Tec Empresarial
P-ISSN: 1659-2395; E-ISSN: 1659-3359

MAGNITUDE AND INTENSITY OF URBAN FLOOD IN KOLKATA MUNICIPAL CORPORATION USING ANALYTICAL HIERARCHY PROCESS BY MULTI-CRITERIA DECISION ANALYSIS

Dibakar Dutta[1*] and Ramkrishna maiti[2]

[1]Research Scholar, Department of Geography, Vidyasagar University, Midnapore, Dist - Paschim Medinipur, West Bengal, India, Midnapore, West Bengal-721102, India, *dibakardutta1993@gmail.com

[2]Professor, Department of Geography, Vidyasagar University, Midnapore, Dist - Paschim Medinipur, West Bengal, India, Midnapore, West Bengal-721102, India, ramkrishna@mail.vidyasagar.ac.in

Abstract

Urban flooding in Kolkata is an increasing challenge that is characterized by rapid urbanization. Other important factors include inadequate drainage, and climate change, which leads to frequent flooding in Kolkata municipal areas. This study explores the primary causes of flooding. The majority of the causes include natural, anthropogenic, and climatic factors. Therefore utilization of a combination of the Analytical Hierarchy Process (AHP) and Multi-Criteria Decision Analysis (MCDA), the research has evaluated the flood risk along with the models that have predictability regarding potential future flood scenarios with SWAT, HEC-RAS, and SWMM. The findings highlight the requirement for improved infrastructure, flood control, and climate adaptation measures. This data-driven approach provides valuable insights for urban planners along with policymakers to improve flood resilience in Kolkata.

Keywords- Urban Flooding, Flood Risk Assessment and Climate Adaptation

. INTRODUCTION

Urban flooding is an increasing problem in megacities like Kolkata with rapid urbanization. Kolkata is among the oldest and largest metropolis in India. The region of Kolkata Municipal Corporation is perennial waterlogged due to the factors of nature, man-made activities, and climatic changes working in unison. In the course of the past several years, floods, in terms of intensity and frequency, have been a rising trend in the region (De et al., 2013). These trends not only have negative impacts on the physical nature of the cities but also touch the socio-economic aspects of them. This research paper attempts to assess flood causation in the urban area of Kolkata by probing the frequency and intensity of urban floods in the city based on models like AHP, SWMM, HEC-RAS, and SWAT.

1.1 Background of Flooding in Kolkata

Kolkata has become particularly exposed to flooding. This is due to its geographical location and level of infrastructure development. Kolkata is located approximately at the confluence of the Hooghly River and in the flat expanses of the Ganges river basin (Rafiq et al., 2016). The city's flat-lying terrain creates experiences of flooding most notably during the rainy season (Dasgupta et al., 2012). It is evident from the historical accounts of flooding in the city of Kolkata that these occurrences of flood have shown an increase in their intensity and frequency over the years due to aspects such as unregulated urban development, population pressure, ineffective drainage system, and climate change. On occasion, outdated drainage systems within the city of Kolkata worsen the urban flooding situation. This drainage system cannot handle the enormous quantities of water produced by both rainfalls and surges from the Hooghly River. Other than this, there is poor flood control in this city as the expansion of water bodies is going on day by day, and regular maintenance is carried out hardly in Kolkata. In fact, changes in the land-use pattern increase the amount of impermeable surfaces through which houses, roads, and other urban infrastructures are erected (Romali and Yusop, 2021). This increases surface runoff and decreases groundwater recharge.

A mix of computational and analytical methods is needed to address the complexity of flood management. An established technique for decision-making, the AHP helps in evaluating the relative significance of different factors that contribute to a particular outcome, in the case of urban floods (Malik et al., 2020). The research looks to evaluate the contributing elements to flooding, such as topography, drainage capacity, rainfall intensity, land use, and proximity to water bodies, and assign weights to each factor based on its influence on floods by combining AHP with Multi-Criteria Decision Analysis (MCDA).

These weighted variables are combined with MCDA to create a decision model. This helps in identifying high-risk locations, setting priorities for places to be protected from floods, and projecting potential future flooding situations. The AHP-MCDA model used for this research has been provided with geographical data, rainfall records, and infrastructure assessments. By offering information on the hydrological and hydraulic behavior during flood occurrences, the incorporation of flood simulation models such as SWAT, HEC-RAS, and SWMM would further improve the accuracy of flood risk assessments.

A complete approach to flood management is made possible by the integration of AHP and MCDA. It enables the decision-makers to formulate their decisions based on a range of factors. This model will prove beneficial in suggesting those areas of Kolkata that are most prone to flooding and in fixing the priorities for flood mitigation by allotting appropriate weights towards different criteria such as rainfall, drainage capacity, and land use. Combining AHP-MCDA with GIS improves the decision further by illustrating various scenarios of the flood while providing spatial insights about areas that are more vulnerable to flooding.

1.2 Flood Models

The Soil and Water Assessment Tool (SWAT) model is primarily concerned with assessing the impact of land use change on surface and other water resources. SWAT will be helpful in understanding how urbanization increases the danger of flooding in Kolkata. Urbanization leads to decreased surface permeability. Even without urban land use, SWAT's capacity for the simulation of land use changes over time implies that it will benefit broadly in assessing the impacts of urbanization on flooding.

HEC-RAS stands for Hydrologic Engineering Center's River Analysis System. It is one of the most common systems utilized in modeling floodplain processes within the rivers. This model will be indispensable when relating river flows with urban drainage at times of severe rain as it lies close to the Hooghly River in Kolkata. Predicting the locations most vulnerable to riverine flooding and recommending appropriate mitigation measures helped by this.

Storm Water Management Model (SWMM) is developed to model urban drainage systems and examine how different storm events affect surface runoff, drainage capacity, and floods. Kolkata's old drainage infrastructure is one of the leading sources of urban floods. SWMM proves essential in analyzing the performance of the current system and researching upgrade solutions.

1.3 Key Factors for Flood in Kolkata

The variables contributing to urban flooding in Kolkata can be broadly divided into three areas. These are physical, anthropogenic, and climatic. The intricate interactions between all of these elements amplify flood occurrences. If one looks at the physical factors, the city of Kolkata was already vulnerable to flooding due to natural causes. The city, having a low-lying geographical location and being near the Hooghly River, made it vulnerable to floods (Dickson et al., 2010). However, the poorly designed stormwater and sewage facilities of the city exacerbated the problem. The sewage system of Kolkata is extremely old to carry this water. When there is a high tide in the river and a lot of rain, water backs up in the drainage system. This leads to extensive flooding.

Another factor is anthropogenic Factors. As a result of factors such as excessive urban infrastructure development and the use of land inappropriately, permeability has fascinatingly lowered in urban centers. The growth of hard surfaces like pavements, roads, and buildings has also fueled surface runoff from rain. Wetlands and natural water retention places have also been diminished in the process of city development, which naturally absorbs and manages excess water.

