ASSESSMENT OF FLOOD VULNERABILITY OF LOWER AJAY BASIN AND ITS SUSTAINABLE MANAGEMENT SOLUTION

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Dedicated to

My parents

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List of Abbreviation

WHO	-	World Health Organisation
GIS	-	Geographic Information System
SRTM DEM	-	Shuttle Radar Topography Mission Digital Elevation Model
DEM	-	Digital Elevation Model
DTM	-	Digital Terrain Model
R.F.	-	Representative Fraction
IMD	-	Indian Meteorological Department
ISGP	-	Institutional Strengthening of Gram Panchayats
UTM	-	Universal Transverse Mercator
FID	-	Feature Identity
SI	-	Sinuosity Index
ECL	-	Eastern Coalfields Limited
GPS	-	Global Positioning System
AHP	-	Analytical Hierarchy Process
FUZZY AHP	-	Fuzzy Analytic Hierarchy Process
HEC-HMS	-	Hydrologic Modeling System
NBSS & LUP	-	National Bureau of Soil Survey and Land Use Planning
USDA	-	Uniteed States Department of Agriculture
HSG	-	Hydrological Soil Group
CN	-	Curve Number
LULC	-	Land Use Land Cover
SCS-CN	-	Soil Conservation Service Curve Number
GP	-	Gram Panchayat
GSI	-	Geological Survey of India
USLE	-	Universal Soil Loss Equation
HEC-HMS	-	Hydrologic Engineering Centre's-Hydrologic Modelling System
HEC-RAS	-	Hydrologic Engineering Centre's River Analysis System
NDMA	-	National Disaster Management Authority
EDL	-	Extreme Danger Level
DL	-	Danger Level
PDL	-	Primary Danger Level
USGS	-	United States Geological Survey
ISRO	-	Indian Space Research Organisation

Abstract

Flood is the most frequent natural hazards in the world. Many factors like hydrology, atmospheric conditions and human behaviour are responsible for flood. In the case of fluvial flood, rivers fluvio-geomorphological factors are significant. In India fluvial flood is mostly dominated. Fluvial flooding is triggered by significant rainfall and the obstruction in drainage systems.

The study adopts a case study in the Ajay basin area which flows through the Bihar, Jharkhand and West Bengal states. The lower part area of the basin lies in West Bengal which is very flood prone. The increased flood potential in the lower Ajay basin has heightened the flood risk in the Bhagirathi-Hugli River basin and its surroundings.

To analyse the flood situation and assess the state of vulnerability, the fluvio-geomorphological characteristics of the basin area are discussed. The characteristics of the basin and the morphometric characteristics are analysed using the GIS platform. Morphometric results reveal that the basin shape is elongated, and it currently stands in the old stage of the erosion cycle. Most significantly, following the break of slope and related factors, the river is divided into three parts: Upper, Middle, and Lower. Morphometric and channel characteristics indicate the high flood potential in the lower part of the basin. The gradual decrease in the channel intake capacity due to high sedimentation and human encroachment on the river is increasing its flood vulnerability. The historical background of the flood is analysed with reference to statistical parameters. The maximum floods were recorded in the years 1978 and 2000 and average flood occur almost every year.

The identification of flood-prone area is a crucial aspect of flood management. Recent disaster management plans, such as those from (2008) and the recommendation of Niti Aayog's 2021 have emphasised the importance of identifying the spatial extent of floods. This study focuses on predicting the spatial extension of floods using both qualitative and quantitative data. In the absence of comprehensive hydrological data, AHP (Analytic Hierarchy Process) and FUZZY-AHP methods are applied on a geospatial platform to identify potential flood areas. Notably, the study integrates limited past hydrological data, such as peak gauge heights over the past 40 years, with current topographic data to delineate flood-prone areas.

Simulation-based hydrological models, implemented through software like HEC-HMS and HEC-RAS, are used to identify flood areas and flood depths. The study also examines the relationship between flood-prone areas and contributing factors, determining that low carrying capacity, channel width variation, poor drainage conditions, tributary channel degradation, and human encroachment are major causes of flooding. Spatial validation through KAPPA statistics and overall accuracy assessments are used to analyse the model's suitability. The predicted spatial flood extension is used to estimate vulnerability potential and risk.

To analyse the state of vulnerability, the study considers factors closely related to social, economic, and physical aspects. A vulnerability index is developed at the micro-level, using Gram Panchayat administrative areas. The region's agriculture-based economy, characterised by prevalent mud houses, is highly vulnerable to floods. The study incorporates existing resilience factors to enhance risk prediction. Results are classified according to intensity and vulnerability index values, with risks identified using a GIS platform.

For better flood management, the study discusses several existing non-structural solutions. The current condition of embankments is analysed by measuring soil texture, and texture graphs are used to assess seepage probability. An empirical formula is applied to predict seepage probability. Although the Lower Ajay basin is protected by earthen embankments, their failure has resulted in significant economic and social losses, with long-term damage effects. The failure of the earthen embankment is due to the unscientific use of the embankment, particularly the movement of sand-loaded heavy vehicles, bed cultivation, and unscientific sand quarrying. Therefore, the research emphasises non-structural solutions such as constructing flood shelters in required area, improving road networks quality and increase the road length according to route mapping from resident to flood shelter area, modifying paddy seeds, providing crop insurance from the government side, raising awareness.

The scope of resilience is discussed both quantitatively and qualitatively, with a cost-benefit assessment included for the development of resilience strategies. Prediction of flood potential area in is a critical step in this study. The study's uniqueness lies in its ability to predict vulnerability by combining socio-economic conditions with an assessment of resilience.

This study takes a holistic approach to understanding hydro-fluvial conditions in the river, presenting an analysis of flood conditions, predicting the state of vulnerability, and providing recommendations for sustainable management solutions.

Chapter -1

Introduction

1.1 General overview

Floods certainly create significant challenges worldwide and in India, it can be especially devastating due to the country's dense population and complex socio-economic conditions. The convergence of factors such as high population density in floodplains, fertile soil attracting settlements, monsoonal effects on rivers, and the overlap of flood events with the agricultural calendar creates a perfect storm for disaster. In regions like West Bengal, where rivers like Damodar, Ajay, and Mayurakshi play a crucial role in the local ecosystem and economy, floods can wreak havoc. The Bhagirathi-Hugli River system, which is vital for irrigation and transportation, becomes vulnerable during flood events. The challenges are further compounded by the intricate drainage networks, which often struggle to cope with the excess water, leading to prolonged inundation and damage.

1.2 Types of flood

Floods are the most frequent type of natural disaster. It occurs when an overflow of water submerges dry land. Floods are often caused by heavy rainfall, rapid snowmelt, or a storm surge from a tropical cyclone or tsunami in coastal areas (WHO). Generally, floods are a part of the hydrological cycle. However, floods devastate the whole environment and society. Most of the major floods have been triggered by natural causes, but man-made floods also threaten lives. For instance, dam failures and artificial bank failures can cause heavy floods. According to major classifications, four significant types of floods are identified (Parker, 2000).

i) *Fluvial flood*: Fluvial flood occurs by the over flow of the river water onto the dry land. Due to high rain fall when channel capacity exceeds, fluvial flood is observed. Terrain profile, extreme climatic phenomena normally determines the flood intensity. As per river catchment volume, flood intensity varies spatially. Fluvial flood could affect wide spread area. It also directly threatens the human life, agricultural system, drinking water etc. In the year 2000, a significant fluvial flood simultaneously affected the Damodar, Ajay, and Mayurakshi river basins. A heavy and prolonged monsoon rain lashed the Chotanagpur Plateau region, leading to excessive runoff into the Damodar, Ajay, and Mayurakshi rivers. These rivers, which flow through Jharkhand and West Bengal, experienced rapid swelling. As a result, the rivers breached their banks and caused extensive flooding in adjoining districts like Bardhaman, Birbhum, Murshidabad, and Hooghly in West Bengal. The flood resulted in widespread devastation – thousandsof homes were submerged, over 50 people lost their lives, and lakhs of people were displaced. Croplands across vast areas were destroyed, leading to severe economic losses and food insecurity in affected regions. Roads, bridges, and railway lines were damaged, disrupting transport and communication for days.

ii) *Flash flood*: Due to certain torrential rainfall within short period of time flash flood causes. Flash flood is very dangerous for human life and high velocity of water and debris flow without any warning maximise the risk potentiality.

iii) *Coastal flood:* This flood can happen along the coastal area. Due to coincide of the high tide and storm surge coastal floods appears. Sometimes due to tsunami coastal area badly affected by flood. At present by the sea-level rise and climate change coastal flood is the most challenging phenomena.

iv) *Urban flood*: By the extreme rainfall and failure of the drainage system urban flood occur. Due to impermeable condition of the soil, urban flood trend is gradually increasing. For the heavy density of the population, urban flood results in huge vulnerability. Unplanned development of the urban areas, poor drainage system, and demand of the infrastructural facilities leads to the frequent urban flooding.

1.3 Flood scenario in world and Indian sub-continent

Excessive rainfall and the seasonal pattern of rainfall cause high flood vulnerability in the Indian subcontinent (Figure 1.2). The climatic scenario, combined with the socio-economic characteristics and poor economic situation, creates a more dangerous situation in the Indian subcontinent. India is the second largest populated country of the world. Most significantly India is one of the highly exposed countries to natural disaster (Table 1.1). Due to its geographical location India is also highly seismic prone and atmospheric hazards are common phenomena.

Table 1.1 Types of natural disasters in India and nature of losses

Types of disaster	Natural disasters (%)	Natural loss (%)	Human loss (%)
Floods	52	63	32
Hurricanes	30	19	32
Landslides	10	0	2
Earthquakes	5	10	33
Droughts	3	5	1

(Source-World Bank, retrieved from Atlas Magazine Insurance News around the World, 2021)

Heavy monsoon rains lead to recurring floods in the Indian subcontinent. Major rivers like the Ganga, Brahmaputra, and Indus flow across Indian soil, leading to significant drainage congestion. The entire country is blessed with some of the best riverine floodplains, but this also means that significant losses are common during floods. Historical data shows that many developed civilisations flourished in India's riverine plains, but they were also vulnerable to destructive floods. This historical pattern continues today, with floods causing significant losses and affecting millions of people annually (Figure 1.1). Presently, due to the high density of population, the risk potentiality of flood impacts is increasing. In the Indian context, fluvial floods are the most common and widely spread phenomena, but coastal and urban floods are also becoming increasingly challenging. According to the report from the World Resource Institute (WRI), 4.84 million people are affected yearly by fluvial floods in India (Luo et al., 2015).

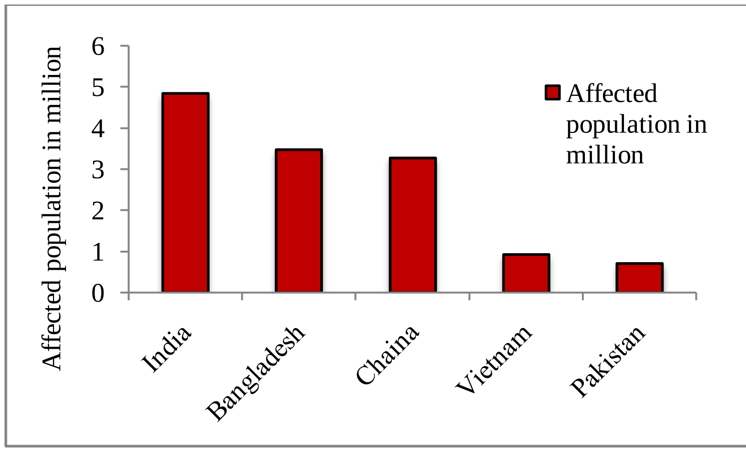

Figure 1.1 Flood affected population in top five countries

(Source-World Resource Institute, 2015)

The assertion that India is one of the countries with the highest flood potential in terms of economic loss is indeed significant (Figure 1.3). The World Bank's report, 2022 estimating an average economic loss potentiality of 890.16 USD million, underscores the immense financial impact of floods in the country. This data highlights the urgent need for robust flood management strategies, investment in infrastructure resilience, early warning systems, and community preparedness initiatives. Addressing the economic risks posed by floods is crucial for sustainable development and resilience-building efforts in India.

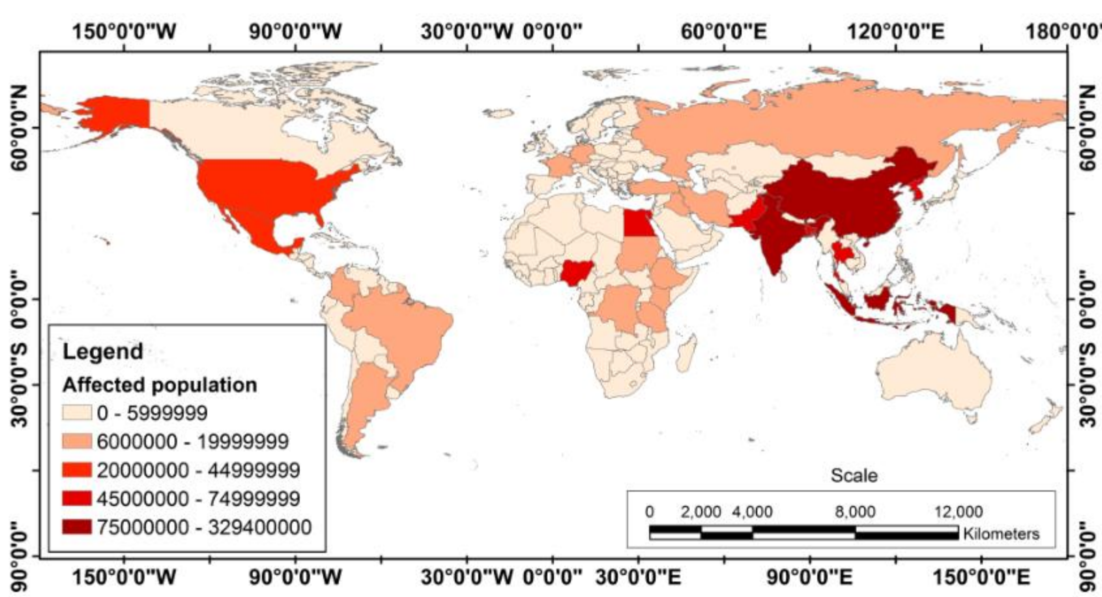

Figure 1.2 Absolute population exposure to 15 cm or more flood inundation risk at the country level

(Source- Rentschler and Salhab, 2020)

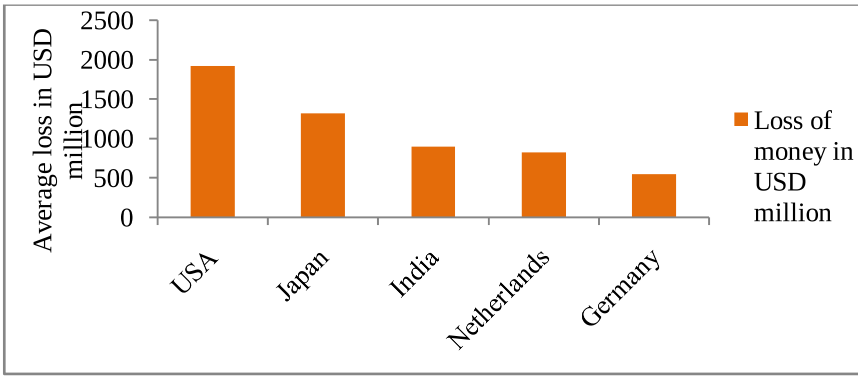

Figure 1.3 Estimated economic loss in top five countries

(Source-World Bank Report, 2022)

India is fortunate to have fluvial floodplains. However, the lack of scientific land use and land cover planning, combined with an overcrowded population in these floodplains, can lead to devastating impacts from floods. Even a minor flood can create significant challenges and make things more difficult.

In Indian perspective the impact of flood is very deep rooted and overall consequences are long run. Most of the times the consequences are calculated in terms of loss of life, crops, damage of houses etc.. But the societal impact is ignored. Flood frequent area is lagged very much and deprived of the development. Due to frequent floods, recovery takes a long time. The damage is often so severe that it weakens the core of the economy and the morale of the people.

1.4 Indian flood: spatio-temporal scenario

India is frequently afflicted by flood hazards, impacting a substantial portion of its landmass and population. Agricultural damages are particularly prevalent in the Indian context. The National Disaster Management Authority and Ministry of Water Resources, 2018 publishes comprehensive data on the extent and frequency of floods throughout India (Table 1.2).

Table1.2 Flood scenario in India

Year	Flooded area in million Hectare	Population affected in million	Damage crops area in million Hectare
1990	9.303	40.259	3.179
1991	6.357	33.889	2.698
1992	2.645	19.256	1.748
1993	11.439	30.409	3.206
1994	4.805	27.548	3.963
1995	5.245	35.932	3.245
1996	8.049	44.729	3.827
1997	4.569	29.663	2.258
1998	10.845	47.435	7.495

Year	Flooded area in million Hectare	Population affected in million	Damage crops area in million Hectare
1999	7.765	27.993	1.753
2000	5.382	45.013	3.58
2001	6.175	26.463	3.964
2002	7.09	26.323	2.194
2003	6.12	43.201	4.268
2004	5.314	43.725	2.88
2005	12.562	22.925	12.299
2006	1.096	25.224	1.822
2007	7.145	41.402	8.795
2008	3.427	29.91	3.186
2009	3.844	29.537	3.592
2010	2.624	18.297	4.994
2011	1.895	15.973	2.718
2012	2.141	14.689	1.95
2013	7.546	25.927	7.484
2014	12.775	26.505	8.007
2015	4.478	33.203	3.374
2016	7.065	26.555	6.658

(Source-Ministry of Water Resources, 2018)

Table 1.3 Affected flood area in India

States	Flood prone area in percentage
Andhra Predesh	34.80
Assam	38.20
Bihar	68.80
Kerala	14.70
Orissa	33.40
Punjab	40.50
West Bengal	37.66
Rajasthan	32.60

(Source-National Disater Management Authority, 2008)

The seasonal rainfall pattern dominated by monsoons in India can be highly unpredictable, leading to bursts of heavy rainfall and widespread flooding. The characteristics of floods vary significantly on a regional scale (Table 1.3). Extra-peninsular India, including regions affected by the Gangetic and Brahmaputra River basins, experiences flooding, while peninsular India faces floods from rivers like the Godavari and Kaveri.

