanced through Thomas L. Saaty in the 1970s and has seeing that been broadly utilized in various fields, together with urban making plans, danger management, and environmental evaluation.

4.1 Key Features of AHP

Hierarchical Structure: AHP breaks down a trouble into a hierarchical shape, beginning from the general intention on the pinnacle, followed by using standards, sub-standards, and options at the decrease tiers. This facilitates in organizing the trouble in a scientific manner.

Pairwise Comparison: The center of AHP includes making pairwise comparisons between the elements at each level of the hierarchy. The selection-makers evaluate two factors at a time and investigate their relative significance or desire the usage of a scale of values. The scale degrees from 1 (identical importance) to nine (extremely more essential), wherein values like 3, 5, and 7 constitute intermediate ranges of importance.

Mathematical Consistency: AHP uses mathematical techniques to mixture the outcomes of pairwise comparisons. The system ensures that the comparisons are steady and that the judgment made by means of the selection-makers is reliable.

5. UTILIZATION OF AHP IN URBAN RIVERINE FLOOD RISK AND VULNERABILITY ANALYSIS

The Analytic Hierarchy Process (AHP) can be extremely useful in assessing urban riverine flood risk and vulnerability, as it allows for a structured, systematic evaluation of the complex interplay of factors that contribute to flood risk. Here's how AHP can be applied in this study.

5.1. Defining the Goal

The primary goal of the study is to assess flood risk and vulnerability in urban areas along the riverine regions of the Ganga basin, particularly in Uttar Pradesh.

5.2. Identifying the Criteria

The key factors or criteria influencing flood vulnerability in urban areas can be identified as:

Urbanization Patterns: This includes factors like population density, land use patterns, infrastructure, and urban sprawl.

Hydrology: Factors such as river discharge, flood frequency, river bank erosion, and seasonal variations in water levels.

Topography: Physical characteristics of the land, such as elevation, slope, and proximity to the river, which determine how water flows and accumulates during floods.

Socio-Economic Factors: Vulnerability of certain groups based on income, health, and social conditions.

Environmental Factors: Detrimental environmental effects of flooding can include soil and bank erosion, bed erosion, siltation or landslides. It can damage vegetation and pollutants carried by flood water can impact on water quality, habitats and flora and fauna.

5.3. Pairwise Comparison of Criteria

Experts or stakeholders can compare the importance of these criteria. For example:

Urbanization patterns might be considered more important than topography in flood vulnerability analysis because urbanization often leads to poor drainage systems and encroachment on floodplains.

Hydrology could be ranked higher than socio-economic factors if the focus is on the physical flood hazard itself.

5.4. Assigning Weights

Based on the pairwise comparisons, weights are assigned to each of the criteria. For example, the relative importance of urbanization patterns (weight = 0.4), hydrology (weight = 0.3), topography (weight = 0.2), and socio-economic factors (weight = 0.1) could be calculated.

5.5. Risk Aggregation and Final Ranking

The weighted scores for each city location are computed through multiplying the criteria weights by means of the scores. The final rating would show which urban regions are maximum at risk of flooding. The region with the very best rating will be the maximum prone to riverine flood danger. Benefits of AHP in Flood Risk and Vulnerability Analysis:

Systematic and Transparent: AHP gives a clear, based technique to comparing complicated flood chance and vulnerability elements.

Incorporates Expert Judgment: AHP is based on professional opinions that is treasured whilst precise information may be missing or while subjective elements like network resilience or infrastructure nice are difficult to quantify.

Multi-Criteria Decision Making: It allows for the attention of more than one criteria concurrently, that is crucial in city flood risk evaluation wherein various factors (social, physical, environmental) have interaction.

Helps Prioritize Areas for Intervention: By rating city regions based on their vulnerability and danger, AHP allows prioritize places that need greater immediate flood mitigation efforts, coverage changes, or infrastructure improvements.