The last factor is climate factors. The two major factors of climate change that exacerbate the issues with urban flooding are rising sea levels and greater numbers and intensities of events of rainstorms. The Intergovernmental Panel on Climate Change indicates that the frequency of extreme weather events, including those of heavy precipitation, will rise. That would have an important effect on cities like Kolkata. The rising sea levels raise the risk of surges during flood events. Flood wave surges are further increased in low-elevation areas, especially along the coastal regions.

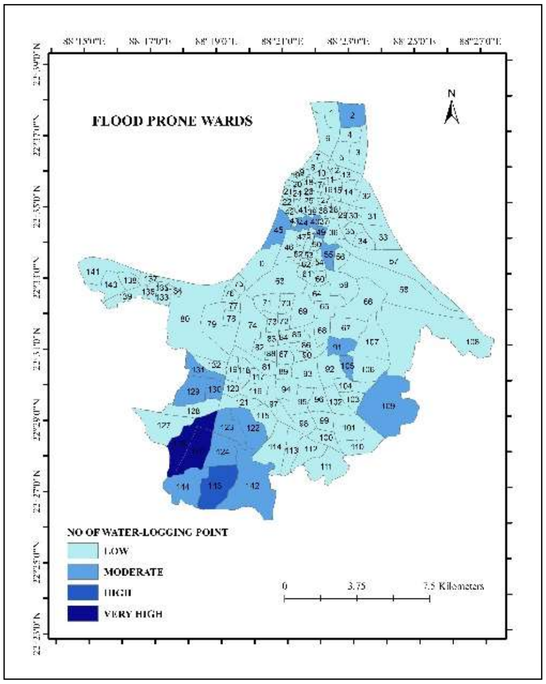

Figure 1: Flood Condition Map

This research centers on assessing the extent and magnitude of flooding in the municipal city of Kolkata and the main factors responsible for the increased frequency and severity of the floods. In order to achieve this, this study was conducted with the use of Multi-Criteria Decision Analysis (MCDA) and the Analytical Hierarchy Process (AHP) because the case factors are intended to be analyzed in a very comprehensive manner (EM-DAT 2010). A flood risk model has also been made in this research using the modern, innovative techniques of the Storm Water Management Model (SWMM), HEC-RAS, and Soil and Water Assessment Tool (SWAT), aimed at replicating possible future flooding scenarios. In this line of thinking, based on research outcomes, the research project put forward some recommendations for flood management strategies improvement in the city of Kolkata. This research is in focus with modernization and changing the strategy of land use planning by implementing climate adaptation measures and infrastructure improvement in order to reduce the impacts of urban floods.

Kolkata is exposed to all aspects of urban flooding, which essentially calls for an overarching and data-driven management strategy. Combining AHP and MCDA with advanced flood models like SWAT, HEC-RAS, and SWMM is considered a fruitful framework for understanding and reducing flood hazards. The findings of the research are going to benefit other researchers by expanding their current knowledge regarding the dynamics of flooding in the city and providing practical guidance to urban planners and lawmakers on how best to strengthen flood resilience in the city in light of growing climate concerns.

It has been deteriorating over the past few years with respect to the flood situation in Kolkata Municipal Corporation (KMC). Millions of people are impacted, and pluvial flooding often makes the infrastructure unreliable. At an administrative level, the governing body for Kolkata has also seen an increase in the frequencies and severities of floods, especially during the monsoon months. The problem is influenced both by natural and man-made elements; the terrain of the city, rainfall pattern, fast urbanization, and unplanned development, as well as insufficient drainage systems

.The near-level terrain and location on the eastern bank of the Hooghly River ensure that the city is prone to flooding. The natural gradient in the city ranges between 0° and 2°. This implies that the water discharge from the city will be gradual. If accompanied by heavy monsoonal rains, this enhances the likelihood of pluvial flooding. Data indicate that more than 75% of the total rainfall in Kolkata is received during June and September. Even short, heavy storms of this season may flood the city system easily and bring significant waterlogging (Dutta &Maiti, 2024). Elevation is another important component. A significant portion of KMC is below sea level, especially in the eastern and southern wards. It makes these areas more vulnerable to water buildup. These locations are most vulnerable to heavy rains that cause persistent and frequent flooding.

The flooding issues in KMC are largely attributable to the city's rapid growth. The ability of the city to absorb excess rainwater has decreased due to the large-scale reclamation of wetlands and natural water bodies, such as the East Kolkata Wetlands, for urban expansion over the previous three decades. In addition, the city's outdated drainage system is unable to manage the additional runoff volume brought on by contemporary urbanization.

Debris frequently clogs the system, causing more inefficiency and protracted floods in many areas of the city. Surface runoff has also been made worse by the increase of impermeable surfaces like concrete buildings and roadways. Instead of seepage into the earth, water is now poured into the streets and drainage systems, which soon become overloaded. In places like Bhowanipore, Park Circus, Behala, and Jodhpur Park, streets flood within hours of heavy rain, interfering with daily life and transportation. This persistent urban waterlogging issue impacts these neighborhoods.

2. Study Area: Kolkata Municipal Corporation

Kolkata is the capital of West Bengal which is a densely populated urban center which has 14 million residences in the metropolitan area. The city is located along the eastern bank of the Hooghly River which is a distributary of Ganga River. This region has seasons with heavy monsoon rain which leads to frequent flooding. The study area for the flooding model covers an urbanized 53 km square core region which is surrounded by an extended study area of 541 km². These include the Hooghly river basin. The drainage network in this religion includes 26783 nodes followed by 36 pumping stations and 44 storage units. All these lead to obstruction in the management of water logging especially during heavy rainfall events.

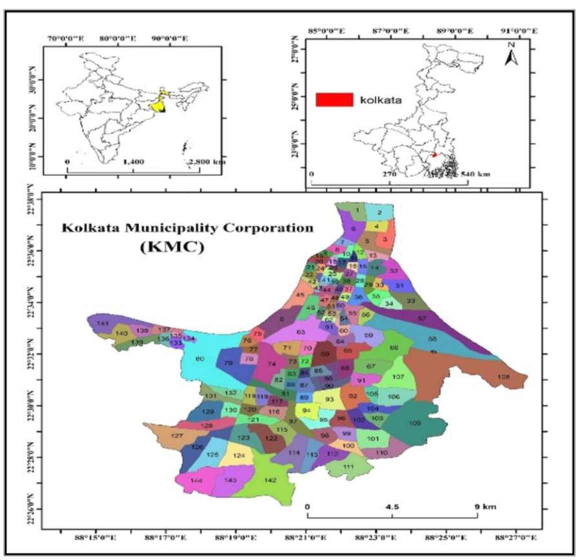

Figure 2: Study Area Map

The topography of Kolkata is relatively flat which makes it complicated for natural drainage of excess water during flood. This is integrated with the old-age drainage infrastructure which contributes to frequent urban floods. In addition to all these, Kolkata has experienced intense rainfall during the monsoon season with an annual rainfall that exceeds 1600 mm. The flat with a human-made drainage channel increases the difficulty regarding the proper implementation of flood management efforts.

3. Data Collection and Criteria for Flood Risk Mapping

The multi-criteria flood risk analysis is dependent on different datasheets which include the following aspects.