Recent approaches prioritise non-structural solutions for flood control. However, the effectiveness of flood control planning is often hindered by the failure to address stakeholders demands, leading to ineffective planning outcomes. Addressing these challenges requires a holistic approach, integrating structural and non-structural measures while actively involving stakeholders in planning processes to ensure more effective flood management strategies.

1.5 Challenges of flood in Indian scenario

India lies in a tropical monsoon climatic region, where the flood patterns are predominantly influenced by the monsoon system. The flood characteristics in Northern India differ significantly from the Southern India.

In Northern India, the outbreak of clouds coincides with the monsoon rainfall, leading to widespread flooding in the vast areas of the Ganga and Brahmaputra basins. This region experiences intense rainfall during the monsoon season, which typically lasts from June to September. The combination of heavy monsoon rains and the large catchment areas of these rivers results in substantial flooding. The floods in Northern India are further exacerbated by the melting of snow in the Himalayas, adding to the water volume in the rivers.

In Southern India, the flood scenario is influenced by the burst of the monsoon over the Western Ghats and the Central Plateau region. The heavy rains in these regions lead to spill over effects that inundate vast areas. In Northern India, flash floods are common due to cloudbursts and fragile geology, while in Southern India, flash floods occur due to excessive rainfall and the terrain character of Western Ghats region. Additionally, the eastern coast of Southern India is vulnerable to floods during the northeast monsoon season, which occurs from October to December.

Both Northern and Southern India face increased flood risks due to rapid urbanisation and unplanned land use. The conversion of natural landscapes into urban areas reduces the land's natural absorption capacity, leading to higher runoff and increased flood severity.

Cyclonic storms and deep depressions over the Bay of Bengal and the Arabian Sea contribute to flooding, even during the pre-monsoon or post-monsoon seasons. These weather systems bring intense rainfall and strong winds, causing floods in coastal and inland areas alike. Inadequate drainage systems and poor infrastructure planning also play a significant role in aggravating flood situations in both regions.

While Northern India's floods are primarily driven by monsoon rains and the extensive river systems of the Ganga and Brahmaputra basins, Southern India's floods are characterised by intense rains over the Western Ghats and Central Plateau, with significant contributions from cyclonic activities. Rapid urbanisation and unplanned land use exacerbate the flood risks in regions, necessitating improved urban planning and better flood management strategies to mitigate the impacts.

1.6 Fluvial flood risk in West Bengal

West Bengal, being a major riverine state in India with 26 major drainage basins, experiences common fluvial floods due to this congestion and the high population density in flood-prone areas. The flood scenario in West Bengal is complex, with different areas facing varying degrees of risk. According to the Irrigation and Water Ways Government of West Bengal (2015), approximately 42.3% of the state's area is flood-prone (Figure 1.4). However, the nature of flooding differs between North Bengal and South Bengal. In North Bengal, where glacial-originated rivers flow continuously even in the lean season, the flood scenario is distinct. Conversely, South Bengal's rivers are primarily rain-fed, leading to reduced base flow during the lean season. Additionally, human encroachment and unscientific river usage have disconnected several tributary channels from the main river, exacerbating flood risks.

The formation of low-pressure systems in the Chotonagpur plateau and Bay of Bengal areas can trigger dangerous flood scenarios in South Bengal's river basin (Malik and Pal, 2021). Historical data from 1978 and 2000, as reported by the Irrigation and Waterways Department, indicates the extensive impact of floods in West Bengal, affecting large areas of land (Table 1.4).

During the monsoon season, adjoining basins become interconnected, leading to widespread flooding in South Bengal. This region is extensively cultivated during the monsoon, increasing the damage caused by floods to agricultural lands and communities.

West Bengal, flooded by the Gangetic River basin and its tributaries, suffers significant economic losses due to its agrarian economy. Many people lose their sources of income during floods, leading to societal unrest. Crisis management becomes a primary focus to minimise risks, but the lack of long-term planning and awareness often increases the intensity of risks.

The post-disaster scenario exacerbates health issues, and the lack of recovery planning doubles the impact of floods. Poor database management and unavailability of comprehensive databases pose major challenges to flood management planning. While steps have been taken post-independence, including the construction of major dams and barrages, many flood problems persist.

Table 1.4 Historical record of flood in West Bengal

Flood affected Area (in Sq. km)	Years during which the Flood occurred
< 500	1985,89,92,94,97,2001,2005, 2006 & 2013, 2014
500 – 2000	1962,63,64,65,66,72,75,96,2003,2004, 2007, 2009 & 2011
2000 – 5000	1960, 61, 67, 69, 70, 74, 76, 80, 81 & 82
5000 – 10000	1973,77,93,95,98 & 2008
10000 – 15000	1968, 79, 83, 90 & 99
15000 – 20000	1971, 86, 87 & 88
> 20000	1978, 84, 91 & 2000

(Source-Irrigation and Waterways Department, Government of West Bengal, 2015)

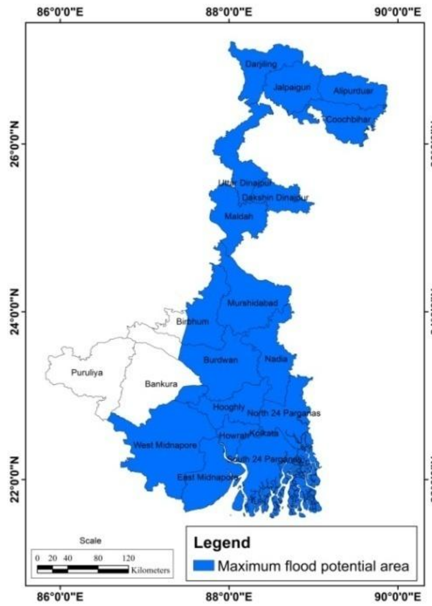

Figure 1.4 Maximum Flood potential areas in West Bengal

(Source- Disaster Management and Civil Defence Department, Government of West Bengal)

To address these challenges, holistic flood management strategies are essential, including improved river management, sustainable land-use practices, early warning systems, and community resilience measures (Suwanno et al., 2023). Collaboration among government agencies, local communities, and experts is crucial for effective flood risk reduction and management in West Bengal (Kwak et al., 2011).

1.7 Flood risk in Ajay basin area

The Ajay River is a significant river in Eastern India, originating from the Chotanagpur plateau area. Its journey traverses through Bihar and Jharkhand before reaching its lower course in West Bengal. This flooding has a profound impact on the confluence region of the Bhagirathi-Hugli River.

The flooding situation is exacerbated by heavy rainfall in the upper region and the influx of excessive runoff from tributaries such as Higlow, Kunur, and Khandar. These factors contribute to a heightened risk of flooding, creating a hazardous environment. As a result, significant portions of Bardwan and Birbhum districts in West Bengal are frequently inundated during periods of intense rainfall and flooding events. The extensive agricultural development in the area exacerbates the losses during floods, which directly impacts the region.

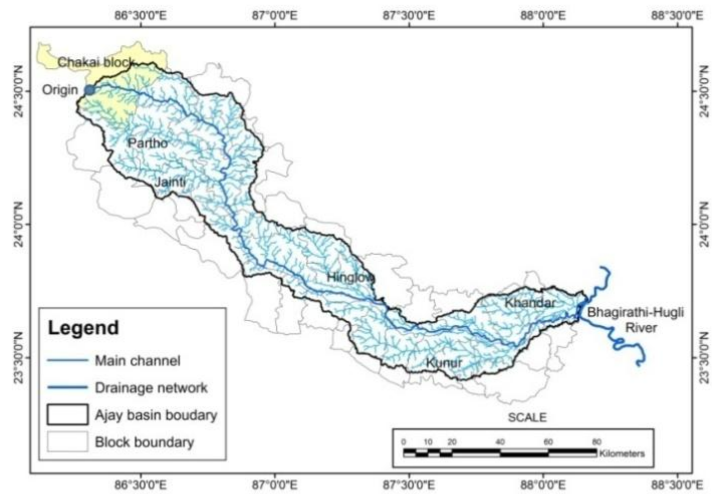

Figure 1.5 Ajay River basin

1.8 Hazard, vulnerability, risk and resilience assessment

Hazard refers to a situation that poses a significant threat to life. In disaster research, the term 'vulnerability' holds substantial importance, and researchers have made continuous efforts to define it. Gabor and Griffith (1980) define vulnerability as "the risk context," highlighting its association with risk assessment. Lewis (1999) views vulnerability as the root causes of disasters, emphasising its role in understanding disaster origins (Balica, 2012). The Intergovernmental Panel on Climate Change (IPCC) in 1992 defined vulnerability as the degree of inability to cope with the consequences of climate change and sea-level rise, linking it to climate-related risks.

Burton and Cutter (2008) describe vulnerability as the potential for loss, encompassing a combination of factors that determine the extent to which a person's life or livelihood is at risk during a specific event. Quantifying vulnerability involves considering social, economic, physical, and other factors to develop a comprehensive index, aiding in decision-making processes. Vulnerability varies depending on the type of hazard, as defined by the United Nations in 1982, reflecting the degree of loss to specific elements or sets of such elements.

Vulnerability studies aim to identify appropriate actions that need to be taken, despite their inherent uncertainty. Validation and comparison of vulnerability assessments assist in their practical application (Balica, 2012).

The actual level of risk depends on the vulnerability of socio-economic conditions and environmental fragility. Flood vulnerability analysis requires careful selection of risk factors and elements. Resilience, on the other hand, refers to the capacity to cope with floods, thereby reducing overall risk. With climate change and population growth, the impact of floods is increasing. Increasing infrastructural capacity is essential for long-term development, but protection solely against flood hazards is insufficient as their size and volume continue to rise.

Flexible, non-structural measures are crucial for effective flood solutions. These measures include spatial zonation of floods, improved flood prediction systems, and identification of hazard-prone areas. Advancements in technology have made flood prediction systems more popular, moving away from solely crisis management during floods. Previously, structural solutions negatively affected fluvial character, with a negative cost-benefit ratio. However, modern flood prediction systems and hazard identification are contributing positively to flood risk management efforts.

1.9 Flood management and sustainable solution

Providing complete protection to all flood-prone areas, especially against all flood magnitudes, is neither feasible nor economically viable. Instead, a reasonable level of protection through a combination of structural and non-structural measures is practical for addressing flood situations.

Structural approaches such as reservoir construction are common but often expensive and not sustainable in the long term. Embankments can reduce spilling and damage, but they are prone to collapse during high floods, leading to increased damage. Moreover, sediment trapping reduces channel intake capacity, posing additional challenges.

A Plinth Raised building structure indicates constructions with plinth levels higher than conventional. A village with buildings at elevated plinths is called as ‘plinth raise village’. This is a flood-resilient settlement planning strategy, wherein the entire village buildings or at least its critical infrastructures – such as schools, healthcare centres, and community shelters – are constructed on an artificially elevated plinth platform. This platform is designed to be higher than the historical or projected flood levels, thereby offering a protective buffer against seasonal inundation, flash floods, and even prolonged water logging.
The plinth is typically raised using locally available materials like earth fill, sandbags, concrete blocks, or compacted soil, ensuring both cost-effectiveness and community involvement in construction. The elevation height is determined based on historical flood records, hydrological modelling, and community knowledge, with consideration of climate change projections that might alter future flood patterns.

To mitigate flood effects, many rivers undergo artificial channel improvements, but these interventions can be economically costly and challenging to justify in terms of cost-benefit analysis.

Non-structural measures, on the other hand, have shown to be more practical and effective. These measures include developing pre-warning systems, identifying spatial floodplains, modifying land use and land cover, establishing flood shelters, identifying rescue routes, implementing crop insurance and improving housing structures. These measures are tangible and yield fruitful results in flood management.

Modern advancements in geospatial technology, such as GIS and remote sensing, have made it easier to develop blueprints for flood potential area identification and create frameworks for sustainable development. These tools provide access to physical and socio-economic data, enabling integrated river basin management planning that considers both environmental and societal factors.

Overall, a balanced approach that combines structural and non-structural measures is essential for effective flood management, considering both practicality and cost-effectiveness in long-term flood risk reduction strategies.

1.10 Role of geospatial technology in the flood management

Geospatial platforms play a crucial role in storing, analysing, and visualising spatial data accurately. Accessing spatial data, especially in remote areas, has become easier and cost-effective with the advent of geospatial technology. Modern geospatial software allows for the overlay and analysis of different layers of data within a single platform, enhancing the accuracy and efficiency of flood prediction models.

The integration of recent technological advancements with spatial tools has made real-time flood prediction more accessible to stakeholders and planners. Geospatial data, such as Digital Elevation Model (DEM) data, aids in physical quantification and characterization, facilitating risk assessment and mapping processes.

Geospatial technology enables timely rescue operations and relief efforts in remote areas by utilising active remote sensing data, such as radar systems, to accurately predict atmospheric conditions. Additionally, software-based geospatial technology like MIKE, HEC-HMS, HEC-RAS etc. combined with available remote sensing data simplifies flood prediction at a micro-level.

1.11 Interdisciplinary relevance

A comprehensive understanding of disaster management requires an interdisciplinary approach that integrates spatial science, natural science, social science, and technology. Natural disasters, including floods, exhibit varying characteristics across space and time, necessitating collaboration between spatial and natural sciences to analyse their root causes.

Social science plays a pivotal role in assessing the social impacts of disasters, including loss of life, damage to property, economic disruptions, health issues, and psychological trauma. Economic considerations are crucial, as the loss of agricultural crops, infrastructure, and livelihoods affects the economic balance of affected regions.

Proper management of any natural disaster strongly depend on the administrative policies which always get influenced through political role and decision making. This plays a critical role in both disaster preparedness and response. The effectiveness of policies, governance structures, resource allocation, and institutional coordination can significantly influence the outcomes of disaster management efforts. Governance determines the level of investment in risk reduction measures, the speed and fairness of aid distribution, and the implementation of long-term recovery plans. Furthermore, inclusive decision-making, participation of local governance and involvement of local communities and stakeholders are essential for ensuring that policies are both effective and socially just.

Environmental impacts, such as biodiversity loss and ecological changes, are also significant and fall within the realm of environmental science. Understanding changes in the environment during and after floods is essential for effective environmental management.

A legitimate disaster management plan must bridge the gap between natural and social sciences, considering factors like cost-effectiveness, engineering solutions, and regional variations in disaster management needs. Spatial science contributes to flood prediction and risk assessment by analysing physical factors like topography, hydrology, and geomorphology.

Collaboration among various disciplines is essential. For instance, atmospheric science and hydrology contribute to flood prediction, while oceanography and hydrological engineering are crucial for coastal flood management. Post-flood health issues are addressed by public health systems, and flood insurance is linked to agricultural and economic studies.

By breaking traditional barriers and fostering cooperation among disciplines, a comprehensive and interdisciplinary approach can provide effective solutions to minimise flood risk. This approach combines hydrology, geomorphology, geology, social sciences, management aspects, and technology to achieve holistic disaster management objectives (Peek and Guikema, 2021) (Figure 1.5). Utilising GIS platforms aids in presenting risk patterns and correlating topography, hydrology, and social-economic scenarios for informed decision-making and risk mitigation strategies.

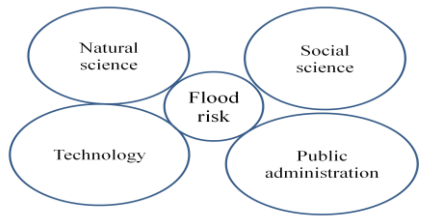

Figure 1.6 Mother domains involved in disaster research

(Source- Peek and Guikema, 2021)

1.12 Motivation of the study

Floods pose a recurring and multifaceted hazard, requiring an interdisciplinary approach for comprehensive understanding and effective management. Flood definitions vary across disciplines, encompassing hydrological aspects like excessive runoff and geomorphological features such as river overtopping and levee saturation. This interdisciplinary nature underscores the need to analyse both the causes and effects of floods from various perspectives.Climate uncertainties and increasing population densities exacerbate flood risks globally, necessitating micro-level studies and ground-level validation to mitigate flood impacts effectively. Fluvial floods, influenced by river encroachment and bed cultivation, reduce river flow capacity and demand continuous monitoring and prediction for increased resilience.

Spatial pattern analysis and hazard identification are crucial, integrating hydrological data, river channel characteristics, and socio-economic factors. However, challenges arise in data availability and quality, especially in areas lacking gauge stations or with inadequate data management practices.

Researchers strive to improve methodologies for spatial flood pattern analysis and validation, acknowledging the dynamic nature of flood risks influenced by changing socio-economic patterns, population growth, and land use changes. The Ajay River basin, situated between Damodar and Mayurakshi basins, plays a significant role as a tributary of the Bhagirathi Hugli River, with lower regions experiencing annual inundation.

The complex hydrological and climatic scenarios in the catchment area, combined with meandering river formations and flood-prone characteristics, create challenges for flood risk prediction and management. The confluence of tributaries with the main channel exacerbates flood situations, affecting downstream areas extensively.

High population densities in fertile deltaic regions amplify socio-economic risks, particularly impacting rural economies reliant on agriculture. Sustainable flood management solutions require continuous monitoring, risk identification, and interdisciplinary collaboration to achieve resilience-based outcomes. In conclusion, ongoing studies considering micro-level socio-economic behaviours are essential for developing sustainable flood management solutions tailored to regional complexities and vulnerabilities.

Chapter -2

Review of Literature

2.1 General overview

Literature review play crucial role for the research work. It helps to identify the research problems and another hand it fulfill the knowledge gap. Details study of literature review help to formulate the research methodology. For a good research work details and serious literature review is a crucial part. To fulfill the demands of present research work the whole literature reviews are broadly categorised into three segments.