6. PARAMETERS INFLUENCING VULNERABILITY AND RISK DERIVED FROM THE STUDIES

Flood risk in urban riverine regions is influenced by a combination of hydrological, topographical, urban development, socio-economic, and environmental factors. Understanding these parameters is crucial for effective flood management and mitigation strategies.

The important main Factors and their corresponding sub-factors for Uttar Pradesh urban riverine region identified from the literature study are:

Hydrological Factors

Rainfall Intensity: Heavy rainfall can quickly overwhelm drainage systems, leading to flooding.

Rainfall Duration: Prolonged rainfall saturates the soil, reducing its ability to absorb water and increasing runoff.

River Discharge: High volumes of water flowing through rivers can cause them to overflow, flooding nearby areas.

Topographical Factors

Slope: Steeper slopes lead to faster water flow, increasing the risk of erosion and flash floods.

Soil Permeability: Soils with high permeability absorb more water, reducing runoff, while low permeability soils lead to higher surface runoff.

Elevation: Low-lying areas are more prone to flooding compared to elevated regions.

Urban Development Factors

Impervious Surfaces: Urban areas with surfaces like concrete and asphalt prevent water infiltration, increasing runoff.

Drainage Infrastructure: Effective drainage systems are essential for managing excess water. Poor infrastructure can exacerbate flooding.

Land Use: Dense construction and limited green spaces in urban areas contribute to higher flood risks.

Socio-Economic Factors

Population Density: Higher population densities increase the potential impact of floods, leading to more casualties and property damage.

Economic Value of Exposed Assets: Financial losses are higher in areas with valuable assets.

Vulnerable Communities: Disadvantaged groups often reside in flood-prone areas and have limited resources for recovery.

Environmental Factors

Vegetation Cover: Dense vegetation helps absorb water, reducing runoff. Loss of vegetation increases flood risk.

River Channel Condition: Well-maintained river channels can handle larger water volumes, while blocked channels can overflow.

Floodplain Encroachment: Human activities in floodplains, such as construction, can alter natural water flow and increase flood risk.

7. HIERARCHY OF PARAMETERS INFLUENCING VULNERABILITY AND RISK USING AHP

Using Analytical Hierarchy Process (AHP) a hierarchy of above mention factors which influence vulnerability and risk for riverine flood in Uttar Pradesh is been created, which will help to identify the area with are most vulnerable and risk prone if these factors are checked for the same.

Table -1: Main factors influencing vulnerability and risk for riverine flood

Main Factors	Main Weight	Rank
Hydrological Factors	0.497	1
Topographical Factors	0.245	2
Urban Development Factors	0.105	3
Environmental Factors	0.105	4
Socio-Economic Factors	0.047	5

Table -2: Weightage Calculation of hydrological sub-factors influencing vulnerability and risk

Sub-Factors	Local Weight	Global Weight (Main × Local)
Rainfall Intensity	0.633	0.315
Rainfall Duration	0.261	0.13
River Discharge	0.105	0.052

Table -3: Weightage Calculation of topographical sub-factors influencing vulnerability and risk

Sub-Factors	Local Weight	Global Weight (Main × Local)
Slope	0.633	0.155
Soil Permeability	0.261	0.064
Elevation	0.105	0.026

Table -4: Weightage Calculation of urban development sub-factors influencing vulnerability and risk

Sub-Factors	Local Weight	Global Weight (Main × Local)
Impervious Surface	0.633	0.067
Drainage Infrastructure	0.261	0.027
Land Use	0.105	0.011

Table -5: Weightage Calculation of environmental sub-factors influencing vulnerability and risk

Sub-Factors	Local Weight	Global Weight (Main × Local)
Vegetation Cover	0.633	0.067
River Channel Condition	0.261	0.027
Floodplain Encroachment	0.105	0.011

Table -6: Weightage Calculation of Socio-Economic sub-factors influencing vulnerability and risk

Sub-Factors	Local Weight	Global Weight (Main × Local)
Vegetation Cover	0.633	0.067
River Channel Condition	0.261	0.027
Floodplain Encroachment	0.105	0.011