Digital elevation model- the elevation data is obtained from global DSM with 30 m resolution for the extended study area. This model is utilized to identify the low-lying areas along with the slope of the terrain. Both of these are crucial to understanding the water flow during flood events.

Land use land cover- High-resolution satellite imagery is utilized to classify the land into categories like built-up areas vegetation water bodies and open land. This also includes the recognition of urbanized areas which contribute to increased runoff.

Soil type- the data was obtained from FAO soil map which demonstrates the different degrees of water detention and permeability. This also highlights areas with clay soil which exacerbates the surface runoff.

Rainfall data- Hourly rainfall data is gathered from rain gauge stations that are distributed across KMC. The data is interpolated to utilize of inverse distance weighing method.

Distance from the river - The proximity of urban areas to the Hooghly River along with its tributaries is a significant factor in flood vulnerability. Therefore, a distance map from the river channel is important with the utilization of GIS tools.

4. Methodology

Analytical Hierarchy Process - The Analytical Hierarchy Process is a structured technique to organize and analyze different complex decisions. For this study, the flood-related criteria (elevation, slope, LULC, soil type, rainfall intensity, and distance from rivers) were ranked depending on their relative importance to flood risk. A pairwise comparison matrix was created to assign weights to each criterion. These weights are important to generate the flood hazard map through a weighted overlay analysis in QGIS.

Data Sources

Data	Source	Data used
DEM, Slope, Curve Number, Aspects		SRTM data is used for the identification of the elevation

	https://search.earthdata.nasa.gov/search.	and slope of the region.
Rainfall	https://pypi.org/project/imdlib/	Gridded IMD data used for measuring the rainfall variability
LULC, NDVI, NDBI	http://earthexplorer.usgs.gov	Landsat 5 and Landsat 8 used to calculate LULC and MNDWI
Population related data	District statistical handbook-Kolkata	Census Data,2011
Drainage data	KMC Report	KMC drainage map.
Distance from river	https://www.openstreetmap.org/#map	

4.1 Flood Hazard Factors:

Rainfall Intensity- Considering the heavy monsoonal rainfall in Kolkata, this criterion is to be ranked at the highest.

Elevation and Slope- Low-lying areas and flatter slopes have a high risk of flooding and receive higher weights.

LULC and Soil Type- The built-up areas with impermeable surfaces along with the areas with clayey soils are also high-risk zones.

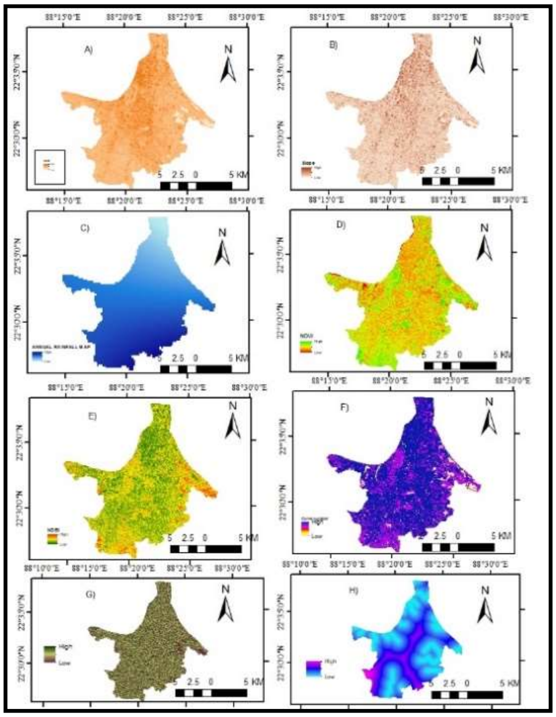

Figure3: Flood hazard influencing factors- A) elevation, B) slope, C) rainfall, D) NDVI, E) NDBI, F) CN, G) aspects, H) distance from river

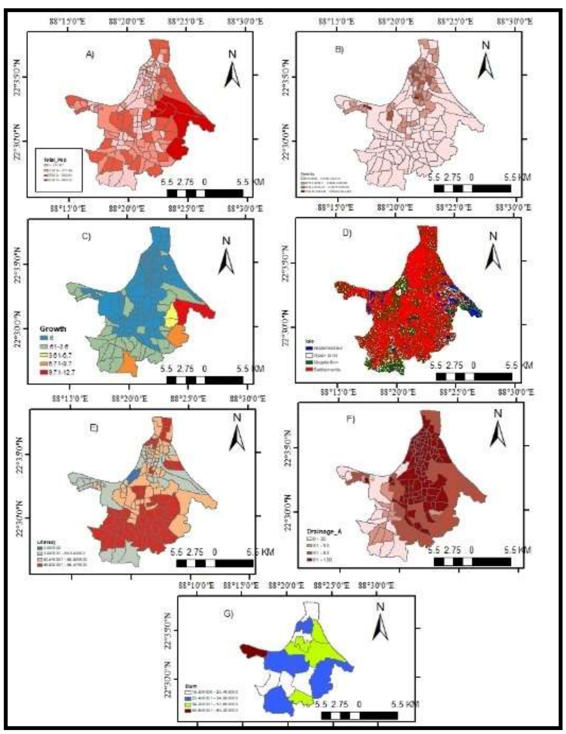

Figure4: Flood vulnerability influencing factors- A) total population, B) population density, C) population growth, D) LULC, E) literacy rate, F) urban drainage, G) slum concentration

4.2 Flood Models

Three flood models were integrated to simulate and validate the findings from the AHP-based MCDA

Soil and Water Assessment Tool- This is utilized to simulate the hydrological processes of the area, particularly surface runoff. The model includes rainfall, temperature, and soil data. This tool helps to predict the way in which it leads to infiltration within the ground along with the consideration of the fact that how much will result in runoff.

HEC-RAS – This tool simulates water flow through the river systems in Kolkata. For this study, the Hooghly River followed by the tributaries was modeled to understand water levels during different rainfall events. This tool helps to calculate the water surface profiles along with the identification of potential areas where the river may overflow into urban areas.

Storm Water Management Model - SWMM is utilized to model the drainage network of Kolkata. It also simulates the flow of water through urban drainage systems during storm events. The model also includes important details regarding the pumping stations and drainage pipes of the city. This also allows for real-time analysis of drainage efficiency during heavy rainfall.

4.3 Analytical hierarchical process (AHP)

One cannot ignore the importance of the Analytical Hierarchy Process (AHP) which is a useful MCDA technique that helps to solve complex decision-making problems. This is more so in cases when many factors contribute to the overall result, for instance in managing flood risk. The application of the Analytic Hierarchy Process (AHP) in the research on evaluating the extent and severity of urban floods in the KMC provides for the systematic ranking of different flood-inducing components according to their relative relevance by integrating them into a hierarchical model. The goal, criteria, sub-criteria, and alternatives are all arranged in a hierarchy as part of the initial AHP issue structuring process (Mitra et al., 2022). Elevation, slope, rainfall, land use, and drainage system performance are important considerations for urban flood analysis. The main goal is to evaluate flood risk by examining these variables and how they interact.