1) Study of fluvial characteristics

2) Study on flood hazard vulnerability and risk analysis

3) Study on flood management

2.2 Study of fluvial characteristics

In the present research work context, understanding of the fluvial characteristics is one of the significant part. Fluvial character study opens a gateway to understand the relation between fluvial character and flood behavior. So the detail literature study in this context is discussed here.

2.2.1) The paper authored by Swetasree Nag, Malabika Biswas Roy, Shuvoshri Bhattacharya, Souvik Mondal, and Pankaj Kumar Roy, titled "Assessment of Topographic Complexity Zone of a Drainage Basin Using Geographic Information System" (2021), delves into the intricate analysis of a drainage basin's three-dimensional attributes. Their approach involves leveraging SRTM Digital Elevation Model (DEM) data within a Geographic Information System (GIS) platform to extract critical features like drainage lines and basin boundaries. A significant aspect of their study is the comprehensive examination of the basin's linear, areal, and relief properties. This includes factors such as the length and pattern of waterways, the basin's size, shape, and land cover, as well as variations in elevation and terrain ruggedness. Furthermore, the researchers qualitatively assess the hydrological behaviour of the basin using statistical graphs and cartographic techniques. By establishing correlations between drainage characteristics and physiographic features, they aim to elucidate how the topographic complexity of the basin influences its hydrological dynamics. This research contributes valuable insights into understanding watershed complexities and aids in informed decision-making for effective watershed management strategies.

2.2.2) In the research paper titled "Fluvial Processes and Evolution of Quaternary Landscape of the Ajay River Basin in West Bengal, India" (2018), researcher Sujay Bandyopadhyay conducted a comprehensive study of the physical environment of the basin. This included an analysis of the geology, soil composition, and climatic conditions prevailing in the basin region. Additionally, the researcher examined the land use and land cover patterns, particularly focusing on the lower part of the region.

A significant aspect of the research was the stratigraphy of the basin and the analysis of its Quaternary evolution. The researcher delved into the geological layers and formations within the basin, aiming to understand the historical processes that shaped its landscape over time.

Furthermore, the study involved an in-depth analysis of the river flow patterns within the main channel of the Ajay River. The researcher studied these flow patterns over different time periods to capture variations and trends. Additionally, the longitudinal profile of both the main channel and tributary channels was drawn, and various methods were employed to fit curves to these profiles. This analysis provided insights into the morphological characteristics of the river channels and their evolution over time.

Overall, this research contributed valuable knowledge regarding the physical processes and evolutionary history of the Ajay River Basin, shedding light on the complex interplay between geological factors, river dynamics, and landscape evolution.

2.2.3) In the research paper titled "Hydro-geomorphological Characterization of Dhidhessa River Basin, Ethiopia" (2018), researchers Gizachew Kabite and Berhan Gessesse conducted a detailed analysis comparing SRTM (Shuttle Radar Topography Mission) DEM (Digital Elevation Model) data with ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM data for morphometric analysis.

The researchers utilised SRTM DEM data to analyse the morphometry of the Dhidhessa River Basin. Morphometric analysis involves studying the quantitative measurements and characteristics of landforms, particularly focusing on the river basin's topographic features.

A significant aspect of their analysis was the assessment of soil erosion and the geomorphic character of the basin based on the morphometric results. This involved understanding how the basin's topography, slope, drainage patterns, and other morphometric parameters influence soil erosion processes and shape the geomorphological features within the basin.

By comparing different DEM datasets and conducting detailed morphometric analyses, the researchers aimed to gain insights into the hydro-geomorphological characteristics of the Dhidhessa River Basin. This research contributes valuable information for understanding landscape dynamics, erosion vulnerability, and geomorphic processes in the study area, which is essential for sustainable land management and environmental conservation efforts.

2.2.4) In the paper "Modelling River History and Evolution" (2018) authored by T. J. Coulthard and M. J. Van de Wiel, the focus was on analysing the river system with respect to the topographic conditions of the region. The researchers employed modelling techniques to understand the historical evolution of the river and its dynamics.

A key aspect of their analysis was the discussion on river flood dynamics based on fluid dynamics principles. This involved studying how the river behaves during flood events, including flow patterns, sediment transport, and erosion/deposition processes.

In the results section of the paper, the researchers emphasised the river's erosion and depositional characteristics. This likely included insights into how the river reshapes its channel through erosion and sediment deposition over time.

Furthermore, the paper delved into the hydro-geomorphological characteristics of the river, which encompassed a holistic understanding of the interactions between water flow, geological features, and landforms within the river basin. This analysis provided valuable insights into the complex processes shaping the river's evolution and morphology.

Overall, this research contributed significant knowledge regarding river dynamics, flood behaviour, erosion and deposition processes, and hydro-geomorphological interactions, which are crucial for understanding and managing river systems effectively.

2.2.5) In the research paper titled "Morphotectonics of the Jamini River Basin, Bundelkhand Craton, Central India; Using Remote Sensing and GIS Technique" by Researchers K. Prakash, T. Mohanty, J. K. Pati, S. Singh, and K. Chaubey (2016), the focus was on analysing the morphotectonics of the Jamini River basin using remote sensing and GIS techniques.

One of the key methodologies employed by the researchers was the use of SRTM (Shuttle Radar Topography Mission) DEM (Digital Elevation Model) data within a GIS platform. This allowed them to conduct detailed morphometric analyses of the basin, focusing on linear, areal, and relief properties.

A significant aspect of their analysis was the utilisation of specific morphometric indices such as the Transverse Topographic Index (TPI) and Asymmetry Factor. These indices are commonly used in geomorphological studies to assess tectonic influences on landforms and drainage patterns. The TPI helps in identifying areas prone to mass wasting or erosion, while the Asymmetry Factor indicates the degree of asymmetry in drainage basins, which can be indicative of tectonic activity.

By applying these morphometric techniques and indices, the researchers aimed to understand the tectonic influence on the Jamini River basin area. This research contributes valuable insights into the geomorphological processes and tectonic dynamics shaping the landscape of the Bundelkhand Craton region in Central India, which is essential for geological and environmental studies in the area.

2.2.6) In the research paper titled "Role of Hydrological Regime and Floodplain Sediments in Channel Instability of the Bhagirathi River, Ganga-Brahmaputra Delta, India" by Researchers Sanat Kumar Guchhait, Aznarul Islam, Sandipan Ghosh, Balai Chandra Das, and Nishith Kumar Maji (2016), the focus was on understanding the impact of tributaries such as Ajay, Mayurakshi, and Damodar on the lower course of the Bhagirathi-Hugli River.

A significant aspect of the research was the examination of the effect of sediments in the floodplain area. Sediments play a crucial role in shaping river channels and floodplains, affecting channel stability and overall river dynamics.

Furthermore, the researchers analysed the sinuosity character of the Bhagirathi-Hugli River and its relation to the floodplain. Sinuosity refers to the degree of meandering or curvature in a river's course. Understanding sinuosity patterns helps in assessing river behaviour, erosion, and sedimentation processes.

By studying the interactions between tributaries, sediment dynamics, sinuosity, and floodplain characteristics, the researchers aimed to gain insights into the channel instability of the Bhagirathi River. This research contributes valuable knowledge for better understanding the geomorphological processes and hydrological regime of river systems in the Ganga-Brahmaputra Delta region, which is essential for effective river management and flood risk assessment.

2.2.7) In the study titled "Environmental Impact of Sand Mining: A Case Study Along the Lower Reaches of Ajay River, West Bengal, India" by researcher Mrinal Mandal (2016), the focus was on investigating the effects of sand mining on the Ajay River bed and its surrounding environment.

One of the primary aspects discussed in the study was the impact of sand mining activities on the Ajay Riverbed. Sand mining can lead to significant alterations in river channel geometry, including changes in depth, width, and shape. These alterations can have far-reaching environmental consequences, affecting water flow dynamics, sediment transport, and habitat conditions.

The researcher emphasised the changes in river channel geometry resulting from human activities such as sand mining. This involved analysing the features of the riverbed, particularly focusing on the impact of sand mining on river bars. River bars are natural sediment deposits that form within river channels, and their stability is crucial for maintaining healthy river ecosystems.

To assess the impact of sand mining, the researcher compared cross-sectional profiles of the riverbed before and after mining activities. This comparison allowed for the identification and analysis of changes in the riverbed's topography, highlighting the extent of alterations caused by sand mining operations.

Overall, the study sheds light on the environmental consequences of sand mining in river systems, with a specific focus on the Ajay River in West Bengal, India. By understanding the effects of sand mining on river channel morphology and ecosystem health, the research contributes to informed decision-making for sustainable river management practices.

2.2.8) In the study titled "Sand Quarrying Activities in an Alluvial Reach of Damodar River, Eastern India: Towards a Geomorphic Assessment" by researchers Prasanta Kumar Ghosh, Sujay Bandyopadhyay, Narayan Chandra Jana, and Ritendu Mukhopadhyay (2016), the researchers aimed to assess the impact of sand quarrying activities on the Ajay River's geomorphic health.

One of the primary objectives of the study was to analyse how sand quarrying from the Ajay riverbed affects the overall geomorphology of the river. To achieve this, the researchers collected data on sand quarrying activities from various locations along the riverbed.

Using this data, the researchers conducted a detailed analysis focusing on the impact of sand quarrying on the geomorphic features of the Ajay River. This included measuring the cross-sectional profiles of the riverbed at different locations to establish a direct relationship between human-induced impacts and changes in the river's morphology.

Specific geomorphic conditions such as the pool-riffle sequence and thalweg conditions were analysed as part of the study. The pool-riffle sequence refers to alternating sequences of deeper pools and shallower riffles in a river channel, which are important for maintaining aquatic habitat diversity. Thalweg conditions pertain to the deepest part of a river channel where water flow fastest, influencing sediment transport and channel morphology.

By assessing these geomorphic features and their alterations due to sand quarrying, the researchers aimed to provide insights into the environmental consequences of human activities on river systems. This research contributes valuable knowledge for understanding the geomorphic dynamics of alluvial rivers and supports informed decision-making for sustainable river management practices.

2.2.9) The application of Hack’s Stream Gradient Index (SL Index) to longitudinal profiles of rivers flowing across the Satpura-Purna Plain, Western Vidarbha, Maharashtra, was a study conducted to assess the gradient and slope characteristics of these rivers. Researchers aimed to utilise Hack's index, a geomorphic parameter commonly used in river studies, to understand the longitudinal profiles and channel gradients of rivers in the specified region.

Hack's Stream Gradient Index, often denoted as the SL Index, quantifies the steepness of a river's channel based on its vertical drop over a horizontal distance. This index is valuable for assessing river profiles and understanding the erosional and depositional processes shaping river channels.

In this study, researchers collected longitudinal profile data from rivers across the Satpura-Purna Plain in Western Vidarbha, Maharashtra. They applied Hack's Stream Gradient Index to these profiles to calculate and analyse the gradient characteristics of the rivers.

The findings of the study likely provided insights into the slope variations, channel stability, and erosional and depositional patterns of the rivers in the region. Understanding the gradient characteristics of these rivers is essential for various purposes, including watershed management, flood risk assessment, and environmental conservation.

Overall, the application of Hack's Stream Gradient Index to longitudinal river profiles in the Satpura-Purna Plain of Western Vidarbha, Maharashtra, contributed valuable geomorphic data, aiding in the assessment and management of river systems in the area.

2.2.10) In the study "Neo-tectonics, River Capture, and Landscape Evolution in the Highlands of SE Brazil" by researchers Chrystiann Lavarini, Antônio Pereira Magalhães Júnior, Fábio Soares de Oliveira, and Alex de Carvalho (2016), a comprehensive analysis of morphological and morphometric techniques applied to a river basin was conducted, focusing on its relationship with present topography.

One of the key methodologies utilised in the study was the division of the river basin into watershed tectonic anomalies. These anomalies represent areas where tectonic processes have influenced the landscape and river system. By identifying and analysing these anomalies, researchers gained insights into the neo-tectonic activity and its impact on landscape evolution.

Both traditional and modern morphometric techniques were employed in the study to assess various aspects of the river basin. Traditional techniques may include measurements of river length, basin area, and drainage density, while modern techniques could involve GIS-based analysis, remote sensing data, and digital elevation models.

A significant aspect of the research was establishing relationships between the present litho-structural condition (referring to the geological and structural characteristics of the area) and the character of the river basin. This analysis helped in understanding how geological features influence the morphological and morphometric properties of the river basin.

Overall, the study is contributed valuable insights into the neo-tectonics, river capture processes, and landscape evolution in the highlands of SE Brazil. The integration of morphological, morphometric, and litho-structural analyses provided a holistic understanding of the complex interactions shaping the river basin and its surrounding environment.

2.2.11) In the research paper "Quaternary Tectonic Control on Channel Morphology over Sedimentary Lowland: A Case Study in the Ajay-Damodar Interfluve of Eastern India" by researchers Suvendu Roy and Abhay Sankar Sahu (2015), the focus was on investigating the influence of tectonic and litho-structural factors in the Ajay-Damodar interfluve region of Eastern India.

One of the key methodologies employed in the study was the mapping of lineaments and fault lines in the region. Lineaments represent linear geological features that can indicate underlying tectonic structures. By mapping these lineaments and fault lines, researchers aimed to understand the tectonic framework of the study area.

Additionally, the study utilised techniques such as the Transverse Topographic Method and Topographic Asymmetry Index to assess the tectonic influence on channel morphology. These methods help in quantifying the relationship between topographic features and tectonic forces acting on the landscape.

Furthermore, longitudinal profile analysis and the stream length gradient index were used to establish the relationship between river characteristics and the underlying geological structure of the region. Longitudinal profiles provide insights into the slope variations along a river's course, while the stream length gradient index indicates changes in channel gradient.

By integrating these techniques and analyses, the researchers were able to demonstrate how Quaternary tectonic activities have influenced the channel morphology and landscape evolution in the Ajay-Damodar interfluve region. This research contributes valuable knowledge to understanding the complex interactions between tectonics, litho-structure, and river morphology in sedimentary lowland areas.

2.2.12) In the research work titled "Litho-Structural Control on the Upper Part of the Dwarakesher Basin, Purulia, West Bengal" (2015) by researchers S. Das and B. Mistri, the focus was on assessing the influence of litho-geological factors on the upper part of the Dwarakesher River basin.

To measure the litho-geological control on the river basin, the researchers utilized various data sources including topographical maps, geological maps, and DEM (Digital Elevation Model) data. These data sources provided information about the terrain and geological formations in the study area.

By using DEM data and geological maps, the researchers identified lineaments, which are linear geological features that often indicate underlying structural controls. These lineaments were then overlaid on a GIS (Geographic Information System) platform to analyse their relationship with the river channel.

The researchers quantified the degree to which the river channel is regulated or influenced by litho-geological factors. This analysis involved examining parameters such as stream number, stream order, and sinuosity index. Stream number and stream order relate to the hierarchical organization of streams within a river network, while the sinuosity index indicates the degree of meandering in the river channel.

Through their analysis, the researchers concluded that the upper part of the Dwarakesher River basin is indeed controlled by litho-geological factors. This suggests that geological formations and structures play a significant role in shaping the morphology and behavior of the river in this particular region.

Overall, the study provides valuable insights into the relationship between litho-geological factors and river basin characteristics, contributing to a better understanding of landscape evolution and geomorphic processes in the Purulia region of West Bengal.

2.2.13) In the EIA report titled – "Supplementary Note to the EIA & EMP for Composite plan Of Sand mining (major mineral) in the riverbed of Ajoy River" (2015) published by Raniganj Coalfield Eastern Coalfields Limited. In Ajoy river bed there is 21 sand mining stations. The sand extraction methods are discussed here-

The sand will be mined manually from surface of river-bed.

- There is no drilling and blasting involved.
- There is no rehabilitation & resettlement involved.
- There is no dust generation and liquid effluent generation during collection of sand.
- The transport of sand from thesand ghat is done through tippers covered with tarpaulin / thick plastic sheets. Sand is transported either directly to the linked underground mines or stored in depots at transfer points for subsequent transport to the mines. The maximum distance of transportation is around 5 to 6 kms.
- Sand extraction and transportation activities are outsourced to experienced contractors and carried out under the supervision and guidelines of ECL.
- All necessary facilities like shelter, drinking water, safety equipment, etc are provided to the contractual workers deployed for the collection of sand from the river bed.

In this report it is also discussed that due to break of slope near Pandebeswar region the volume river bed deposition is maximum in this region. As per this report river bed will not affect due to sand quarrying. It is also mentioned that it will increase the riverbed capacity and minimum the flood affect.

2.2.14) In the research work titled "Entropy Application to Evaluate the Stability of Landscape in Kunur River Basin, West Bengal, India" by researchers Sujay Bandyopadhyay, Subhajit Sinha, N. C. Jana, and Debasis Ghosh (2014), the focus was on assessing the stability of the landscape in the Kunur River Basin, with a specific emphasis on the tectonic impact on river behaviour.

A notable aspect of the study was the utilisation of the laws of thermodynamics, particularly entropy, for analysing the longitudinal profile of the river. Entropy is a concept from thermodynamics that measures the degree of disorder or randomness in a system. In the context of river behaviour, entropy can be used to assess the complexity and stability of the landscape.

The researchers identified the presence of knick points in the longitudinal profile of the river. Knick points are abrupt changes in channel slope that can indicate underlying geological or tectonic processes. The influence of tectonic action on the presence and characteristics of knick points was analysed in detail.

Furthermore, the study involved analysing human interventions on the river channel. To assess the impact of human activities, researchers applied the concavity index to the river. The concavity index helps in evaluating changes in the curvature of the river channel, which can be influenced by human alterations such as channel straightening or bank modifications.

By integrating entropy analysis, knick point identification, and concavity index evaluation, the researchers gained insights into the stability, complexity, and human-induced changes in the Kunur River Basin. This research contributes to understanding the dynamic interactions between geological, tectonic, and anthropogenic factors shaping river behaviour and landscape stability in West Bengal, India.