Table -7: Overall hierarchy ranking each sub factors with respect to its weightage of importance

Rank	Sub-Criterion	Main Criterion	Global Weight
1	Rainfall Intensity	Hydrological Factors	0.315
2	Slope	Topographical Factors	0.155
3	Rainfall Duration	Hydrological Factors	0.13
4	Impervious Surface	Urban Development Factors	0.067
4	Vegetation Cover	Environmental Factors	0.067
6	Soil Permeability	Topographical Factors	0.064
7	River Discharge	Hydrological Factors	0.052
8	Population Density	Socio-Economic Factors	0.03
9	Drainage Infrastructure	Urban Development Factors	0.027
9	River Channel Condition	Environmental Factors	0.027
11	Elevation	Topographical Factors	0.026
12	Economic Value	Socio-Economic Factors	0.012
13	Land Use	Urban Development Factors	0.011
13	Floodplain Encroachment	Environmental Factors	0.011
15	Vulnerable Communities	Socio-Economic Factors	0.005

8. IMPLICATIONS OF STUDY FOR GANGA BASIN IN U.P.

The Ganga Basin in Uttar Pradesh faces significant flood risks due to extensive urbanization, high population density, and hydrological variability. Applying the findings of the report to this context:

1. Use of AHP for Risk Prioritization

AHP can help rank important flood threat factors precise to the Ganga Basin, together with severe monsoonal rainfall, proximity to most important rivers (e.g., Ganga, Ghagra), and urban improvement styles. The method allows for tailor-made mitigation techniques by identifying the maximum influential elements in city flood vulnerability.

2. Flood Risk Mapping for High-Risk Zones

Using GIS, flood susceptibility maps can be created for main urban centers in Uttar Pradesh, such as Varanasi, Prayagraj, Kanpur, and Ballia, which might be often laid low with Ganga floods. These maps can manual land use planning, zoning regulations, and infrastructure improvement to decrease publicity.

3. Addressing Anthropogenic Impacts

Urban regions alongside the Ganga have witnessed fast increase, main to impervious floor enlargement and decreased infiltration capacity. There need for inexperienced infrastructure answers, such as Permeable pavements, Retention basins, Restoration of herbal floodplains.

4. Inclusion of Socioeconomic Factors

Vulnerable companies in Uttar Pradesh, especially the ones in casual settlements or economically weaker sections, require centered interventions, consisting of Construction of community flood shelters, Improvement in early caution systems & Enhanced get entry to assets during flood events.

5. Improved Policy Framework

Policymakers can use the AHP-based method to allocate sources more efficaciously, focusing on flood-susceptible zones diagnosed through vulnerability indices. Incorporating AHP into catastrophe management plans might make certain data-driven selection-making.

6. Climate Change Adaptation

With changing rainfall styles due to weather change, the Ganga Basin faces growing flood dangers therefore dynamic elements like rainfall intensity and frequency is specifically applicable for preparing long-term mitigation techniques.

9. CONCLUSIONS

The study highlights the effectiveness of the Analytical Hierarchy Process (AHP) as a structured method for flood risk analysis by enabling the prioritization of key vulnerability factors such as elevation, slope, rainfall, and land use. When integrated with geospatial tools like GIS and Remote Sensing, AHP enhances the accuracy of identifying high-risk flood zones by combining environmental, physical, and spatial data. It demonstrates that areas with flat terrain, low elevation, and proximity to rivers are especially prone to flooding, emphasizing the importance of topographical analysis. Human activities such as urbanization and land use changes further exacerbate flood risks by increasing surface runoff and reducing water absorption.

The study also stresses the unequal impact of floods on socioeconomically disadvantaged groups, highlighting the need to include social vulnerabilities in flood management strategies. Overall, the findings underscore the value of a multi-criteria, spatial approach for creating reliable flood vulnerability maps and support the use of such frameworks for disaster preparedness and sustainable urban planning in flood-prone regions.

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