The first step in AHP is identifying and categorizing the flood-inducing factors. In the case of KMC urban flood modeling, the parameters that affect urban flooding include elevation, slope, rainfall, land use and land cover (LULC), normalized difference vegetation index (NDVI), and drainage.

Pairwise Comparison Matrix (PCM): A PCM is developed in order to understand the significance and relevance of different parameters. Using a scale, each component is compared to the others. This is how the matrix looks like:

$$PCM = \begin{vmatrix} 1 & 2 & n \\ 1/2 & 1 & 2 \\ 1/n & 1/2 & 1 \end{vmatrix}$$

Normalized Weights: The matrix is normalized by computing the sum of its columns. The following formula is used to find each criterion's relative weight (W_i):

W_i= Sum of row elements/ Total sum of all elements

Consistency Check: The consistency of the matrix is verified through the Consistency Ratio (CR), which is given by:

CR= Consistency Index (CI)/ Random Consistency Index (RCI)

Where, Consistency Index, $CI = \frac{\lambda max - n}{n-1}$

TABLE 1: Scale of Preference between parameter

Intensity Importance	Description
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extremely Importance
2,4.6,8	Intermediate Value
Reciprocals	Inverse Comparison

TABLE 2: RI for different matrix

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

TABLE 3: Comparison matrix for flood hazard

Criteria	Elevation	Slope	Rainfall	NDVI	NDBI	CN	Aspects	Drainage
Elevation	**1.00**	2.00	3.00	5.00	5.00	7.00	7.00	7.00
Slope	0.50	**1.00**	2.00	4.00	4.00	6.00	6.00	7.00
Rainfall	0.33	0.50	**1.00**	3.00	4.00	5.00	5.00	6.00
NDVI	0.2	0.25	0.333333	**1.00**	3.00	4.00	4.00	5.00
NDBI	0.2	0.25	0.25	0.3333333	**1.00**	3.00	3.00	3.00
CN	0.142857	0.17	0.2	0.25	0.33333333	**1.00**	2.00	3.00
Aspects	0.142857	0.17	0.2	0.25	0.33333333	0.5	**1.00**	3.00
Drainage	0.142857	0.14	0.166667	0.2	0.33333333	0.3333333	0.3333333	**1.00**

λmax	N	CI	CR
8.63	8	0.901	0.056601

TABLE 4: Comparison matrix for flood vulnerability

Parameter	Total population	Population density	Population growth	LULC	Literacy rate	Underground drainage	Slum
Total population	1.0	2.00	2.00	3.00	4.00	4.00	5.00
Population density	0.50	1.00	1.00	2.00	3.00	3.00	4.00
Population growth	0.50	1.00	1.00	2.00	3.00	3.00	4.00
LULC	0.33	0.50	0.50	1.00	2.00	2.00	3.00
Literacy rate	0.25	0.33	0.33	0.50	1.00	1.00	2.00
Underground drainage	0.25	0.33	0.33	0.50	1.00	1.00	2.00
Slum	0.20	0.25	0.25	0.33	0.50	0.50	1.0

λmax	N	CI	CR
7.07	7	0.01196	0.01

The outputs from the flood models and the AHP were combined using the weighted overlay approach (Parsian et al., 2021). The weighted scores of each theme layer are added up to determine the flood risk index or FRI:

$$\mathrm{FRI} = \sum_{n=1}^{n} (\mathrm{Wi} \times \mathrm{Ri})$$

Where W_i is the weight assigned to each factor and Ri is the rank of each factor.

5. RESULTS

The outcome of the research provides an integrated overview of flood risk in the KMC area. Regions prone to floods were determined using MCDA and AHP. Analyses from these studies describe that flooding is more intense in the southern and eastern parts of the city due to their low elevation, lack of a proper drainage system, increased population density, and rapid urbanization. These wards-Kasba, and Topsia, and Behala-contain most of those classified as 'high-risk places', merely on account of their tendency to get constantly flooded with monsoonal rain. Overall, the findings suggest that roughly 55% of KMC's wards fall under the high or very high flood risk category. Therefore, the study puts attention to the serious requirement for better urban design, enhanced drainage systems, and long-term flood mitigation techniques in view of the rising hazards of floods in KMC.

5.1. Flood Hazard Map

The various levels of flood danger throughout the city have been determined by combining multiple important factors in a weighted overlay analysis. This analysis helped to create the flood hazard map for Kolkata. This technique made it possible to identify five separate flood risk zones, ranging from extremely high risk to very low risk. This provides a complete understanding of how flooding affects the city as a whole.

Very High Risk: Particularly near the Hooghly River's banks, low-lying, highly populated communities form extremely high-risk areas. These areas have inadequate drainage systems and are closest to rivers. These factors make them the most vulnerable. These areas often have severe flooding, due to strong monsoon rains and low ability to contain excess water, making them highly vulnerable.

High Risk: The high-risk areas consist of urban landscapes with a high percentage of impervious surface area such as pavement, buildings, and roads. This lack of open soil significantly increases surface runoff during periods of intense rainfall. Water builds up quickly in these areas, and the current drainage system is frequently overloaded. Though they are less sensitive than the very high-risk zones, these places are still susceptible to significant flood events due to the frequent waterlogging that results from this.

Moderate Risk: Areas that are categorized as moderate risk usually have higher rainfall amounts and better drainage systems. Even though these places do not flood as often as the high-risk zones, they can still get occasionally waterlogged and flooded during strong storms, especially if the rainfall is more than the drainage systems can handle.

Low and Very Low Risk: Higher elevation areas and areas away from the city's waterways, especially the Hooghly River, are subject to low-risk and very low-risk zones (Gupta, 2009). Both manmade and natural drainage systems that are better at controlling runoff and less likely to cause major flooding are beneficial to these places. They are positioned higher and have greater infrastructure, so they are less affected by the monsoon.

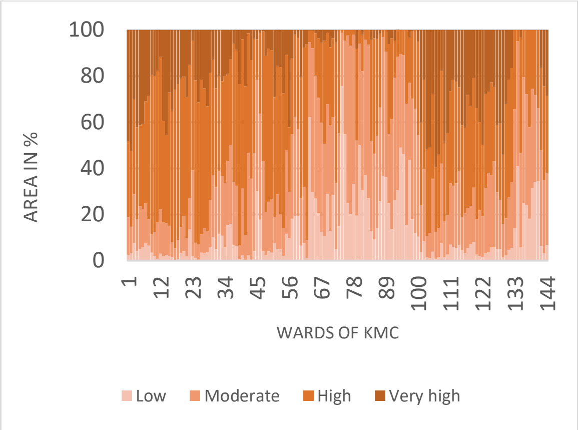

Figure 5: Ward wise flood risk area in KMC

The flood hazards map indicates that low-lying urban areas and locations close to riverbanks are often the highest risk zones. These locations are repeatedly flooded throughout the monsoon season (Kashyap and Mahanta, 2021). This creates a severe threat to the lives, properties, and livelihoods of locals.