2.2.15) In the research work titled "Characterisation and Evolution of Primary and Secondary Laterites in North Western Bengal Basin, West Bengal, India" by Researchers Sandipan Ghosh and Sanat K. Guchhait (2014), the study focuses on the formation and characteristics of laterites in the Rarh Bengal region.

A significant aspect of the research was the identification of fault line locations within the Ajay, Mayurakshi, and Damodar River basin regions. These fault lines play a crucial role in the geological and geomorphological processes affecting the formation and distribution of laterites.

The researchers conducted a detailed analysis of the laterite profiles in this region. Laterites are soil and rock types rich in iron and aluminum, formed in humid tropical areas through intense and prolonged weathering of the underlying parent rock. The study differentiated between primary and secondary laterites, examining their formation processes, characteristics, and spatial distribution.

By mapping fault lines and analysing laterite profiles, the researchers were able to draw conclusions about the tectonic influences on lateritisation in the region. The presence of fault lines suggests that tectonic activities have impacted the geomorphology, contributing to the formation and evolution of laterites.

This research provides valuable insights into the geological history and landscape evolution of the north-western Bengal Basin, highlighting the interplay between tectonic processes and weathering in shaping the region's lateritic landscapes.

2.2.16) In the research paper titled "A GIS-based Approach in Drainage Morphometric Analysis of Kanhar River Basin, India" (2014) by researchers Praveen Kumar Rai, Kshitij Mohan, Sameer Mishra, Aariz Ahmad, and Varun Narayan Mishra, the focus was on utilising ASTER DEM data to conduct a detailed morphometric analysis of the Kanhar River Basin.

The researchers employed a GIS-based approach to analyse the morphometry, which involves measuring the geometric characteristics of the basin and its drainage network. They divided the basin into upper, middle, and lower parts, providing a detailed analysis of each section. This division allowed for a more nuanced understanding of the morphometric characteristics specific to different parts of the basin.

Furthermore, the basin was divided into separate watersheds, and the morphometric parameters were discussed individually for each watershed. This approach helped in identifying the geomorphological units and understanding the erosional plains within the basin. The relationship between the geomorphological characteristics and the morphometric parameters was emphasised, offering insights into how the physical features of the landscape influence the drainage patterns and erosional processes.

Overall, this research highlights the importance of using GIS and remote sensing data to perform detailed morphometric analyses, which can provide valuable information for understanding the geomorphological and hydrological behavior of river basins.

2.2.17) In the study titled "Combined Techniques in Fluvial Geomorphology: An Application of Sampling and GIS for Quantitative Analysis of the Kunur" (2013), Researcher Suvendu Roy analysed the morphometry of the Kunur River, a tributary of the Ajay River. The study utilised a combination of sampling techniques and GIS for a comprehensive quantitative analysis.

A significant aspect of this research was the focus on first-order and second-order streams. The researcher established relationships between stream orders, stream numbers, and stream lengths. This detailed analysis provided insights into the hierarchical organization of the river's drainage network.

Moreover, the study examined the tectonic influences and topographic characteristics of the Kunur River basin. By analysing morphometric parameters and their spatial distribution, the research highlighted how tectonic activities and topographic features affect the river's geomorphology. This dual focus on both fluvial geomorphology and tectonic-topographic relationships enriched the understanding of the river basin's dynamics.

Overall, this research underscored the importance of integrating various techniques in fluvial geomorphology to achieve a nuanced and comprehensive analysis of river systems. The use of GIS and quantitative methods facilitated a detailed investigation of the Kunur River's morphometry, contributing valuable knowledge to the field of fluvial geomorphology.

2.2.18) Researcher Suvendu Roy, in the work titled "Generating Iso-Erosion Rate Zones for the Kunur River Basin Using Combined Methods of Soil Erosion Estimate" (2013), focused on predicting soil erosion within the Kunur River basin area. This study employed the Universal Soil Loss Equation (USLE) method to analyze and delineate soil erosion zones.

A notable aspect of the research was the use of the Continuous Wavelet Entropy Estimate (CWEE) method to identify soil erosion in first-order stream areas. This method provided a detailed and nuanced understanding of soil erosion patterns in the smaller, headwater streams of the basin.

To ensure the accuracy and reliability of the predictions, the researcher validated the soil erosion intensity through field visits and photographic documentation. This field validation was crucial for corroborating the results obtained from the computational methods, providing a robust assessment of soil erosion rates across different zones of the basin.

Overall, this work highlights the integration of advanced computational techniques with field validation to generate accurate iso-erosion rate maps. Such maps are essential for effective soil conservation planning and for mitigating the adverse effects of soil erosion in the Kunur River basin.

2.2.19) In the study titled "River Sinuosity in a Humid Tropical River Basin, South West Coast of India" (2013), Researchers B. Ajay Kumar, Girish Gopinath, and M. S. Shylesh Chandran examined the sinuosity index of a river basin by dividing it into 15 watersheds. This detailed approach allowed them to measure the sinuosity values for each individual watershed.

By analysing these sinuosity values, the researchers established correlations between sinuosity and various basin topographical features and conditions. This comprehensive examination provided insights into how the river's sinuosity is influenced by the underlying topography and other environmental factors within each watershed.

Their findings highlighted the relationship between the river's meandering patterns and the physical characteristics of the basin. This study contributes to the broader understanding of how river sinuosity can be affected by geographical and environmental conditions, offering valuable information for river basin management and planning.

2.2.20) In the study titled "Locating Archaeological Sites in the Ajay River Basin, West Bengal: An Approach Employing Remote Sensing and Geographical Information System" (2012), Researcher Sutapa Roy focused on identifying archaeological sites along the Ajay River using remote sensing and GIS techniques. By analysing various types of satellite images, the researcher was able to trace the paleopaths of the Ajay River, providing valuable insights into the river's historical courses and transformations.

From the archaeological records and remote sensing data, different locations of archaeological sites along the river's track were identified and marked. This study significantly contributes to understanding the region's archaeological history and landscape evolution.

The researcher also discussed the character of three key geological formations in the basin: Illambazar, Natunhat, and Katwa formations. These formations' distinct geological characteristics were examined to understand their influence on the distribution and preservation of archaeological sites. This comprehensive approach combining archaeological and geological analysis provided a multidimensional perspective on the historical and cultural significance of the Ajay River Basin.

2.2.21) In their research paper titled "Terrain Classification of the Dulung Drainage Basin" (2012), Prof. Ashis Sarkar and Priyank Pravin Patel discussed the soil, geology, and geomorphic units of the Dulung drainage basin. The researchers utilized various physical data of the basin area to assess its characteristics comprehensively.

By leveraging this physical data, the researchers were able to extract the runoff potentiality of the basin using the Runoff Potentiality Index. This index helped them evaluate how different terrain types and geological formations influence the basin's hydrological behaviour. Their study provides a detailed understanding of the basin's physical environment, contributing valuable insights into the relationship between terrain classification and runoff potentiality. This information is crucial for effective watershed management and planning.

2.2.22) In the study titled "Geo-informatics Based Geo-structural and Geomorphological Study of Lower Ajay Catchment, West Bengal, India" (2011), Researchers A. K. Jha, A. Chakraborty, Praveen Kumar, Dr. V.S. Rathore, and Dr. M.S. Nathawat analysed the Ajay River's channel characteristics in relation to the underlying geological conditions of the region. Their research focused on understanding how geological structures and lineaments influence the river's channel behaviour.

The researchers used geo-informatics techniques to map and analyze the geological structures, identifying significant features such as lineaments and their alignment with the river channel. They discovered the presence of an eyed drainage pattern along the river track, establishing a correlation between this pattern and the current geological structure. This relationship highlights the impact of geological formations on the river's morphology.

Additionally, the study identified buried paleo channels within the Ajay River's track. These paleo channels become particularly significant during the monsoon season, as water influxes into these old channels, affecting the current hydrological and geomorphological dynamics. This comprehensive analysis provides valuable insights into the historical and contemporary interactions between geological structures and river channel behaviour in the lower Ajay catchment area.

2.2.23) In Kuldeep Pareta's study, the focus was on conducting a quantitative morphometric analysis of the Yamuna basin in India. The study utilized ASTER (DEM) data and GIS techniques to analyse the morphometry, which involves the quantitative study of the form and configuration of the Earth's surface. Here are some key points from the study:

ASTER (DEM) data refers to Advanced Space borne Thermal Emission and Reflection Radiometer Digital Elevation Model data. This type of data provides detailed information about the topography of an area, including elevation and slope.

The study would have likely analysed various morphometric parameters such as drainage density, stream frequency, relief ratio, ruggedness number, slope, aspect, etc. These parameters provide insights into the terrain characteristics and how water flows through the basin.

Relief features refer to the variations in elevation across the landscape. By analyzing relief features, researchers can understand the topographical variations within the Yamuna basin, which is crucial for studying watershed dynamics and water flow.

This likely refers to the longitudinal profile of the basin, which shows how the elevation changes along the course of the river or watershed. Understanding the profile character helps in identifying areas of high and low elevation, which influence water movement and erosion patterns.

The study would have explored the relationship between the morphometric parameters and the underlying geology, soil types, and topographical features. For example, certain geological formations may influence drainage patterns or erosion rates, which can be reflected in the morphometric analysis.

Overall, studies like these are valuable for watershed management, environmental planning, and understanding the interactions between natural features and human activities in a region like the Yamuna basin.

2.2.24) Researcher Lalan Prasad Singh, in the research paper "Geomorphological and Pedological Evolution of Parts of Lower Gangetic Plains in West Bengal" (1995), worked on pedo-geomorphological formations in the lower Bhagirathi plain area. In this work, the researcher discusses the Ajay-Silai plain area, emphasising the location of fault lines in the lower Genetic plain area. Three major faults have been identified in this region: the Chotanagpur Foot Hill Fault, Mednipur-Farraka Fault, and Damodar Fault. The researcher also discusses the tectonic impact on topography. The presence of a paleo-channel has also been identified in the Ajay-Silai plain area, and the sinuous channel is also discussed in this work.

2.3 Flood hazard, vulnerability and risk analysis

Literature review regarding the flood vulnerability is the back bone of this study. Flood vulnerability related literature review has various dimension like flood history, spatial scaling of flood vulnerability, damage by flood effect etc. All areas in this field are reviewed thoroughly.

2.3.1) In the paper "Flood risk assessment using Analytical Hierarchy Process: A case study from the Cheliff-Ghrib watershed, Algeria" authored by Elhadj Mokhtari, Farouk Mezalia, Brahim Abdelkebir, and Bernard Engel (2023), the researchers conducted an in-depth analysis of an Analytical Hierarchy Process (AHP)-based method within a Geographic Information System (GIS) platform. The study focused on employing a multi-criteria approach to assess flood risk in the Cheliff-Ghrib watershed.

One of the significant contributions of this research was the integration of various criteria to determine the spatial extent of flood-prone areas. Factors such as slope characteristics, drainage density, soil properties, rainfall patterns, population density, land use patterns, and the infrastructure of the sewerage system were carefully considered and incorporated into the analysis. This comprehensive approach allowed for a more holistic understanding of the factors contributing flood risk within the watershed.

The use of the AHP method within the GIS framework provided a structured and systematic way to prioritize and weigh these multiple criteria. This methodology not only identified areas susceptible to flooding but also facilitated the creation of spatial donation maps based on the varying degrees of flood potentiality across the region. This zoning is crucial for effective flood management and mitigation strategies, as it helps in delineating areas that require immediate attention and intervention.

Moreover, the researchers went beyond merely identifying flood hazard areas. They also integrated vulnerability assessments into their analysis, considering factors such as socio-economic vulnerability, infrastructure resilience, and environmental sensitivity. By combining flood hazard and vulnerability assessments, the study generated a final flood risk map that provides a comprehensive overview of the potential impact of floods on the region.

Overall, this research significantly contributes to the field of flood risk assessment by demonstrating a robust methodology that combines advanced analytical techniques with geospatial data. The findings from this study can be instrumental in informing decision-makers and stakeholders about the most effective strategies for managing and mitigating flood risks in the Cheliff-Ghrib watershed and similar regions globally.

2.3.2) In the article "Flood risk assessment for Indian sub-continental river basins" by Researchers Urmin Vegad, Yadu Pokhrel, and Vimal Mishra (2023), the focus is on analysing flood risks in major river basins such as the Ganga, Brahmaputra, and Sutlej. A key aspect of the study is the utilisation of data characteristics essential for flood simulation or prediction, particularly the rainfall-temperature data provided by the Indian Meteorological Department (IMD). The researchers also delve into the significance of grid data, specifically the 0.25° by 0.25° grid prepared by IMD, in understanding and modeling flood dynamics.

A crucial component of this research lies in the simulation of flood spatial areas within the Ganga, Brahmaputra, and Narmada basins. The simulation results obtained are then rigorously compared with actual observed results to validate the accuracy and reliability of the flood modeling approach used.

Furthermore, the researchers analyse flood risk based on the impact of key infrastructural elements such as road networks, National Highways, and State Highways. This analysis provides insights into how these critical infrastructures may exacerbate or mitigate flood risks in the studied river basins, thereby contributing to informed decision-making in flood risk management and disaster preparedness strategies.

By focusing on major river basins in the Indian subcontinent and employing advanced data analysis techniques coupled with robust modeling approaches, this research contributes significantly to enhancing our understanding of flood risk dynamics in the region. The findings and methodologies presented in this study hold immense value for policymakers, urban planners, and disaster management authorities involved in mitigating the impacts of floods in vulnerable areas.

2.3.3) In the article "Estimation of the flood vulnerability index (FVI) for Alexandria city, Egypt: A case study" authored by Researchers Mai Mohamed Afifi, Abdelkawi A. Mokhtar Khalifa, Rifaat Abdel Wahaab, Ibrahim Moukhtar, and Ezzat Elalfy (2023), the researchers conducted a comprehensive assessment of flood vulnerability using the Flood Vulnerability Index (FVI) methodology. The study specifically focused on Alexandria city in Egypt.

The FVI methodology involves the calculation of exposure, susceptibility, and resilience factors to determine the overall vulnerability to flooding. These factors are categorized into five risk intensity levels: very high, high, moderate, low, and very low. Weightage is assigned to each factor based on its risk probability, allowing for a more nuanced understanding of the vulnerability levels.

The study encompasses the analysis of social, physical, and environmental vulnerabilities within the city. Social vulnerability factors may include population density, demographics, and access to resources. Physical vulnerability factors often involve infrastructure resilience, building codes, and flood protection measures. Environmental vulnerability factors encompass natural hazards, climate patterns, and land use practices.

By combining the results of exposure, susceptibility, and resilience assessments across these different vulnerability categories, the researchers were able to draw a comprehensive vulnerability scenario for Alexandria city. This scenario provides insights into the areas and aspects of the city most susceptible to flooding and helps prioritize mitigation and adaptation strategies.

The study was conducted across 16 zones within Alexandria city, and the results were spatially represented to facilitate a clear visualization of vulnerability hotspots and areas requiring targeted interventions. Overall, this research contributes significantly to the understanding of flood vulnerability in urban settings and provides a valuable framework for assessing and addressing flood risks in coastal cities like Alexandria.

2.3.4) In their article titled "Flood Risk Assessment and Its Mapping in Purba Medinipur District, West Bengal, India," Researchers Sumita Gayen, Ismael Vallejo Villalta, and Sk Mafizul Haque (2022) conducted a thorough assessment of flood risk in Purba Medinipur district, West Bengal, India. The researchers focused on estimating both the hazards and the overall risk posed by floods in this region.

To evaluate the hazards, the researchers calculated the intensity based on flood frequency. This analysis helped to understand the frequency and severity of flooding events in Purba Medinipur district, which is crucial for assessing the potential impact on communities and infrastructure.

In addition to hazard assessment, the researchers considered 25 different factors for estimating flood risk. These factors likely included aspects such as topography, land use patterns, drainage systems, population density, infrastructure vulnerability, and historical flood data. To analyze these factors effectively, the researchers employed Principal Component Analysis (PCA), a statistical technique that helps in identifying patterns and correlations within a dataset.

The PCA was conducted block-wise, which means the analysis was carried out for different geographic blocks or subdivisions within the district. This approach allowed for a more granular understanding of risk intensity across different areas, considering the unique characteristics and vulnerabilities of each block.

Based on the block-wise PCA results and risk assessment, the researchers divided the risk intensity into five classes. This classification likely ranged from low-risk areas to high-risk zones, providing a clear depiction of the varying degrees of flood risk within Purba Medinipur district.

By conducting such a comprehensive assessment and mapping of flood risk, the researchers' work contributes significantly to disaster preparedness, land use planning, and infrastructure resilience strategies in the region. The results of this study can inform decision-makers and stakeholders about priority areas for implementing mitigation measures and improving flood risk management practices.

2.3.5) In their research paper titled "Application of HEC-HMS for flood forecasting in Hazara catchment Pakistan, South Asia" (2022), Researchers Muhammad Umer Nadeem, Zeeshan Waheed, Abdul Mannan Ghaffar, Muhammad Mashood Javaid, Ameer Hamza, Zain Ayub, Muhammad Asim Nawaz, Wajahat Waseem, Malik Faisal Hameed, Ali Zeeshan, Saliha Qamar, and Kainat Masood utilised various data sources and the HEC-HMS platform for flood forecasting in the Hazara catchment area of Pakistan.

The researchers incorporated several key datasets into their analysis, including the Land Use Land Cover map, Digital Elevation Model (DEM), rainfall data, and discharge data. These datasets were integrated into the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) platform, which is widely used for hydrological modeling and flood forecasting.

One of the primary objectives of the study was to determine the peak discharge data for each sub-basin within the Hazara catchment area. This involved analyzing historical discharge data to identify the maximum flow rates experienced during flood events in different sub-basins.

By leveraging the capabilities of HEC-HMS and integrating multiple datasets, the researchers were able to develop a comprehensive flood forecasting model for the Hazara catchment. This model takes into account factors such as land use patterns, topography (as represented by the DEM), rainfall patterns, and hydrological characteristics of the area to predict potential flood scenarios and peak discharge levels.