A flood hazard map is an important tool to understand the distribution of geographical risk in flooding. Since flooding due to pluvial water in the city frequently occurs, especially in metropolitan cities like Kolkata Municipal Corporation (KMC), a flood hazard map form is considered pretty beneficial based on the analysis of physical, environmental, and infrastructural variables for flooding. This is an essential input into disaster preparedness and urban planning. Multi-criteria decision Analysis (MCDA) is a method assisting in ranking factors contributing to flood risk by attaching weights. The Analytical Hierarchy Process (AHP) when combined with Multi-Criteria Decision Analysis (MCDA) was used in the present research to create the flood hazard map for KMC. An essential aim is to identify flood risk zones for the municipality so as to facilitate the enhancement of flood management plans. The map of flood hazards will thus be produced by a combination of several geographic layers, each of which is an essential constituent influencing flood hazards in the region (Skilodimou et al., 2021).

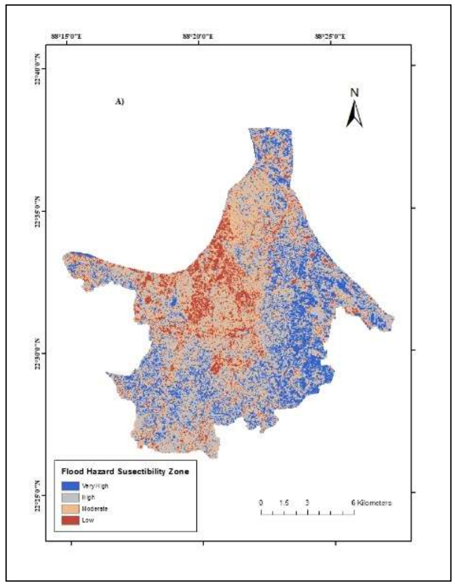

Figure 6: **Flood hazard zone map**

AHP provides a relative priority to each component based on statistical methodologies or expert judgment. Using AHP these layers are weighted. The dominant factors responsible for the flood hazard in KMC are elevation, slope, rainfall intensity, land use/land cover (LULC), Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), drainage capacity, and proximity to water bodies.

Elevation: The elevation of ground level was one of the most important variables influencing flood susceptibility in KMC. Low-lying locations are more vulnerable to floods and water formation, particularly after a lot of rain. Lower elevations (below 6 meters) are designated as high-risk zones on the flood hazard map. These locations are mainly found in the city's eastern and southern regions. These regions are more likely to flood because of their elevation.

Slope: Slope, in addition to elevation, is a significant factor in determining the vulnerability to flooding. Less steep slopes (0° to 2°) typically have slower surface runoff. Due to this less runoff, water builds up and makes floods more likely. The association between topography and flood risk is further supported by the flood hazard map. This map classifies areas with flatter terrain as more susceptible.

Rainfall Intensity: In KMC, as intense rainfall often occurs in the monsoon, heavy showers during the monsoon season highly contribute to pluvial floods. Based on historical data and rain gauging patterns, this danger map indicates a flooded-prone area with heavy rain. The high rainfall intensity zones on the map indicate the increased danger of flooding caused by rainwater that is unable to enter because of inadequate drainage infrastructure.

Land Use and Land Cover (LULC): How the land absorbs or blocks water is directly influenced by the type of land use. By combining LULC data, the flood hazard map illustrates how more urbanized areas, such as built-up areas with impermeable surfaces are more vulnerable to flooding. Surface runoff rises as a result of the loss of naturally permeable surfaces like wetlands and open green areas brought about by urbanization. The flood hazard map's LULC component highlights these urbanized areas as significant flood hotspots.

NDVI and NDBI: The map illustrates the inverse relationship between flood danger and the NDVI. It evaluates the density of vegetation cover. Flooding is more likely to occur in places with lower NDVI values. This indicates smaller vegetation, whereas dense vegetation helps absorb excess water (Maranzoni et al., 2023). On the other hand, the NDBI denotes places that are populated and, similar to LULC, are associated with an increased risk of flooding. Elevated NDBI values signify locations with a high density of structures and impermeable surfaces. The hazard map has also highlighted these regions as areas of flooding within the KMC.

Drainage system: Flood scenarios have been created critical areas awaiting flood mapping are areas where there is the potential for urban flooding. They include poorly or over-strained drainage systems or existing ones that are old and lack appropriate maintenance. The drainage systems in the cities are usually responsible for urban floods especially during the monsoons when most part of the cityis waterlogged.

Distance to Water Bodies: Defining a flood zone, naturally near any watercourse like a river, channel, or pond heightens the tendency of any such area to flood. When preparing the KMC flood hazard map the Hooghly River and some smaller water bodies in the vicinity were also considered. Flood events were shown to be more likely in areas near these sources of water, particularly in relatively low-lying and poorly drained areas.

The city is divided into low, moderate, high, and very high-risk zones on the flood hazard map created for KMC according to the respective contributions of the aforementioned variables. It was found that the eastern and southern parts of the city are the most vulnerable to disasters due to their high population density and low topographical areas. They have been prone to seasonal flooding for years, and even with a few alterations to the city's drainage systems and land use, they are bound to remain stretchy to floods. In contrast, the flood risk map showed a limited threat in certain western parts of KMC as they are raised, and have few hardscapes and effective natural drainage facilities. Extreme weather conditions have the potential to exceed the current infrastructure, therefore even these areas are not completely safe from the risk of flooding

5.2 Flood Vulnerability Map

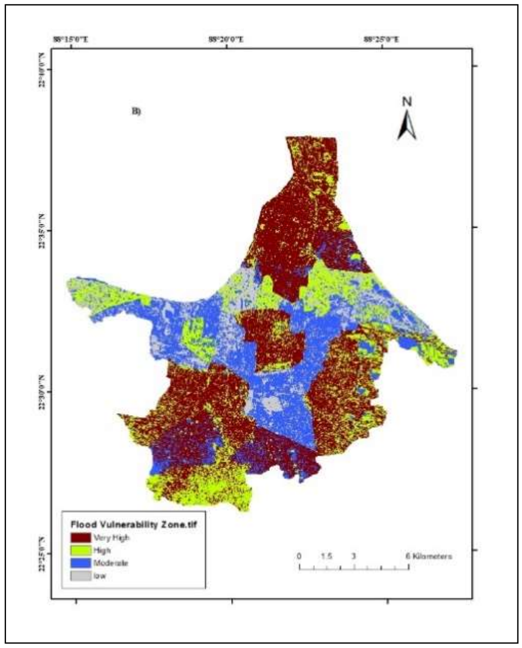

Figure7: **Flood vulnerability zone map**

One of the most important parts of flood risk analysis is the flood vulnerability map, which at a location level indicates which areas of the KMC are most susceptible to the negative impacts of urban floods. Flood vulnerability maps ponder on socio-economic and infrastructure flaws that worsen the effects of flooding, while flood hazard maps are more centered on the physical features that cause flooding. This distinction is of great importance in the context of a metropolitan city like KMC, where the risk of flooding is increased due to changes in land use, population density, and poor drainage infrastructure.

By using a hybrid technique like MCDA and AHP, the KMC produced a flood vulnerability map. To check the susceptibility of floods in the region, this method allows multifaceted combinations of various socioeconomic and infrastructural factors. A number of factors like drainage systems, slum concentration,land use/land cover (LULC), literacy rate, population density, total population, and population growth rate have their specific influence. Every component is essential in identifying the parts of KMC that are most susceptible to floods.

Two of the most critical factors when assessing vulnerability to flooding are the population density and the total population size. High population concentration in flood-risk areas poses difficulties when it comes to evacuation and rescue operations. It makes highly populated regions more vulnerable to severe flood consequences.

The flood vulnerability map identifies regions in the southern and eastern KMC that are more vulnerable to flooding due to increased population densities brought on by fast urban expansion (Chan et al., 2022). These locations also pose a greater risk of economic loss, injury, and displacement during flood occurrences. Another important issue is the rate of population growth. The population of KMC has grown quickly, particularly in the areas designated for urban expansion. The current infrastructure, especially the drainage systems, is under tremendous strain from this population growth and is frequently unable to handle the growing demands. These recently created or rapidly expanding areas are shown on the risk map as being more vulnerable to flooding since urban planning has frequently lagged behind population growth.

Flood susceptibility is also influenced significantly by land use and land cover (LULC). The process of transforming naturally permeable terrain into built-up regions with impermeable surfaces is known as urbanization. This significantly raises the danger of waterlogging and surface runoff. LULC data is integrated into the flood vulnerability map. It indicates that areas with high levels of urbanization and low levels of green space are more vulnerable to flooding. Because parks, wetlands, and open spaces absorb extra rainfall and lessen surface runoff, these natural features make less vulnerable areas easier to maintain. Since literacy rates show the connection between education and preparedness for emergencies, they are also taken into account in the flood vulnerability map.

Higher literacy rates are associated with a higher probability of residents being aware of the risk of flooding and having the skills necessary to act appropriately in an emergency. These people frequently have easier access to safety precautions, evacuation protocols, and flood alerts. Inadequate or antiquated drainage systems greatly increase flood vulnerability, therefore they are essential for controlling flood hazards.

The drainage system in many of KMC's older neighborhoods was created decades ago and was not updated to handle the city's present population and level of urbanization (Feloni et al., 2020). Areas with inadequate drainage systems are shown as very vulnerable on the flood risk map because they are unable to handle the water generated by heavy rains, which can cause protracted waterlogging and floods. Lastly, a major contributing element to flood vulnerability is the concentration of slums. Slums are especially vulnerable to flooding because of their poor living conditions, lack of basic necessities, and unstable locations. Many of them are close to drainage canals or bodies of water.

The municipality is divided into low, moderate, high, and extremely high susceptibility zones on the flood vulnerability map created for KMC based on the combined impact of these socioeconomic and infrastructural elements. Extremely vulnerable areas are found in the southern and eastern regions of KMC.

These regions have had quick urban growth, dense populations, and poor drainage infrastructure. Their susceptibility is further increased by the large slum populations that typically exist in these places. On the other hand, the city's flood danger map reveals that certain areas, especially those in the north and west, are less vulnerable than others because of improved infrastructure, lower population densities, and greater rates of literacy. While not completely immune to the effects of heavy floods, certain places are better prepared to handle flood disasters.

5.3Ward Wise Flood Risk Area in KMC

Using a weighted sum method, each element contributing to flood risk was given a weight based on its relative relevance, and the result was the flood risk index (FRI) for each ward. In addition to socioeconomic elements like population density, land use, and drainage efficiency, the determinants also include physical elements like elevation, slope, and intensity of rainfall. Then, the wards were divided into four risk categories, which are low, moderate, high, and extremely high.

Wards in the South and East: According to the flood risk map, these areas of KMC are most vulnerable to floods. These locations, which are primarily the KMC expanded wards, are more likely to flood because of a number of variables, including flat slopes, high population density, and low elevation (below 6 meters).These areas have also seen fast urbanization, which led to a large concentration of impermeable surfaces in built-up areas. Because of this, these wards are prone to waterlogging even during brief but heavy rainstorm events due to their poor drainage capabilities

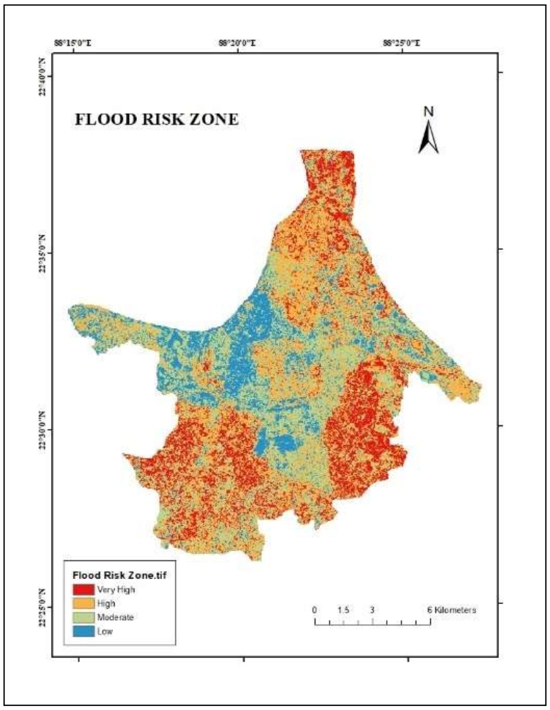

Figure 8: **Flood vulnerability zone map**

High-risk wards including Behala, Topsia, Kasba, and Mukundapur are frequently designated as such. Significant urban growth has occurred in these areas, and the risk of flooding has increased due to the disappearance of natural wetlands and water bodies. For instance, because so many residential and commercial constructions have replaced the natural drainage systems, Kasba and Topsia have been designated as areas of high vulnerability. Frequent flooding in these wards is a result of increased surface runoff caused by the absence of open places to absorb rainwater.

Wards in the West and Central KMC: In comparison, the areas in the West and Central KMC, including Bhowanipore, Alipore, and portions of North Kolkata, have comparatively lower flood risk. These areas have higher elevations and steeper slopes. This creates more effective water runoff. Due to this reason, these places have superior natural drainage. Long-term waterlogging is less likely in these wards because the drainage systems have been improved or properly maintained over time.

However, localized flooding is still possible, especially in places with more ancient drainage systems or in places where there has been a noticeable increase in human density (Mukherjee &Bardhan, 2021). Though the risk is lower than in the southern and eastern wards, flooding is still a possibility in the central wards, especially those close to the city's historic core, like Central Avenue. These places' century-old drainage infrastructure can hardly cope with increased runoff emanating from the spread of towns and how intensities of rainfall occur today. It is not one of the most vulnerable wards, yet it must still be cared for, especially regarding improvement in drainage systems as well as the development of urban areas to avoid flooding in the future.

North Kolkata Wards: While North Kolkata is not typically as prone to serious flooding events as the eastern and southern halves of the city, there are still certain wards within North Kolkata that are considered to be at a moderate risk. And yet even traditionally lesser-risk neighborhoods are now feeling the effects of the rapid urbanization that is sweeping over the city as ever more concrete and people outstrip local drainage capacity. It is found that, for example, the Hooghly River nearby and the archaic and inefficient drainage systems in North Kolkata wards 6, 7, and 8 have produced moderate to high flood risks. These places are particularly vulnerable to flooding because they frequently experience both pluvial and riverine flooding.