The application of HEC-HMS in conjunction with geospatial data sets not only facilitates accurate flood forecasting but also enables authorities and stakeholders to implement proactive measures for flood management and disaster preparedness in the Hazara catchment area. This research contributes to enhancing our understanding of flood dynamics and improving flood risk mitigation strategies in the region.

2.3.6) The researchers Muhammad Umer Nadeem, Zeeshan Waheed, Abdul Mannan Ghaffar, Muhammad Mashood Javaid, Ameer Hamza, Zain Ayub, Muhammad Asim Nawaz, Wajahat Waseem, Malik Faisal Hameed, Ali Zeeshan, Saliha Qamar, and Kainat Masood delved into flood forecasting in the Hazara catchment area of Pakistan, South Asia, in their 2022 research paper titled "Application of HEC-HMS for flood forecasting in Hazara catchment Pakistan, South Asia."

Their study was grounded in the integration of diverse datasets crucial for comprehensive flood analysis. These included the Land Use Land Cover map, Digital Elevation Model (DEM), rainfall data, and discharge data. These datasets were meticulously integrated into the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) platform, renowned for its utility in hydrological modeling and flood prediction.

A pivotal aim of their research was to ascertain the peak discharge data specific to each sub-basin within the Hazara catchment. This endeavour necessitated a detailed analysis of historical discharge data to pinpoint the maximum flow rates encountered during past flood occurrences across different sub-basins.

Leveraging the functionalities of HEC-HMS and amalgamating multiple datasets, the researchers crafted an intricate flood forecasting model tailored to the Hazara catchment's unique attributes. This model factored in crucial elements such as land use configurations, topographical features (as captured by the DEM), precipitation patterns, and hydrological properties of the region. The amalgamation of these factors enabled the prediction of potential flood scenarios and the identification of peak discharge levels.

The application of HEC-HMS alongside geospatial datasets not only facilitates precise flood forecasting but also empowers decision-makers and stakeholders to proactively devise and implement strategies for flood management and disaster readiness in the Hazara catchment region. This research significantly contributes to our comprehension of flood dynamics and augments flood risk mitigation endeavours in the area.

2.3.7) In this article "Flood Exposure and Social Vulnerability Analysis in Rural Areas of Developing Countries: An Empirical Study of Charsadda District, Pakistan" ResearchersAbdur Rahim Hamidi, Li Jing, Muhammad Shahab, Kamran Azam, Muhammad Atiq Ur Rehman Tariq, and Anne W. M. Ng (2022) measured social vulnerability by the relation of exposure, susceptibility and resilience. Researchers studied a district of Pakistan-Charsadda district. In terms of exposure few important factors are chosen-

Exposure

i) flood inundated area

ii) flooded locations map

iii) elevation map

iv) distance from river

v) household proximity distance

vi) flood experience

vii) causalities and losses

Susceptibility

i) household size

ii) dependent population

iii) female-male ratio

iv) fatal illness

v) illiteracy

Resilience

i) Flood risk awareness

ii) Employment

iii) Multiple income sources

iv) Social network

v) Financial capacity

Finally, a composite index is prepared on the basis of said factors. Most importantly all the resulted values are spatially analysis in the field of ARC GIS.

2.3.8) In their work titled "HEC-HMS Hydrological Modelling for Runoff Estimation in Cameron Highlands, Malaysia" (2021), Researchers Laith Abdulsattar Jabbar, Ibrahim Abdulrazak Khalil, and Lariyah Mohd Sidek delved into the analysis of hydrological modeling and runoff estimation. The researchers employed the Soil Conservation

Service (SCS) Curve Number method based on soil and Land Use/Land Cover (LULC) data to estimate runoff. This approach allowed them to assess the loss amount based on the Curve Number value derived from the soil and LULC data.

Utilising the HEC-HMS software platform, the researchers integrated the Curve Number values with daily rainfall data to extract daily discharge. This process enabled them to generate a trend graph illustrating the daily discharge over three conservative flood years.

By analysing the daily discharge trend graph, the researchers gained insights into the hydrological dynamics of the study area, particularly in relation to runoff patterns during flood events. This analysis likely involved assessing the peak discharge levels, flow variability, and the duration of high-flow periods during flood years.

The utilisation of HEC-HMS and the SCS Curve Number method provided a robust framework for understanding the runoff processes in the Cameron Highlands region of Malaysia. This research contributes valuable information for water resource management, flood risk assessment, and the development of effective flood mitigation strategies in the area.

2.3.9) In the work titled "Field-based Index of Flood Vulnerability (IFV): A New Validation Technique for Flood Susceptible Models," Researchers Susanta Mahato, Swades Pal, Swapan Talukdar, Tamal Kanti Saha, and Parikshit Mandal (2021) utilized a comprehensive approach involving nine key factors to assess flood vulnerability. These factors include elevation, flow direction, Land Use and land Cover (LULC), slope, Terrain Wetness Index (TWI), distance from the river, Standardized Precipitation Index (SPI), and curvature.

The researchers employed Artificial Neural Network (ANN) techniques to calculate the weightage assigned to each factor. This process involved training the ANN model using historical data and observed flood events to determine the relative importance of each factor in contributing to flood vulnerability.

Based on the weighted factors, the researchers developed flood susceptibility maps categorizing areas into five distinct groups based on their vulnerability to flooding. This mapping provides a visual representation of areas at varying levels of risk, aiding in targeted planning and mitigation efforts.

One of the significant contributions of this study is the validation technique used for the flood susceptibility models. The researchers employed Receiver Operating Characteristic (ROC) curve analysis, a widely recognized method for evaluating the performance of predictive models. The ROC curve helps assess the model's ability to distinguish between areas that experienced flooding and those that did not, providing a measure of the model's accuracy and reliability.

By integrating advanced modelling techniques with field-based data and validation procedures like ROC curve analysis, this research offers a robust framework for assessing flood vulnerability and enhancing flood risk management strategies. The findings of this study can be instrumental in informing policymakers, planners, and stakeholders about areas prone to flooding, thus facilitating more effective decision-making and disaster preparedness efforts.

2.3.10) In the research paper titled "Social Vulnerability to Environmental Hazards in the Ganges-Brahmaputra-Meghna Delta, India and Bangladesh," Researchers Shouvik Das, Sugata Hazra, Anisul Haque, Munsur Rahman, Robert J. Nicholls, Amit Ghosh, Tuhin Ghosh, Mashfiqus Salehin, and Ricardo Safra de Campos (2021) conducted an in-depth analysis of social vulnerability in relation to flood hazards in the Ganges-Brahmaputra-Meghna (GBM) delta region spanning India and Bangladesh.

The researchers selected various components related to social aspects, considering factors such as demographics, socio-economic status, access to resources, infrastructure, and community resilience. These components were then subjected to Principle Components Analysis (PCA), a statistical technique used to identify underlying patterns and correlations within complex datasets.

By employing PCA, the researchers were able to quantify and measure social vulnerability block-wise across the GBM delta region. This approach allowed for a nuanced understanding of the spatial distribution and variation in social vulnerability levels within different blocks or subdivisions of the delta area.

The resulting values from PCA, representing social vulnerability, were then integrated into a Geographic Information System (GIS) platform. This integration facilitated the analysis of spatial patterns, enabling researchers to visualize and map the distribution of social vulnerability across the study area.

The utilisation of GIS technology in conjunction with PCA-enhanced social vulnerability assessment provides valuable insights for policymakers, disaster management authorities, and stakeholders. Understanding the spatial patterns of social vulnerability can inform targeted interventions, resource allocation, and resilience-building initiatives aimed at reducing the impacts of environmental hazards, particularly floods, in the GBM delta region.

2.3.11) In the work titled "Mapping Flood Inundation Areas using GIS and HEC-RAS Model at Fetam River, Upper Abbay Basin, Ethiopia" (2021), Researchers Hunegnaw Desalegn and Arega Mulu conducted a comprehensive analysis of flood inundation using Geographic Information System (GIS) and the HEC-RAS model in the Fetam River within the Upper Abbay Basin of Ethiopia.

One of the primary focuses of their research was analyzing flood frequency, for which they utilized the Gumbel distribution method to plot flood intensity. This approach allowed them to understand the likelihood and severity of floods occurring over different return periods.

Based on the results of flood intensity for various return periods, the researchers extracted the actual flood inundation area. They then analyzed the spatial distribution of these flood-prone areas using GIS technology, providing valuable insights into the extent and patterns of flooding within the Fetam River basin.

A significant aspect of their study is the recommendation of non-structural measures for flood control. These measures include soil conservation methods and appropriate land use/land cover practices, both upstream and downstream of the river. Implementing soil conservation techniques can help reduce erosion and sedimentation, which are contributing factors to flooding. Similarly, adopting appropriate land use and land cover practices can improve water retention and infiltration, thereby mitigating flood risks.

By suggesting these non-structural measures, the researchers emphasize the importance of holistic flood management strategies that integrate engineering solutions with natural resource conservation practices. This approach aligns with sustainable development principles and can contribute to enhancing resilience against flooding in the Fetam River and similar river basins in Ethiopia.

2.3.12) In the paper "Delineation of the Evacuation Route Plan, Relief Camp, and Prioritization using GIS Science" by Researchers Jean Joy, Shruti Kanga, Suraj Kumar Singh, and Sudhanshu (2021), an in-depth analysis of evacuation route planning and flood shelter site suitability using Geographic Information System (GIS) techniques was conducted.

The researchers utilised various datasets and methodologies within GIS to accomplish their objectives:

Evacuation Route Analysis: The evacuation route details were analyzed, considering factors such as road network accessibility, flood-prone areas, and flood depth. By overlaying the road map with flooded areas and flood depth information, the researchers could identify the safest routes for evacuation. This involved performing network analysis within the GIS platform to determine optimal evacuation paths.

Site Suitability for Flood Shelter: The suitability of sites for establishing relief camps and flood shelters was assessed based on factors like elevation, accessibility, proximity to flood-prone areas, and capacity to accommodate evacuees. GIS was used to analyze and prioritize potential sites, taking into account the safety and convenience of evacuees.

Prioritisation of Evacuation Areas: The flooded area and flood depth data were crucial for prioritising areas for evacuation. High-risk areas with greater flood depths or extensive flooding were given priority in the evacuation planning process. GIS spatial analysis techniques were likely employed to identify and prioritise these areas effectively.

By integrating GIS science into the evacuation route planning and relief camp site selection processes, the researchers were able to generate detailed maps and plan that aid in disaster preparedness and response efforts. The final output, marked in the GIS field, provides a visual representation of the recommended evacuation routes, suitable relief camp sites, and prioritized evacuation areas, facilitating efficient and organized evacuation procedures during flood events.

2.3.13) The researchers in the paper "Physical Flood Vulnerability Assessment using Geospatial Indicator-Based Approach and Participatory Analytical Hierarchy Process: A Case Study in Kota Bharu, Malaysia" (2021) define vulnerability and physical vulnerability in the context of flood risk assessment. They focus on physical vulnerability and identify three main categories of indicators:

Flood Intensity: This includes the severity and frequency of flood events, which directly impact the physical structures in the area.

Building Condition: This involves assessing the structural integrity, materials, and age of buildings to determine how susceptible they are to flood damage.

Surroundings Environment: This encompasses the surrounding environmental features such as land use, topography, and proximity to water bodies, which influence the extent and impact of flooding.

To quantify these indicators, the researchers used expert opinions to assign weightage values to each category. These weightages reflect the relative importance of each indicator in contributing to physical vulnerability. The spatial distribution of physical vulnerability was then mapped using a Geographic Information System (GIS) platform. This approach allowed for a detailed and visual representation of areas in Kota Bharu, Malaysia, that are more susceptible to flood damage based on the selected indicators and their calculated weightages.

2.3.14) Researchers Preeti Ramkar and Sanjay Kumar M. Yadav, in their research paper "Flood risk index in data-scarce river basins using the AHP and GIS approach" (2021), explain flood risk assessment by combining the Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) platforms. They selected a tributary drainage basin of the Tapi River for their flood risk analysis.

To conduct their study, the researchers extracted the Flood Hazards Index (FHI) using the AHP method within a GIS platform. They identified flood-prone areas by analyzing six parameters related to flood hazards:

Slope: The gradient of the land surface, influencing runoff and water flow speed.

Rainfall: The amount and intensity of precipitation, contributing to potential flooding.

Distance from River: Proximity to water bodies, affecting the likelihood of inundation.

Drainage Density: The network of rivers and streams, indicating potential pathways for floodwaters.

Land Use and Land Cover (LULC): The type and extent of vegetation, urban areas, and other land uses, affecting water absorption and runoff.

Soil: Soil type and characteristics, influencing water infiltration and retention.

The identified flood hazard areas were then analysed for flood vulnerability using three additional data points:

Population Density: The concentration of people in the area, indicating potential human impact.

Crop Production: Agricultural activities and their susceptibility to flood damage.

Road River Interaction: The relationship between infrastructure and water bodies, affecting accessibility and risk during floods.

Both flood hazards and flood vulnerability were assessed using the weightage-based AHP method. The combined results were then used to determine the overall flood risk index for the region. This approach enabled the researchers to integrate various parameters and vulnerabilities into a comprehensive flood risk assessment, providing valuable insights for flood management and mitigation in the data-scarce Tapi River basin.

2.3.15) In the research paper "AHP-GIS analysis for flood hazard assessment of the communities nearby the world heritage site on Ayutthaya Island, Thailand" (2020), researchers Suthirat Kittipongvises, Athit Phetrak, Patchapun Rattanapun, and Katja Brundiers focus on a significant and flood-prone heritage site. The study area is notable both for its cultural value and its susceptibility to flooding. To improve flood management, the researchers aimed to identify spatial flood hazard areas.

They analysed the spatial patterns of nine factors: daily rainfall, past flood event areas, watershed area, slope, drainage density, elevation, runoff, and road density. Using expert opinions, they applied the Analytical Hierarchy Process (AHP) method to calculate the weightage of these factors. This approach allowed them to determine the spatial distribution of flood-prone areas on Ayutthaya Island.

The researchers emphasised the advantages of the AHP method, particularly its flexibility in incorporating various expert inputs and handling complex decision-making processes. In addition to identifying flood hazards, they utilised the GIS platform to demonstrate shortest route planning for effective flood management. They also discussed various remedies to minimise potential losses, highlighting the practical applications of their findings for disaster preparedness and response in heritage sites.

2.3.16) In the paper "A Model-Based Flood Hazard Mapping on the Southern Slope of Himalaya" (2020), authors Dibit Aryal, Lei Wang, Tirtha Raj Adhikari, Jing Zhou, Xiuping Li, Maheswor Shrestha, Yuanwei Wang, and Deliang Chen estimated the flooded area using flood simulation techniques. They focused on the Southern slope of the Himalayas, employing HEC-RAS software to simulate the floodplain area and flood depth based on hydrological data from the 2011 flood events. The researchers assessed the impact of floods on settlements and measured the effects across various scales. This approach enabled a detailed understanding of flood dynamics and their potential impacts on the region.

2.3.17) In the article "Flood Hazard, Vulnerability and Risk Assessment for Different Land Use Classes Using a Flow Model" (2020), researchers Md Abdullah Al Baky, Muktarun Islam, and Supria Paul computed the spatial area and depth of floods using 2D hydrological modeling. They measured the flood area and depth by calculating different return periods, focusing on a part of Bangladesh. The researchers prepared a land use and land cover (LULC) map based on LANDSAT images with a 30 m resolution and validated the study area using references drawn from Google Earth images. The inundation area map was overlaid on the LULC map to calculate the damage. The flood depth was also included in the risk calculations, with the analysis primarily focusing on the impact on rural settlements and cropland damage.

2.3.18) In the paper "GIS-based Flood Hazard Mapping Using HEC-RAS Model: A Case Study of Lower Mekong River, Cambodia" (2020), researchers Vanthan Kim, Sarintip Tantanee, and Wayan Suparta utilised flood frequency data to calculate the flood return period using the log Pearson-III method. By applying the HEC-RAS platform, they detected floodplain areas based on flood intensity data. The flood-prone areas were then classified, and administrative boundaries were overlaid on the Mekong River basin to accurately calculate the extent of the floodplain. This approach allowed for a detailed analysis of flood hazards within the administrative context of the region.

2.3.19) In the paper "Application of Flood Hazard Potential Zoning by Using AHP Algorithm" (2020), authors Abbas Ali Ghezelsofloo and Mahboobeh Hajibigloo predicted flooded areas by applying the Analytical Hierarchy Process (AHP) algorithm. They derived AHP weightage based on factors such as geology, vegetation, iso-rain (rainfall intensity), slope, gravel coefficient, and stream pattern. Before applying the weightage, the researchers ensured the consistency rate (CR) was acceptable. The results were classified into five distinct flood hazard zones. A significant aspect of their study was the recommendation to establish warning stations in flood-prone areas to minimize potential damage.

2.3.20) In the paper "Analysis of Steady Flow using HEC-RAS and GIS Techniques" (2020), researcher Pallavi H employed a combination of SRTM DEM data with a 30-meter resolution, discharge data, and Manning roughness coefficients to simulate floodplain areas. By inputting these datasets into the HEC-RAS software, the researcher was able to create a detailed simulation of the floodplain area.

The study involved analysing steady flow conditions to understand how water levels and flow patterns behave during flood events. The simulated floodplain results were then overlaid onto Google Earth images, which provided a visual context for assessing the accuracy and impact of the flood simulations. This overlay process allowed for a comprehensive evaluation of the flood-affected areas, making it possible to identify specific regions at risk and to analyse the potential impacts on infrastructure and settlements. The integration of HEC-RAS simulations with GIS techniques facilitated a robust and visually intuitive method for flood hazard assessment.

2.3.21) In the paper "Flood Risk and Vulnerability Analysis of the Lower Usuma River in Gwagwalada Town Abuja, using GIS and HEC-RAS Model" (2020), researchers D. O. Balogun, O. O. M. Agunloye, A. B. Mohammed, U. Ogunbiyi, A. A. Okewu, E. S. Ikegwuonu, and B. Nkut utilised both 1D and 2D HEC-RAS models for flood inundation mapping. Their study aimed to estimate flood intensity, hazards, vulnerability, and overall risk in the Lower Usuma River area.