The flood risk map also highlighted the fact that about 55% of KMC wards are at outright high or very high flood risk. Wards like Jodhpur Park, Park Circus, and Golf Green have been suffering from high vulnerability because of low elevation, inadequate drainages, and high population density. The data also reveals that a large number of these wards frequently experience waterlogging, particularly during the monsoon season when even small amounts of intense rainfall can cause significant floods. The most severely impacted areas are frequently the extremely high-risk wards in the city's east and south.

The greatest urbanization has occurred in these areas recently, with substantial wetlands and natural water bodies being filled in to make room for new construction. Due to a significant decrease in their natural drainage capacity, these places are now far more vulnerable to flooding. Furthermore, these wards' fast urban growth has not been accompanied by sufficient infrastructural development, especially when it comes to drainage systems.

6. DICUSSION

The achieved insights regarding the evaluation of Kolkata Municipal Corporation's (KMC) deteriorating flood situation demonstrated that there is an extreme close relation between natural factors and human-driven changes. These factors have exacerbated the frequency and severity of floods within the city. The study also highlighted that there is rapid urbanization followed by the insufficient infrastructure within the area of study. In addition to that city's unique geographical features have also specific contribution to the recurring flood problems. It was also gained that this specifically occurs during the monsoon season.

Geographical Factors and Natural Causes

The geography of Kolkata Municipal Corporation play a significant role within the domain of flood vulnerability. The city is situated on the eastern bank of the Hooghly River and have a natural gradient that ranges between 0° and 2°. Therefore, the city has a near to flat terrain. The limited gradient also yields results in the slow discharge of water. This further get oriented with the heavy monsoonal rains which, further leads to frequent flooding event over the city.

The data also suggest that 75% of the rainfall occurs between the month of June and September this also supports the problem, as this is concentrated with the rainfall that often overwhelms the drainage capacity of the city. This cause waterlogging along with the damage to infrastructure. In addition to the factor of terrain there is a substantial portion of the city whose height is below sea level. The region mainly are the eastern and southern wards which make these areas more prone to frequent water accumulation during periods of heavy rainfall.

The challenges posed by Kolkata's geographical and meteorological factors are compounded by the changing rainfall patterns that have been influenced by climate change. Monsoon rains have become more unpredictable, with shorter, heavier bursts of rainfall that quickly overload drainage systems and flood low-lying areas. This highlights the role of natural factors in the increasing flood risk, emphasizing the need for infrastructure improvements that consider both long-term changes in climate and the city's topographical limitations.

Human-Caused Factors and Urbanization

The human related aspects regarding the flood problem are equally significant. This is oriented with urbanization and unplanned development that further emerged as critical contributors. Over the past few years there are large-scale reclamation of natural water bodies like the East Kolkata Wetlands. This has reduced the capacity of the city to absorb the excess amount of rainwater. These wetlands once acted as natural drainage buffers. However, destruction of these wetlands for urban development has led to a difficult flood mitigation mechanism. The expansion of impermeable surfaces like the concrete buildings followed by the paved roads, and parking areas also extends the problem through the prevention of water seepage in the ground. As a result, the surface runoff flows directly into an overburdened drainage system. As a results these leads to a quicker and more severe waterlogging system.

The outdated and inefficient drainage infrastructure of Kolkata also play a major role within the flood related problems. Irrespective of rapid urban growth, the drainage system has not been significantly upgraded to handle the increased runoff from new developments. Thedebris accumulation in the drainage channels jam the system. This reduce the capacity to handle heavy rainfall. Neighborhoods like Bhowanipore, Park Circus, Behala, and Jodhpur Park experience flooding within hours of rainfall that disrupts the daily activities and this also damage different types of properties.

Impact on Infrastructure and Daily Life

The effects of flooding in KMC extends beyond immediate physical damage. This further impacts the transportation networks of the city. It also impact the residential areas along with the economy of the city. Waterlogged streets within densely populated neighborhoods leads to difficult transportation and cause severe disruptions in public services. All these issues affects millions of people. Moreover, the deteriorating flood situation leads to recurring public health concerns due to waterborne diseases and prolonged periods of stagnation of water in certain areas.

7. CONCLUSION

Integration of AHP with modern flood models, such as SWAT, HEC-RAS, and SWMM, proves very useful in prescribing an in-depth analysis of urban flooding in Kolkata. These techniques make it possible to evaluate the risk of flooding in the Kolkata municipality area while emphasizing important elements such as topography, land use, composition of soil, and drainage systems. Particularly vulnerable places include those that are low-lying and close to the Hooghly River, especially during the monsoon season.

The integration of Geographic Information Systems (GIS) helps the mapping of high-risk areas. This helps to actively construct flood management strategies and prioritize measures. The research highlights how urgently Kolkata's old drainage systems need to be upgraded, particularly in the older urban neighborhoods where they frequently flood during periods of heavy precipitation. Furthermore, in order to help remove excess runoff, the research supports using natural alternatives like fixing floodplains and growing green spaces. To increase tolerance and get the city ready for more flooding difficulties in the future, a mix of these strategies must be implemented.

7. REFERENCES

1. Dasgupta, S., Gosain, A.K., Rao, S., Roy, S. and Sarraf, M. (2012). A megacity in a changing climate: a case study of Kolkata. Climatic Change. Springer Science + Business Media B.V
2. Romali, N. S. and Yusop, Z.(2021). Flood damage and risk assessment for urban area in Malaysia. Hydrology Research. 52.1
3. Hermas, E., Gaber, A., and Bastawesy, M.E. (2021). Application of remote sensing and GIS for assessing and proposing mitigation measures in flood-affected urban areas, in Egypt. The Egyptian Journal of Remote Sensing and Space Sciences 24.119-130. Elsevier
4. Cancado,V., Brasil, L., Nascimento, N., and Guerra, A. (2008). Flood risk assessment in an urban area: Measuring hazard and vulnerability. 11th International Conference on Urban Drainage, Edinburgh, Scotland, UK.
5. L.F. Guimarães, B.P. Battemarco, A.K.B. Oliveira, M.G. Miguez. (2021). A new approach to assess cascading effects of urban floods, Energy Reports, Volume 7, Pages 8357-8367, ISSN 2352-4847, https://doi.org/10.1016/j.egyr.2021.07.047. (https://www.sciencedirect.com/science/article/pii/S2352484721005126)
6. De, U. S., Singh, G. P., and Rase, D. M. (2013). Urban Flooding in recent decades in four megacities in India. J. Ind. Geophys. Union. Vol.17, No.2, pp. 153-165
7. Rafiq, F. Ahmad, S., and Ahmed, S. (2016). Urban Floods in India. International Journal of Scientific & Engineering Research, Volume 7, Issue 1. ISSN 2229-5518
8. Tinsangchali, T. (2012). Urban flood disaster management. Procedia Engineering 32. 25 – 37. Elsevier.
9. Ramachandra, T. V., and Majumder, P.P. (2009). Urban Floods: Case Study of Bangalore. Journal of the National Institute of Disaster Management. *Disaster & Development* Vol. 3 No. 2. ISSN: 0973-6700