The researchers assessed flood vulnerability and risk using existing land use and land cover (LULC) data. By employing the GIS platform, they extracted the polygon boundary layer and overlaid it on the LULC map to estimate risk levels. This process allowed them to visually and quantitatively analyse how different land use types are affected by flood hazards. The integration of HEC-RAS with GIS provided a comprehensive approach to mapping and assessing flood risk, enhancing the understanding of flood dynamics and their impacts on various land use classes in Gwagwalada Town, Abuja.

2.3.22) In their paper "Flood Analysis with HEC-RAS: A Case Study of Tigris River" (2020), researchers Selman Ogras and Fevzi Onen delve into the complexities of flood analysis, focusing specifically on the Tigris River. Despite being situated in a non-tropical climate, the Tigris River region faces significant flood risks, making it an intriguing case study for understanding flood dynamics and developing effective flood management strategies.

The study employs advanced modelling tools, particularly the HEC-RAS (Hydrologic Engineering Center's River Analysis System) software, renowned for its capabilities in hydraulic modelling and floodplain analysis. This software enables the researchers to simulate various flood scenarios, taking into account factors such as river morphology, flow rates, water levels, and velocity. These simulations provide crucial insights into how floodwaters might behave under different conditions, helping to assess potential flood extents and impacts.

To enhance the accuracy of their flood modelling, the researchers utilize AutoCAD Civil 3D software to create detailed cross-sections of the Tigris River and its surrounding areas. These cross-sections offer a comprehensive view of the river's geometry, including variations in width, depth, and channel morphology. Such detailed geometric data is fundamental for developing an accurate flood model that can replicate real-world flood scenarios with precision.

By combining the hydraulic data derived from HEC-RAS simulations with the geometric information from AutoCAD Civil 3D cross-sections, the researchers construct a robust floodplain model tailored to the Tigris River. This model not only helps in understanding flood intensity and dynamics but also assists in assessing flood vulnerabilities in the region.

Overall, the paper provides a valuable contribution to flood risk assessment and management by showcasing the application of sophisticated modelling tools like HEC-RAS and AutoCAD Civil 3D in analysing flood hazards along the Tigris River. The insights gained from this study can inform decision-makers and stakeholders about effective flood risk mitigation strategies tailored to the unique characteristics of the Tigris River region.

2.3.23) In the paper "Analysing Flood History and Simulating the Nature of Future Floods using Gumbel method and Log-Pearson Type III: The Case of the Mayurakshi River Basin, India" (2020), researchers Aznarul Islam and Biplab Sarkar conducted an in-depth analysis of the flood history and potential future floods in the Mayurakshi River Basin in India.

They employed flood frequency methods like Log Pearson II and Gumbel distribution to study historical flood data and calculate return periods for different discharge levels over varying timeframes, from 2 to 200 years. This analysis provided insights into the frequency and severity of past floods in the region.

Furthermore, the researchers focused on the hydro-geological conditions of the Mayurakshi River, aiming to establish a strong correlation between these conditions and flood occurrences. Understanding the geological and hydrological characteristics of the basin is crucial for predicting and managing flood risks effectively.

The study also delved into anthropogenic factors contributing to flood risks in the basin. It discussed changes in land use and land cover (LULC) from 2005 to 2015, highlighting the impact of human activities such as urbanization, deforestation, and agricultural practices on flood dynamics. Additionally, the effects of dam and barrage construction, as well as embankment construction, were examined concerning the current condition of the river and its flood behaviour.

By integrating flood frequency analysis, hydro-geological insights, and considerations of anthropogenic influences, this study offers a comprehensive understanding of flood risks in the Mayurakshi River Basin. The findings provide valuable information for developing effective flood risk management strategies tailored to the specific challenges and dynamics of the basin.

2.3.24) In the paper "Flood Risk Assessment in the Tisa River Basin" (2019), researchers Ionel Sorin Rîndaşu-Beuran, Anemari Luciana Ciurea, Ramona Dumitrache, Bogdan Ion, Diana Achim, Petrişor Mazilu, and Răzvan Dan Bogzianu conducted a comprehensive flood risk assessment in the Tisa River basin in Romania.

One of the primary contributions of their study was the creation of a detailed flood hazard map for the Tisa River basin. This map was developed using historical flood data and GIS (Geographic Information System) technology, which allowed the researchers to visualize and analyze past flood events, identify areas prone to flooding, and assess the severity of flood hazards across the basin.

Moreover, the researchers went beyond hazard mapping and incorporated risk assessment into their study. They analysed the social and economic consequences of flood hazards, considering factors such as population density, infrastructure vulnerability, and economic activities in flood-prone areas. This comprehensive approach provided a more holistic understanding of flood risk, taking into account not only the physical aspects but also the societal and economic impacts of flooding.

In the second part of their study, the researchers projected the potential impacts of climate change on flood risk in the Tisa River basin. They addressed the issue of climate change by considering future scenarios of precipitation patterns, temperature changes, and other climatic variables that could influence the frequency and intensity of floods in the region. This forward-looking analysis added an important dimension to their assessment, helping to anticipate and prepare for potential changes in flood risk due to climate-related factors.

Overall, the paper contributed significantly to flood risk management and adaptation strategies in the Tisa River basin by providing a comprehensive assessment of flood hazards, risks, and potential future scenarios under climate change conditions.

2.3.25) In the research work "GIS-multicriteria evaluation using AHP for landslide susceptibility mapping in Oum Er Rbia high basin (Morocco)" (2019), researchers Aafaf El Jazouli, Ahmed Barakat, and Rida Khellouk aimed to predict landslide occurrences. They opted to use the Analytical Hierarchy Process (AHP) methodology for predicting landslide susceptibility in the Oum Er Rbia high basin in Morocco.

The researchers utilised AHP to assign weightage values to various criteria related to landslide susceptibility, such as slope steepness, soil type, land use, and precipitation patterns. These criteria were selected based on their known influence on landslide occurrence. By combining these weighted criteria in a GIS (Geographic Information System) platform, the researchers were able to identify areas with a high susceptibility to landslides.

The resulting landslide susceptibility map categorized areas based on their level of susceptibility, ranging from low to high intensity. To validate the accuracy of their model, the researchers employed the Area Under Curve (AUC) method, which measures the performance of a predictive model. They found that their model matched approximately 76.7% of the actual landslide occurrences, indicating a reasonably good level of accuracy and reliability in predicting landslide susceptibility.

This research contributes to the field of landslide risk assessment by demonstrating the effectiveness of using AHP in combination with GIS for mapping landslide susceptibility. The validated model can help in identifying high-risk areas and informing land use planning and disaster management strategies in the Oum Er Rbia high basin and similar regions prone to landslides.

2.3.26) In their paper "Flood Hazard Assessment Using Fuzzy Analytic Hierarchy Process: A Case Study of Bang Rakam Model in Thailand" (2019), researchers Chatsudarat, Polpreecha Chidburee, Nattapon Mahavik, Charatdao Kongmuang, and Sarintip Tantanee conducted a thorough analysis of flood hazards. They focused on the Bang Rakam model in Thailand and utilised a combination of methodologies to assess flood hazards effectively.

The study incorporated eight key factors known to influence flood hazards: distance from the river, drainage density, elevation, flow accumulation, slope, land use and land cover, soil infiltration, and average rainfall. These factors were chosen based on their relevance to flood risk assessment and their potential impact on flood severity.

The researchers employed both the Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process (FAHP) models to calculate weightage for each factor. AHP and FAHP are methodologies commonly used for decision-making processes involving multiple criteria. By applying these models, the researchers were able to assign appropriate weightage to each factor, considering their relative importance in flood hazard assessment.

The study also utilised a Weightage-based Multi-Criteria Analysis (MCA) approach, which involves combining the weighted factors to assess flood hazards comprehensively. GIS (Geographic Information System) technology was integrated into the analysis, allowing for spatial mapping and visualization of the flood hazard zones.

The output of the study resulted in the classification of the spatial flooded area into five distinct zones based on the severity of flood hazards. This zoning approach provides valuable information for decision-makers and stakeholders to prioritize mitigation and adaptation measures in areas most susceptible to flood risks.

Overall, the research demonstrates the effectiveness of combining AHP, FAHP, MCA, and GIS techniques in flood hazard assessment, offering a robust methodology for evaluating and addressing flood risks in the Bang Rakam model and similar regions prone to flooding.

2.3.27) The paper "Flood Vulnerability Assessment through Different Methodological Approaches in the Context of North-West Khyber Pakhtunkhwa, Pakistan" (2019) by researchers Muhammad Nazeer and Hans-Rudolf Bork presents a detailed methodology for assessing flood vulnerability. The study employs multiple methodological approaches and integrates various components to comprehensively analyse flood vulnerability in the context of North-West Khyber Pakhtunkhwa, Pakistan.

The researchers identified three existing methods for calculating the composite index of flood vulnerability, with a particular emphasis on statistical methods. These methods likely involved quantifying and aggregating multiple factors that contribute to flood vulnerability, such as population density, flood-prone areas, altitudes above sea level, susceptibility factors (e.g., gender-specific vulnerability, unemployment rates, housing conditions), and resilience factors (e.g., healthcare infrastructure, education levels, transportation networks).

To determine the relative importance of each factor and create a composite index, the researchers utilised Principal Component Analysis (PCA). PCA is a statistical technique commonly used for dimensionality reduction and identifying patterns in complex datasets. By applying PCA, the researchers were able to reduce the number of variables and derive composite scores that represent the overall flood vulnerability of the study area.

The integration of various components and the application of statistical techniques like PCA allowed for a holistic assessment of flood vulnerability, considering both the factors contributing to vulnerability and the resilience measures in place. This comprehensive approach enables policymakers and stakeholders to prioritise interventions and strategies aimed at reducing flood risks and enhancing community resilience in North-West Khyber Pakhtunkhwa, Pakistan.

Overall, the paper contributes significantly to the field of flood vulnerability assessment by providing a robust methodology that combines quantitative analysis, statistical techniques, and multidimensional factors to evaluate flood vulnerability comprehensively.The final result of the vulnerability assessment is presented at the district level, providing insights into the areas most susceptible to flood risks within North-West Khyber Pakhtunkhwa, Pakistan. This information is valuable for disaster management authorities, policymakers, and stakeholders involved in implementing mitigation and adaptation strategies to reduce the impact of floods in the region.

Overall, the research contributes to enhancing our understanding of flood vulnerability assessment methodologies and provides a structured approach for assessing and prioritising vulnerability factors in the context of North-West Khyber Pakhtunkhwa, Pakistan.

2.3.28) In the paper "Assessing Spatial Flood Vulnerability at Kalapara Upazila in Bangladesh Using an Analytic Hierarchy Process" (2019), researchers Muhammad Al-Amin Hoque, Saima Tasfia, Naser Ahmed, and Biswajeet Pradhan conducted a comprehensive assessment of flood vulnerability by considering 16 parameters related to physical, social, and carrying capacity factors.

For physical vulnerability assessment, the researchers included parameters such as elevation, land use and land cover (LULC), slope, distance to active channels, and precipitation intensity. These factors are crucial in determining the susceptibility of an area to flooding based on its geographical and environmental characteristics.

Social vulnerability, another important aspect, was evaluated using parameters like population density, dependent population (e.g., children and elderly), disabled population, female population, presence of wooden houses, households with ponds, households without sanitation facilities, and the proportion of agricultural population.

These factors reflect the social dynamics and demographics of the area, which can significantly impact vulnerability and resilience during flood events.

Additionally, the researchers analysed factors related to carrying capacity, such as distance from flood shelters, distance from health complexes, and literacy rates. These factors contribute to the community's ability to cope with and recover from flood impacts.

To synthesise these diverse factors and assess flood vulnerability comprehensively, the researchers employed the Analytic Hierarchy Process (AHP). AHP is a decision-making tool that facilitates pair wise comparisons between criteria to derive weightages and prioritize factors based on their relative importance. By utilising AHP-based pair wise comparison matrices, the researchers were able to quantify and rank the significance of each parameter in contributing to overall flood vulnerability in Kalapara Upazila, Bangladesh.

This research framework provides a structured and systematic approach to understanding and addressing flood vulnerability, offering valuable insights for disaster risk reduction and management strategies in flood-prone areas.

2.3.29) In the paper of “Flood risk assessment in South Asia to prioritize flood index insurance applications in Bihar, India” researchers Karthikeyan Matheswaran, Niranga Alahacoon, Rajesh Pandey & Giriraj Amarnath (2019) used index based studies on the basis of MODIS data. LSWI and EVI method is applied on the basis of algorithm.

LSWI = (NIR - SWIR) / (NIR + SWIR)

EVI = G * (NIR - RED) / (NIR +CI) * (NRI - C2) * (BLUE + L)

DVEL = EVI – LSWI

By using this algorithms flood spatial area is extracted and priorised by using K means statistical method. Most importantly as per grid area population data is overlay and risk factor is analysed. Risk map also classified by K means. The agricultural damage also included in this work and the significance of insurance coverage to protect the farmers is also discussed here.

2.3.30) In the research paper "Assessment of Social Vulnerability to the Impact of Flood Hazard: A Case Study of Kopili River Basin, Assam, India" by researchers S V Shiva Prasad Sharma, Partha Sarathi Roy, and Chakravarthi V (2018), the authors undertook a comprehensive assessment of social vulnerability to flood hazards in the Kopili River basin, located in Assam, India.

The study initiated by extracting spatial flood area data using satellite imagery covering the period from 1998 to 2015. This data allowed for the identification and delineation of flood-prone areas within the basin. By integrating the annual flood data from these years, a combined flood area map was generated using GIS (Geographic Information System) technology. This map provided a visual representation of the areas susceptible to flooding over the specified time frame.

The assessment of social vulnerability considered four key factors:

Female Population: Analysing the proportion of females in the population can provide insights into their specific vulnerabilities and needs during flood events.

Poverty Levels: Assessing poverty rates within the region is crucial as economically disadvantaged communities are often more vulnerable to the impacts of natural disasters like floods.

Literacy Rates: The level of education within the population can influence preparedness, resilience, and response capabilities during flood events.

Household Composition: Examining household structures and compositions, such as the presence of elderly or disabled individuals, can help identify vulnerable groups requiring special attention and support during floods.

Based on these social vulnerability factors, a risk map was developed, highlighting areas within the Kopili River basin that are more socially vulnerable to flood impacts. Additionally, the researchers calculated the number of villages affected based on the extent of damage in each area.

This research contributes significantly to understanding and addressing social vulnerability to flood hazards, providing valuable insights for disaster management and resilience-building efforts in the Kopili River basin and similar regions prone to flooding.

2.3.31) In the research work titled "Establishment of Flood Damage Function Models: A Case Study in the Bago River Basin, Myanmar" (2018), conducted by researchers Shelly Win, Win Win Zin, Akiyuki Kawasaki, and Zin Mar Lar Tin San, the focus was on analysing flood damage, particularly in terms of house damage and agricultural losses within the Bago River Basin in Myanmar.

For house damage assessment, the researchers took into account factors such as house building height and types. The height and structural characteristics of buildings play a crucial role in determining their susceptibility to flood damage. Certain types of buildings, such as traditional or low-lying structures, may be more vulnerable to inundation and structural damage during flood events compared to elevated or flood-resistant buildings.

In the case of agricultural losses, the study considered parameters such as crop height and crop growth seasons. The height of crops can influence their resilience to flooding, with taller crops potentially suffering less damage compared to shorter crops. Additionally, the growth stage of crops during flood events can impact their susceptibility to inundation and subsequent yield losses.

By integrating these factors into flood damage function models, the researchers aimed to establish a comprehensive understanding of the potential damage caused by floods in the Bago River Basin. These models can help in predicting and assessing the extent of house damage and agricultural losses, enabling better disaster preparedness and response strategies for mitigating the impact of floods in the region.

Overall, this research contributes valuable insights into flood damage assessment methodologies, particularly focusing on house and agricultural impacts, which are essential for effective flood risk management and resilience-building efforts in flood-prone areas like the Bago River Basin in Myanmar.

2.3.32) In the paper "An Innovative Micro-scale Approach for Vulnerability and Flood Risk Assessment with the Application to Property Level Protection Adoptions" (2018) by researcher Balqis M. Rehan, a unique approach to vulnerability and flood risk assessment is introduced, particularly focusing on property-level protection adoptions.

The study employed a gauge-discharge function to estimate losses associated with flooding. This function relates the gauge (water level) of a river or water body to the discharge (flow rate) of water, providing a basis for understanding the flood dynamics and potential impacts.

Flood depth, a critical parameter in flood risk assessment, was measured based on the topography of the area. The topography plays a crucial role in determining how water inundates the land and affects properties during flood events.

Using the information on flood area and flood depth, the study estimated property losses at different levels of flood depth. By quantifying the relationship between flood depth and property damage, the researchers were able to assess the vulnerability of properties to flooding and determine the potential risk levels.

One of the significant outcomes of the research was the development of a vulnerability curve, which graphically represents the relationship between flood depth and property damage or vulnerability. This curve helps visualize and understand how different flood depths correspond to varying levels of property loss or vulnerability.

Overall, the innovative micro-scale approach presented in the paper offers valuable insights into assessing flood vulnerability and risk at the property level. By establishing relationships between flood characteristics and property damage, the study provides a framework for implementing property-level protection measures and enhancing flood resilience strategies.

2.3.33) In the paper "Qualitative Assessment of Social Vulnerability to Flood Hazards in Romania" (2018) by researcher Ibolya Toro, a comprehensive analysis of social vulnerability to flood hazards in Romania was conducted. The study utilised municipality-scale data from various secondary sources, focusing on factors related to hazards and risk assessment.

A total of 27 variables were considered for the analysis, reflecting a wide range of social, economic, and environmental factors that contribute to vulnerability to flood hazards. These variables likely included aspects such as population density, income levels, housing conditions, access to resources and services, infrastructure resilience, and historical flood data.