10. Gupta, A. K. (2009). Flood Disaster Mitigation and Management: A Synthesis and Key Lessons. Journal of the National Institute of Disaster Management. *Disaster & Development* Vol. 3 No. 2. ISSN: 0973-6700
11. Bajazit, Y., Koc, C., and Bakis, R. (2020).Urbanization impacts on flash urban floods in Bodrum Province, Turkey, Hydrological Sciences Journal, 66:1, 118133, DOI: 10.1080/02626667.2020.1851031
12. Kashyap, S., and Mahanta, R. (2021). SOCIOECONOMIC VULNERABILITY TO URBAN FLOODS IN GUWAHATI, NORTHEAST INDIA: AN INDICATOR-BASED APPROACH. Economic Effects of Natural Disasters. Elsevier Inc.
13. Malik, S.; Pal, S. C.; Sattar, A.; Singh, S. K.; Das, B.; Chakrabortty, R.; and Mohammad, P. (2020) . Trend of extreme rainfall events using suitable Global Circulation Model to combat the water logging condition in Kolkata Metropolitan Area. Urban Climate 32. Elsevier.
14. Sundaram, S., Devaraj, S. & Yarrakula, K. Modeling,(2021). mapping and analysis of urban floods in India—a review on geospatial methodologies. *Environ Sci Pollut Res* **28,** 67940–67956 https://doi.org/10.1007/s11356-021-16747-5
15. Ghosh. A. Kolkata and climate change. Climate Change Policy Paper iv
16. Asian Development Bank (2008) Climate Change ADB Programs. Strengthening mitigation and adaptation in Asia and the Pacific http://www.donorplatform.org/component/option,com_docman/task,doc_view/ gid,940. Accessed December 2011
17. Chatterjee RS, Fruneaub B, Rudant JP, Roy PS, Frison P-L, Lakhera RC, Dadhwal VK, Saha R (2006) Subsidence of Kolkata (Calcutta) city, India during the 1990s as observed from space by Differential Synthetic Aperture Radar Interferometry (D-InSAR) technique. Remote Sensing Environ 102:176–185
18. Dickson E, Tiwari A, Baker J, Hoornweg D (2010). Understanding urban risk: an approach for processing disaster and climate risks in cities. World Bank, Washington, Mimeo
19. Dube SK, Rao AD, Sinha PC, Murty TS, Bahulayan N (1997). Storm surge in the Bay of Bengal and Arabian Sea: the problem and its prediction. Mausam 48:283–304
20. EM-DAT (2010).The International Disaster Database. Prepared by the Centre for Research on the Epidemiology of Disasters-CRED http://www.emdat.be/database. Accessed June 2012
21. Emery D, Finnerty J, Stowe J (2007).Corporate financial management, chapter 6. In: Risk and return. Prentic Hall, Upper Saddle River, NJ
22. Agilan, V., Umamahesh, N.V., 2017. Modelling nonlinear trend for developing non-stationary rainfall intensity–duration–frequency curve. Int. J. Climatol. 37 (3), 1265–1281.
23. Ahmed, I., Das, N.D., 2018. Sedimentation-induced depositional lands of the Gumti River of Tripura and its land use pattern. In: Climate Change, Extreme Events and Disaster Risk Reduction. Springer, Cham, pp. 135–146.
24. Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J., Gleason, B., Tank, A.K., Tagipour, A., 2006. Global observed changes in daily climate extremes of temperature and precipitation. J. Geophys. Res. Atmos. 111 (D5).
25. Allan, R.P., Liu, C., Zahn, M., Lavers, D.A., Koukouvagias, E., Bodas-Salcedo, A., 2014. Physically Consistent Responses of the Global Atmospheric Hydrological Cycle in Models and Observations. Surv Geophys 35, 533–552. https://doi.org/10.1007/s10712-012-9213-z.
26. Allen, R.G., Morse, A., Tasumi, M., Trezza, R., Bastiaanssen, W., Wright, J.L., Kramber, W., 2002. Evapotranspiration from a satellite-based surface energy balance for the Snake Plain Aquifer in Idaho. In Proc. USCID Conference, USCID.

27. Adu, D. T., Kuwornu, J. K. M., Somuah, H. A., & Sasaki, N. (2017). Application of Livelihood vulnerability index in assessing smallholder maize farming households' vulnerability to climate change in Brong-Ahafo region of Ghana. Kasetsart Journal of Social Sciences (2017), 1_11. Retrieved from ,https://doi.org/ 10.1016/j.kjss.2017.06.009..
28. Morris, M. D. (1979), Measuring the condition of the world's poor: The physical quality of life index. NewYork: Pergamon Press for the Overseas Development Council.
29. Chan, S. W., Abid, S. K., Sulaiman, N., Nazir, U., &Azam, K. (2022). A systematic review of the flood vulnerability using geographic information system. Heliyon, 8(3). https://www.cell.com/heliyon/fulltext/S2405-8440(22)00363-2
30. Dutta, D., &Maiti, R. (2024). Magnitude of Urban Flood in Kolkata Municipal Corporation and its Influencing Factors. International Journal of Innovative Science and Research Technology (IJISRT), 895–900. https://doi.org/10.38124/ijisrt/ijisrt24jul498
31. Feloni, E., Mousadis, I., &Baltas, E. (2020). Flood vulnerability assessment using a GIS-based multi-criteria approach—The case of Attica region. Journal of Flood Risk Management, 13, e12563. https://onlinelibrary.wiley.com/doi/abs/10.1111/jfr3.12563
32. Maranzoni, A., D'Oria, M., & Rizzo, C. (2023). Quantitative flood hazard assessment methods: A review. Journal of Flood Risk Management, 16(1), e12855. https://onlinelibrary.wiley.com/doi/abs/10.1111/jfr3.12855
33. Mitra, R., Saha, P., & Das, J. (2022). Assessment of the performance of GIS-based analytical hierarchical process (AHP) approach for flood modelling in Uttar Dinajpur district of West Bengal, India. Geomatics, Natural Hazards and Risk, 13(1), 2183-2226. https://www.tandfonline.com/doi/abs/10.1080/19475705.2022.2112094
34. Mukherjee, A. B., &Bardhan, S. (2021). Flood vulnerability and slum concentration mapping in the Indian city of Kolkata: A post-Amphan analysis. Water Science, 35(1), 109-126. https://www.tandfonline.com/doi/abs/10.1080/23570008.2021.1957641
35. Parsian, S., Amani, M., Moghimi, A., Ghorbanian, A., &Mahdavi, S. (2021). Flood hazard mapping using fuzzy logic, analytical hierarchy process, and multi-source geospatial datasets. Remote Sensing, 13(23), 4761. https://www.mdpi.com/2072-4292/13/23/4761
36. Skilodimou, H. D., Bathrellos, G. D., &Alexakis, D. E. (2021). Flood hazard assessment mapping in burned and urban areas. Sustainability, 13(8), 4455. https://www.mdpi.com/2071-1050/13/8/4455