To analyse the risk, the researcher employed Principal Component Analysis (PCA), a statistical technique used to identify patterns and relationships among variables. PCA helped in reducing the dimensionality of the data and deriving composite scores that represent the overall social vulnerability to flood hazards at the municipality level.

The results of the PCA analysis were then compared in a spatial context using GIS (Geographic Information System) technology. This spatial analysis allowed for visualising and understanding the spatial variations of social vulnerability across Romania, highlighting areas that are more susceptible to flood impacts.

Additionally, the study delved into the causes of social vulnerability, aiming to identify underlying factors contributing to disparities in vulnerability levels across different regions of Romania. Understanding these causes is crucial for developing targeted interventions and strategies to address social vulnerability and enhance resilience to flood hazards.

In the final stage of the study, the researcher proposed soft technology solutions, resilience-building measures, and preparedness strategies as recommendations to minimize the adverse effects of floods. These suggestions likely included community-based initiatives, early warning systems, infrastructure improvements, land use planning, and capacity-building programs.

Overall, the paper provides valuable insights into the qualitative assessment of social vulnerability to flood hazards, highlighting the importance of integrated approaches and proactive measures in disaster risk reduction and management.

2.2.34) In the paper "Rainfall-Runoff Modelling of Ajay River Catchment Using SWAT Model" by Subhadip Kangsabanik and Sneha Murmu (2017), the researchers focused on modeling the rainfall-runoff relationship within the Ajay River catchment using the Soil and Water Assessment Tool (SWAT) model. They processed several datasets including Digital Elevation Model (DEM) data, Land Use/Land Cover (LULC) data, soil data, and daily rainfall data. By utilising the SWAT model, they simulated the discharge pattern on a daily basis and calculated yearly maximum and minimum discharge data to understand flow variability in the river. This study highlights the importance of hydrological modeling in assessing water dynamics and runoff patterns in river catchments.

2.3.35) In their paper "Physical Flood Vulnerability Mapping Applying Geospatial Techniques in Okazaki City, Aichi Prefecture, Japan," researchers Andi Besse Rimba, Martiwi Diah Setiawati, Abu Bakar Sambah, and Fusanori Miura (2017) focus on assessing and mapping physical flood vulnerability using geospatial techniques.

The researchers identified five key risk factors related to flood vulnerability in Okazaki City, Aichi Prefecture, Japan. These risk factors likely included aspects such as elevation, proximity to water bodies, slope, land use/land cover patterns, and infrastructure density.

To evaluate and quantify these risk factors, the researchers employed the Analytic Hierarchy Process (AHP) method. AHP is a decision-making tool that allows for the systematic comparison and prioritization of criteria based on expert judgments and pairwise comparisons.

Using the AHP matrix, the researchers were able to assign weights to each risk factor, reflecting their relative importance in contributing to flood vulnerability. This weighting process is crucial for accurately assessing the overall vulnerability of different areas within Okazaki City.

Additionally, the researchers utilised geospatial techniques to overlay the risk factors onto existing land use and land cover maps. This spatial analysis helped in identifying areas with higher vulnerability to flooding based on the combination of risk factors.

One of the significant aspects of the study is the validation process. The researchers employed the Area Under Curve (AUC) method to validate their flood vulnerability mapping results. AUC is a common metric used in model validation, particularly for assessing the accuracy and reliability of predictive models.

By validating their mapping results using AUC, the researchers ensured the robustness and accuracy of their flood vulnerability assessment. This validation step enhances the credibility of the study's findings and provides stakeholders with confidence in the vulnerability mapping outcomes.

Overall, the paper highlights the effectiveness of geospatial techniques and AHP methodology in mapping physical flood vulnerability, offering valuable insights for flood risk management and resilience planning in Okazaki City and similar urban areas prone to flooding.

2.3.36) In the work "Vulnerabilities to Flood Hazards among Rural Households in India," Researchers Anu Susan Sam, Ranjit Kumar, Harald Kachele, and Klaus Muller (2017) focused on assessing flood hazards and vulnerabilities among rural households, particularly in the coastal area of Odisha state in India.

The researchers adopted the simple random sampling method to collect primary field data from 220 households in the study area. This sampling technique ensures that each household has an equal chance of being selected, contributing to a representative sample for analysis.

The collected data were likely comprehensive and multifaceted, covering various aspects related to socio-economic vulnerability to flood hazards. Some of the key data points that may have been collected include:

Household Demographics: Information about the size of households, family composition, age groups, and education levels of household members.

Housing Conditions: Details about the type of housing structures, construction materials used, and the presence of vulnerabilities such as weak foundations or lack of flood-resistant features.

Livelihoods and Income Sources: Data on primary livelihood activities, sources of income, employment patterns, and economic dependency ratios.

Assets and Resources: Inventory of household assets, including agricultural land, livestock, vehicles, and financial savings or investments.

Access to Services: Availability and accessibility of essential services such as healthcare facilities, schools, clean water sources, and transportation infrastructure.

Previous Flood Experiences: History of past flood events experienced by households, including the frequency, severity, and impacts on livelihoods and assets.

Risk Perception and Coping Strategies: Perceptions of flood risks among households, awareness of early warning systems, and existing coping mechanisms or resilience strategies.

By analysing this data, the researchers aimed to identify and understand the vulnerabilities of rural households to flood hazards. This information is crucial for designing targeted interventions, developing risk reduction strategies, and enhancing community resilience to floods in vulnerable areas like coastal Odisha.

2.3.37) Muhammad Masood and Kuniyoshi Takeuch in the paper of “Flood risk assessment using satellite image and SRTM DEM data: a case study in eastern Dhaka, Bangladesh” (2017) have used SRTM DEM data and hundred years return period hydrological data. In HEC- RAS platform flood plain area is identified. On the basis of spatial flood area in Arc GIS platform risk is estimated. In this work hazard, vulnerability and risk is calculated stepwise. Risk= Hazards into Vulnerability. In this work flood inundation depth is considered as hazard, people exposure, assets are considered as vulnerability. Finally hazards and vulnerability are combined for risk estimation. The resulted data are classified into three distinct categories.

2.3.38) "Assessing flood inundation extent and landscape vulnerability to flood using geospatial technology: A study of Malda district of West Bengal, India" (2015) by Sahana Mehebub, Ahmed Raihan, Hossain Nuhul, and Sajjad Haroon.

To begin their investigation, the researchers employed the Normalized Difference Water Index (NDWI), a key tool in remote sensing, to pinpoint water-submerged areas within the district. This method allowed them to delineate the boundaries of flooded regions accurately, using LANDSAT 8 satellite imagery captured during both dry and wet periods. Through this analysis, they were able to identify and categorize flood-prone areas into three distinct risk levels: high, medium, and low.

A critical aspect of their approach involved integrating the extracted flood data with the land use/land cover (LULC) map of the region. By overlaying these datasets, they gained insights into how different land types and human activities intersected with flood-prone zones. This step was pivotal in assessing landscape vulnerability to floods, as it highlighted areas where human settlements, infrastructure, and agricultural lands were most susceptible to inundation.

The implications of their findings extend to disaster management and urban planning strategies. The delineation of flood risk zones allows stakeholders and decision-makers to prioritise resource allocation and implement targeted mitigation measures. By focusing on areas identified as high-risk, such as densely populated urban centers or critical infrastructure zones, authorities can enhance preparedness and resilience in the face of potential flood events.

In conclusion, research underscores the significance of geospatial technology in understanding and managing flood risks. Their methodological framework, blending remote sensing techniques with geographic information systems (GIS) analysis, offers a robust model that can be replicated in similar regions facing flood-related challenges. This research contributes valuable insights to the broader discourse on disaster risk reduction and climate resilience in vulnerable landscapes.

2.3.39) In their work titled "Application of frequency ratio model and validation for predictive flooded area susceptibility mapping using GIS" (2015), Moung-Jin Lee, Jung-eun Kang, and Seongwoo Jeon delved into flood susceptibility mapping using Geographic Information Systems (GIS) techniques.

The researchers focused on identifying factors contributing to flooding by considering 14 distinct variables. These factors likely encompassed topographical, hydrological, and anthropogenic elements known to influence flood occurrences. Through a frequency ratio model, they quantified the relationship between these factors and the likelihood of flooding, ultimately generating a flooded area susceptibility map.

To validate the accuracy of their predictive model, they employed the Area Under Curve (AUC) method, a widely used measure in assessing the performance of predictive models. Remarkably, their analysis revealed a 91% correlation between the predicted flooded areas and historical flood records. This high level of match signifies the robustness and reliability of their susceptibility mapping approach.

Overall, research underscores the efficacy of GIS-based methodologies in flood risk assessment. Their utilisation of multiple factors and rigorous validation techniques adds credibility to their findings, making a significant contribution to the field of flood susceptibility mapping and disaster management.

2.3.40) In their research paper "Flood hazard zoning in Yasooj region, Iran, using GIS and multi-criteria decision analysis" (2015), Omid Rahmati, Hossein Zeinivand, and Mosa Besharat undertook the task of estimating flood-prone areas and classifying them into three distinct categories: high, moderate, and low.

The researchers identified four critical factors contributing to floods in the Yasooj region and utilized the Analytic Hierarchy Process (AHP) decision-making matrix within a GIS framework. This approach allowed them to systematically assess the impact of each factor on flood occurrence and determine the susceptibility of different areas to flooding.

To assign appropriate weights to these factors, researchers relied on the expertise of field specialists. They gathered input through a questionnaire method, where experts from various relevant domains provided their insights and assessments. This collaborative effort ensured a comprehensive and informed weighting of factors, enhancing the accuracy of the flood hazard zoning process.

By integrating GIS technology with multi-criteria decision analysis and expert input, the researchers were able to create a detailed flood hazard zoning map for the Yasooj region. This map delineated areas at varying levels of risk, providing valuable information for disaster management and land use planning initiatives.

2.3.41) In their paper titled "The use of HEC-RAS modeling in flood risk analysis" (2015), researchers Iosub Marina, Minea I, Hapciuc Oana, and Romanescu Gh. explored the integration of ARC GIS and HEC-RAS for simulating flood areas.

Their methodology involved several key steps. Initially, the researchers conducted pre-processing of the river channel data, which likely included gathering relevant information such as topography, flow rates, and channel characteristics. They then proceeded to draw cross profiles along the river channel to capture variations in elevation and other important factors.

Utilising the HEC-RAS modelling software, the researchers simulated flood scenarios based on the cross-profile data. This simulation allowed them to predict the extent of flooding under different conditions, such as varying water levels or flow rates. By extracting the simulated flood areas, they obtained spatial data representing the potential flooded zones.

Finally, the researchers presented these flooded areas within the GIS platform. GIS technology enabled them to visualise, analyse, and manage the flood risk data effectively. The integration of HEC-RAS modelling with ARC GIS provided a comprehensive approach to flood risk analysis, combining hydraulic modelling with spatial analysis capabilities for a more accurate assessment of flood-prone areas.

2.3.42) In their paper "Hydrostatistical analysis of flood with particular reference to Tilpara barrage of Mayurakshi River, Eastern India" (2015), researchers K.G. Ghosh and S. Mukhapadhaya delve into the intricate relationship between floods in the Mayurakshi River and the Tilpara barrage.

Their study spans a significant historical period, analyzing peak floods from 1945 to 2013. To assess the flood characteristics, the researchers focused on annual peak discharge, annual peak rainfall, and water level data. They employed the moving average method to analyse trends in peak flow over time.

Their analysis revealed notable patterns. In terms of peak flow, there was a discernible upward trend, with the highest peak discharge recorded in 2000 and the lowest in 1966. This trend suggests a changing hydrological regime that warrants attention.

Interestingly, the relationship between peak annual rainfall and peak discharge showed a relatively poor correlation coefficient of 0.316. This finding challenges the common assumption that rainfall alone is the primary driver of floods. Instead, the researchers highlighted the significant impact of dam releases on flood distribution.

To quantify the impact of the dam, the researchers measured the reservoir's water level. This measurement provided crucial insights into how dam operations contribute to flood dynamics in the Mayurakshi River basin.

This research underscores the complex interplay of natural and anthropogenic factors in flood occurrences. By highlighting the role of dam operations alongside rainfall, their study contributes valuable information for flood risk management and water resource planning in the region.

2.3.43) In their paper "Social vulnerability of rural households to flood hazards in western mountainous regions of Henan province, China" (2015), researchers Delin Liu and Yue Li conducted an analysis of social vulnerability status in the region. They employed Principal Component Analysis (PCA) to derive weights for various indicators, which included factors like family size, dependency ratio, literacy rate, the ratio of perennial workers, income per capita, access to hazards-related information, vehicle per capita, and hazards-related training.

The weightage assigned to each indicator through PCA analysis was as follows: family size (0.13), dependency ratio (0.09), literacy rate (0.12), the ratio of perennial workers (0.17), income per capita (0.14), and access to hazards-related information (0.12), vehicle per capita (0.10), and hazards-related training (0.14). This approach allowed the researchers to objectively assess the relative importance of these factors in determining social vulnerability to flood hazards among rural households.

The weightage calculation methods are broadly categoriese into three:

1. Subjective methods, such as Delphi techniques, which involve expert opinions and consensus.

2. Objective methods, exemplified by PCA analysis, which rely on statistical algorithms to derive weights.

3. Hybrid methods that combine both subjective and objective approaches, like Analytic Hierarchy Process (AHP), which integrates expert judgment with quantitative analysis.

In this work researchers opted for the objective method of PCA analysis for weightage calculation. They then validated these weights against past results, emphasizing the significance of validation in index-based studies. This validation process ensured the reliability and accuracy of their social vulnerability assessment model.

Overall, this research contributes valuable insights into social vulnerability assessment methodologies, highlighting the importance of combining objective analysis with expert judgment for a comprehensive understanding of vulnerability to natural hazards like floods in rural areas.

2.3.44) In their paper "Revealing the Vulnerability of Urban Communities to Flood Hazard in Tanzania: A Case of the Dar es Salaam City Ecosystem" (2015), researchers Herbert Hambati and Greg Gaston provided a qualitative analysis of the impact of floods on urban society. They highlighted several key aspects related to flood vulnerability in Dar es Salaam City.

One significant finding discussed in the paper is the migration pattern observed during floods, where there's an increase in rural-to-urban migration. This influx of people into urban areas during and after floods can strain resources and infrastructure, leading to challenges in managing the growing population.

Another important aspect addressed is the rise in anti-social activities such as drug addiction, which tends to escalate during and after flood events. This can be attributed to various factors including displacement, economic stress, and disruptions in social structures.

The researchers utilised interviews as a primary method to gather data and insights from the affected population. Through these interviews, they were able to gauge the level of awareness among residents regarding flood risks and preparedness measures. The representation of the aware population ratio helped in understanding the community's perception and response to flood hazards.

Additionally, the study delved into the post-flood effects, highlighting issues like the spread of epidemics and serious food crises that often follow in the aftermath of flooding. These secondary impacts can exacerbate the vulnerability of urban communities, especially those already facing socio-economic challenges.

Research sheds light on the complex interplay between floods and urban vulnerability in Dar es Salaam City. By qualitatively analysing the societal impacts of floods and post-flood challenges, the study contributes valuable insights for disaster management and resilience planning in urban areas prone to flooding.

2.3.45) In their research work titled "Flood frequency estimation for ungauged catchments in Iceland by combined hydrological modelling and regional frequency analysis" (2014), researchers Philippe Crochet and Tinna Þórarinsdóttir focused on estimating flood frequencies for ungauged river catchments in Iceland.

The researchers employed a combination of hydrological modeling and regional frequency analysis to estimate streamflow within the river catchments. Through empirical analysis of streamflow data, they derived flood frequency estimates for each catchment. This approach allowed them to assess and analyse flood scenarios within the basin.

By integrating hydrological modelling techniques with regional frequency analysis, the researchers were able to overcome the challenge of limited data in ungauged catchments. This methodology provided valuable insights into flood frequency patterns, aiding in the understanding of flood risk and informing flood management strategies for these areas in Iceland.

This research contributes to the field of flood frequency estimation in ungauged catchments, offering a practical approach for assessing flood risk and enhancing resilience in vulnerable regions.

2.3.46) In the research paper "Flood hazards and risk assessment of the Hoang Long river basin in Vietnam" (2014), V.T. Tu and T. Tinsangchali embarked on a detailed exploration of flood dynamics and associated risks within this specific region of Vietnam.

Their study commenced with a thorough examination of flood occurrences across different return periods, ranging from relatively common events like 5-year floods to rarer, more severe incidents like 200-year floods. This broad spectrum of flood magnitudes was crucial for understanding the full range of potential hazards faced by the Hoang Long river basin.

To simulate and analyse flood scenarios, the researchers employed the MIKE-11 hydrodynamic model. This sophisticated software enabled them to create accurate simulations of flood extents and depths under various return period scenarios. By visualizing the simulated flood areas, they gained insights into the spatial distribution and severity of potential flooding within the basin.

One of the key aspects of their study was the integration of flood simulation data with a Land Use Land Cover (LULC) map. This integration allowed them to overlay the simulated flood areas onto the map, thereby identifying the different land use types affected by floods. By categorizing land use into segments such as agricultural land, residential areas, and infrastructure, they could calculate the percentage of damage inflicted on each land use category during flood events.

The damage assessment aspect of their study was crucial for understanding the potential socio-economic impacts of floods on the Hoang Long river basin. By quantifying the damage to different land use types, the researchers could evaluate the economic losses, potential displacement of populations, and infrastructural damages that may occur during flood events.

Through their comprehensive approach combining hydrological modelling, flood simulation, and damage assessment,

Researchers provided a holistic view of flood hazards and risks within the Hoang Long river basin. Their work not only highlighted the vulnerability of different land use types to floods but also informed decision-makers about potential mitigation strategies and adaptation measures to reduce the impacts of future flood events in the region..

2.3.47) In their research work titled "Analyzing fluvial hydrology to estimate flood geomorphology from channel dimension using ASTER DEM, GIS, and statistics in the controlled Damodar river, India" (2014), Sandipan Ghosh and Sanat Kumar Guchhait delved into the intricate relationship between river geomorphology and flood characteristics.

The researchers focused on extracting channel characteristics from ASTER Digital Elevation Model (DEM) data, which provided detailed information about the topography and morphology of the Damodar River in India. This data allowed them to analyse the fluvial hydrology of the river and gain insights into its geomorphological features, particularly focusing on the channel morphology.

Utilising Geographic Information Systems (GIS) and statistical analysis techniques, Ghosh and Guchhait performed Principal Component Analysis (PCA) on the extracted channel data. PCA is a powerful statistical method used to identify patterns and relationships in multidimensional data, in this case, relating to the hydro-geomorphology of the river channel.

By applying PCA analysis, the researchers aimed to uncover significant correlations between the spatial dimensions of the river channel and flood characteristics. This analytical approach enabled them to understand how the channel's physical attributes, such as width, depth, and sinuosity, influence the dynamics of flood events.

The study's findings shed light on the complex interactions between river geomorphology and flood behavior, providing valuable insights for hydrological modeling and flood risk assessment in the Damodar River basin. Understanding the hydro-geomorphological characteristics of the channel is crucial for effective river management, flood mitigation, and sustainable development in the region.

2.3.48) In their paper titled "Simplified Flood Inundation Mapping Based On Flood Elevation-Discharge Rating Curves Using Satellite Images in Gauged Watersheds" (2014), researchers Younghun Jung, Dongkyun Kim, Dongwook Kim, Munmo Kim, and Seung Oh Lee undertook a comprehensive approach to predict and map flooded areas using simulation-based modeling.

The researchers began by leveraging satellite imagery from sources such as Synthetic Aperture Radar (SAR), LANDSAT, and SPOT to identify the extent of flooded areas within gauged watersheds. This initial step was crucial for obtaining accurate spatial data on flood-affected regions.

Next, the researchers focused on analysing the elevation-discharge relationship, which is fundamental in understanding how water levels vary with flow rates during flooding. By establishing flood elevation-discharge rating curves, they could predict flood extents based on known discharge levels.

To further refine their flood mapping efforts, the researchers utilised HEC Georas to create cross-sections along the river. These cross-sections provided detailed information about the topography and morphology of the river channel, aiding in floodplain extraction within the HEC-RAS platform.

By integrating satellite imagery analysis, elevation-discharge modelling, and hydraulic modelling techniques, the researchers were able to extract floodplains and generate simplified flood inundation maps. These maps are valuable tools for emergency management, land use planning, and disaster risk reduction efforts in gauged watersheds.

Overall, the paper presents a robust methodology for floodplain mapping using satellite imagery and hydrological modelling, contributing to the advancement of flood risk assessment and management strategies.

2.3.49) In the paper "Estimation of flash flood magnitude and flood risk in the lower Damodar river basin in India" (2013), S. Ghosh delves into the dynamics of floods in relation to climate change within the lower part of the Damodar river basin in India. The research emphasizes the impact of human activities, particularly dam construction, on flood characteristics and risks.

To analyse the evolving nature of floods, Ghosh employs various indices such as the Flood Potential Index, Flash Flood Index, and Flood Frequency. These indices provide insights into the likelihood and magnitude of flash floods, essential for understanding flood dynamics and assessing associated risks.

A significant aspect of the study is the measurement of stream power at Rhondia using Kale's formula for stream power (2003). The results reveal a stark contrast before and after dam construction. Prior to construction, the stream power ranged from 4100 to 8500 watts per square meter. However, post-construction, there is a drastic decrease, with stream power now ranging from 2100 to 4200 watts per square meter. This substantial reduction in stream power indicates alterations in flow dynamics due to damming, impacting the river's hydrological regime.

Furthermore, the study highlights the increase in siltation rates post-dam construction, leading to a decrease in the river channel's capacity. This phenomenon is a direct consequence of human intervention and has implications for flood risk management and river basin management strategies.

Overall, researcher analysis the complex interplay between human activities, such as dam construction, and natural processes like floods. The findings contribute valuable insights into understanding flood dynamics, assessing flood risks, and informing sustainable river management practices in the Damodar River basin.

2.3.50) In their work titled "Landslide susceptibility mapping using frequency ratio, Analytic Hierarchy Process, logistic regression, and Artificial Neural Network methods at the Inje area, Korea" (2012), Researchers Soyoung Park, Chuluong Choi, Byungwoo Kim, and Jinsoo Kim employed four distinct methods to predict landslide susceptibility in the Inje area of Korea. These methods included frequency ratio analysis, Analytic Hierarchy Process (AHP), logistic regression, and Artificial Neural Network (ANN) modelling.

The researchers validated their landslide susceptibility mapping results using the Receiver Operating Characteristic (ROC) curve analysis method, which is a widely accepted approach for evaluating the accuracy of predictive models. The ROC curve helps assess the trade-off between sensitivity (true positive rate) and specificity (true negative rate) of a model in predicting landslides.

Through their analysis, the researchers found that all four methods—frequency ratio, AHP, logistic regression, and ANN—demonstrated a suitability of 80% and above in predicting landslide susceptibility. This indicates that each method was effective in identifying areas at high risk of landslides within the Inje area.

The use of multiple methods and the validation through ROC curve analysis add credibility to the research findings, highlighting the robustness of the landslide susceptibility mapping approach employed by the researchers. Such studies are essential for land use planning, disaster risk reduction, and proactive measures to mitigate landslide hazards in vulnerable regions like the Inje area of Korea.

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2.3.51) In their paper titled "Application of HEC/HMS and GIS tools in flood modeling: a case study for river Sironko – Uganda" (2012), Researchers Okirya Martin, Albert Rugumayo, and Janka Ovcharovichova focused on predicting flood areas using hydrological modeling and Geographic Information Systems (GIS) tools.

The researchers utilised the HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System) software to extract discharge data for the River Sironko in Uganda. This discharge data served as a crucial input for flood modeling, as it provided information about the flow rates and volumes of water in the river during various scenarios.

Using the HEC-HMS data, the researchers defined the floodplain area along the River Sironko. This involved mapping out the areas that would be inundated or affected by flooding under different conditions, such as different return periods (e.g., 10-year flood, 50-year flood, etc.).

The integration of GIS tools played a significant role in visualizing and analyzing the floodplain area. GIS allowed the researchers to overlay the floodplain data onto spatial maps, providing a clear and comprehensive representation of the areas at risk of flooding along the River Sironko.

Overall, the study demonstrated the effectiveness of combining hydrological modeling (HEC/HMS) with GIS tools for flood modeling and risk assessment. By accurately predicting flood areas and understanding the potential impacts of different flood scenarios, the research contributes valuable insights for flood management and disaster preparedness in the region.

2.3.52) In their research work titled "Role Of Embankment In Flood: A Study In The Confluence Zone Of Kunur And Ajay Rivers, Lower Ajay River Basin, West Bengal" (2012), Suvendu Roy and Shyamal Dutta examined the relationship between floods and embankments in the lower Ajay River basin, specifically focusing on the confluence zone of Kunur and Ajay Rivers.

One significant aspect highlighted in the paper is the analysis of flood frequency concerning embankment construction. The researchers observed that in the periods following embankment construction, there was an increase in flood frequency. This finding suggests a potential correlation between embankments and the exacerbation of flood events.

The study also delved into the physical changes occurring in the lower part of the river channel. Notably, the width of the river channel was found to be gradually decreasing. This reduction in channel width is significant as it can contribute to increased flood occurrences, especially during events like sudden water releases from dams or periods of high rainfall.

Another critical point discussed in the paper is the impact of improper embankment construction on flood probabilities. The researchers noted that inadequacies or flaws in embankment construction could lead to heightened flood risks. This underscores the importance of proper engineering and maintenance practices when implementing embankments as flood control measures.

Researchers shed light on the complex dynamics between embankments and floods in the Ajay River basin. The findings underscore the need for comprehensive flood management strategies that consider the potential impacts of embankments on flood frequencies and probabilities.

2.3.53) In the research work titled "Spatial variation of flood in the lower Ajay River basin: a geo-hydrological analysis" by Researcher S. Roy (2012), the focus was on understanding flood intensity and vulnerability within the basin. Here are the key points highlighted in the study:

Flood Vulnerability Classification: The researcher classified the entire lower Ajay River basin into four categories based on flood vulnerability. The highly flood-affected area comprised 22.7% of the basin, while the moderately flood-affected area covered 18.75%.

Bank Vulnerability: A notable finding was that the right bank of the river was more vulnerable to flooding compared to the left bank. This asymmetry in vulnerability could be attributed to various factors such as topography, land use patterns, and river dynamics.

River Channel Width: The study emphasised the role of river channel width in flood dynamics. It was observed that the width of the river channel varied significantly within the basin.

2.3.54) In their paper titled "Role Of Embankment In Flood: A Study In The Confluence Zone Of Kunur And Ajay Rivers, Lower Ajay River Basin, West Bengal" (2012), Researchers Suvendu Roy and Shyamal Dutta focused on examining flood hazards specifically in the Kunur river basin, which is a tributary of the Ajay River. The confluence of Kunur and Ajay rivers is a critical juncture where flood dynamics are particularly significant.

The study aimed to understand the impact of floods originating from the Kunur River on the entire Ajay River basin. One of the key points of interest was the role of embankments in flood management within the basin. Historically, embankments such as the Zamindari Bandh were constructed along the Ajay River to protect against floods. However, despite the increased height and length of these embankments over time, the researchers observed that flood frequency remained largely uncontrolled.

This discrepancy between embankment construction and flood control raised questions about the effectiveness of traditional flood protection measures. Additionally, the study highlighted how the construction of embankments altered runoff patterns in the main channel of the river, thereby impacting flood scenarios across the entire basin.

The findings suggest that while embankments were intended to mitigate flood risks, their construction may have unintended consequences on hydrological processes and flood dynamics. This emphasizes the need for a comprehensive approach to flood management that considers not only structural measures like embankments but also factors such as land use changes, climate variability, and river morphology.

This research successfully conducted the complex interactions between embankments, river dynamics, and flood hazards in the lower Ajay River basin. The study underscores the importance of adopting integrated and adaptive flood management strategies to address evolving challenges in flood-prone areas.

2.3.55) In their work titled "A new assessment methodology for flood risk: a case study in the Indus River basin" (2011), Youngjoo Kwak, Akira Hasegawa, Hironori Inomata, Jun Magome, Kazuhiko Fukami, and Kuniyoshi Takeuchi focused on developing a novel methodology for assessing flood risk in the Indus River basin. Here are the key aspects highlighted in their study:

Estimation of Flood Risk: The researchers utilised past flood records to estimate flood risk within the Indus River basin. These records were analysed and divided into grids to create a spatial representation of flood occurrences.

Overlay Analysis: One significant aspect of their methodology was the overlay analysis, where they overlaid population data with flood intensity to extract risk intensity. This approach helped identify areas where the concentration of population coincided with high flood intensity, indicating higher flood risk.

DEM Analysis: The study also involved analyzing the Digital Elevation Model (DEM) to understand the topographic characteristics of the region. By studying the DEM, the researchers were able to estimate flood depths in different areas of the Indus River basin.

Risk Assessment Methodology: The methodology developed by the researchers integrated various factors such as past flood data, population distribution, flood intensity, and topographic features to provide a comprehensive assessment of flood risk. This holistic approach enabled a better understanding of the factors contributing to flood risk in the region.

Overall, the study is presented an innovative methodology for flood risk assessment, particularly in the context of the Indus River basin. By combining historical data, spatial analysis techniques, and topographic information, the researchers aimed to enhance flood risk management strategies and improve resilience in flood-prone areas.

2.3.56) In their paper "Floodplain conflicts: regulation and negotiation" (2011), Researchers J. Pardoe, E. Penning-Rowsell, and S. Tunstall delved into the evolving strategies and challenges surrounding flood management solutions. Here are the key points highlighted in their work:

Floodplain Identification: The researchers emphasized the critical importance of accurately identifying floodplains for effective flood mitigation strategies. Understanding the geographic areas prone to flooding is crucial for implementing appropriate measures to reduce flood risks.

UK Case Study: The paper discussed the UK's approach to floodplain management, particularly highlighting the Town and Country Planning Act of 1947. This legislation defined different zones within floodplain areas, categorizing them into Zone 1, Zone 2, Zone 3A, and Zone 3B based on flood risk levels. These classifications likely influenced development regulations and land use planning in flood-prone zones.

European Floodplain Regulations: The researchers also provided insights into floodplain regulations in various European countries. For instance:

Netherlands: Floodplain zones are typically reserved for agricultural or natural practices, with strict limitations on development.

Austria: Floodplain zones, identified as red zones, are strictly prohibited for any construction activities to minimize flood risks.

Italy: The researchers noted that building construction is generally not allowed in floodplain areas in Italy, indicating a cautious approach to flood risk management.

Overall, the paper highlighted the diversity of approaches and regulations regarding floodplain management across different European countries. It underscored the importance of regulatory frameworks, land use planning, and development restrictions in flood-prone areas to mitigate conflicts and minimize flood hazards.

2.3.57) In their paper "Application of hydraulic, hydrologic and digital terrain modelling in flood risk area mapping" (2011), Researchers Carla Voltarelli Franco da Silva, Cristiano de Pádua Milagres Oliveira, André Sandor Kajdacsy Balla Sosnoski, and Arisvaldo Vieira Méllo Junior explored the significance of Digital Terrain Models (DTM) in floodplain identification and flood risk area mapping. Here are the key aspects discussed in their study:

Role of DTM in Floodplain Identification: The researchers highlighted the critical role of Digital Terrain Models (DTM) in accurately identifying floodplains. DTMs provide detailed information about the terrain elevation, which is crucial for understanding flood dynamics and mapping flood risk areas.

Flood Frequency Analysis: The study involved analyzing flood frequencies for different return periods. This analysis helps in assessing the likelihood and magnitude of floods occurring within a specific timeframe, which is essential for flood risk assessment and management.

Use of SRTM DEM and Hydrological Data: The researchers utilized Shuttle Radar Topography Mission (SRTM) DEM data along with hydrological data to identify floodplains. SRTM DEM provides high-resolution elevation data, which, when combined with hydrological information, enhances the accuracy of floodplain mapping.

HEC-RAS Platform: The floodplain identification process was conducted using the HEC-RAS platform, widely used software for hydraulic and hydrologic modeling. This platform allows for the simulation of river flows and flood extents, aiding in flood risk area mapping.

Validation and Error Correction: A significant aspect emphasized by the researchers was the validation of floodplain mapping results. Due to potential errors in DEM data, validation becomes crucial to ensure the accuracy and reliability of flood risk area maps.

Overall, the study showcased the integration of hydraulic, hydrologic, and digital terrain modeling techniques for effective flood risk area mapping. By leveraging advanced tools and data sources, the researchers aimed to provide valuable insights for flood risk assessment and management strategies.

2.3.58) In the paper "A Geo-Environmental Assessment of Flood Dynamics in Lower Ajoy River Inducing Sand Splay Problem in Eastern India" by Researcher Sutapa Mukhopadhyay (2010), the focus was on understanding the historical context and dynamic nature of floods in the lower Ajoy River region, particularly the issues related to sand splay due to flooding. Here are the key points discussed in the paper:

Historical Overview of Floods: The paper provides a historical overview of flood characteristics in the lower Ajoy River region, highlighting the dynamic nature of floods over time. This historical context is crucial for understanding the current flood dynamics and associated challenges.

Sand Splay Problem: The researcher emphasises the issue of sand splay caused by floods in the region. Sand splay refers to the deposition of sand and sediment by floodwaters, which can lead to hazards and challenges for local communities, particularly those residing in floodplain areas.

Soil Quality Assessment: Researcher conducted assessments of soil quality in areas affected by post-flood effects. This analysis likely focused on changes in soil composition, nutrient levels, and other factors influenced by flood events.

Causes of Flooding: The researcher identifies two main causes of flooding in the region: the sudden onset of monsoon rains and the excessive water discharge from the Bhagirathi River. These factors contribute to increased flood vulnerability in specific areas along the lower Ajoy River.

Impact on Agricultural Practices: The paper also discusses the impact of sand splay and flooding on agricultural practices in the region. These impacts may include soil erosion, loss of crops, and changes in agricultural land use patterns.

2.3.59) In their paper "Probability of flooding and vulnerability assessment in the Ajay River, Eastern India: implications for mitigation" (2010), researchers Sujay Bandyopadhyay, Prasanta Kumar Ghosh, Narayan Chandra Jana, and Subhajit Sinha explored various aspects related to flooding in the Ajay River basin in eastern India. They discussed the soil, geology, and land use characteristics of the basin, along with flood peak heights, return periods, and extreme flood events. The study also analysed changes in land use and land cover due to flooding, the impact of embankments on flood risks and natural fertility, and the classification of the lower Ajay basin into vulnerability zones. The researchers suggested measuring flood vulnerability in comparison to human settlements and identified high runoff areas due to steep slopes in the western part of the basin. They also compared flood events over time to understand variations in flood severity.

2.3.60) The paper "Fluvial flood risk management in a changing world" by B. Merz, J. Hall, M. Disse, and A. Schumann (2010) provides a comprehensive analysis of the shift in flood risk management strategies towards resilience-building measures. The researchers delve into the limitations of traditional structural measures like embankments, which often create a false sense of security and can lead to adverse effects on the fluvial ecosystem.

One of the key insights from the study is the importance of adopting multi-use functions in flood risk management. This approach not only promotes resilience but also facilitates balanced development on both sides of the river, ultimately reducing the costs associated with maintenance and management.

The researchers also emphasise the significance of integrating information systems and warning mechanisms into flood risk management strategies. An awareness-learning information system-based warning system is proposed as a valuable tool for enhancing preparedness and response to flood events.

Furthermore, the paper highlights the integral process of flood risk management, which includes employing various hydrological methods for effective floodplain management. By leveraging hydrological data and techniques, stakeholders can make informed decisions and implement targeted interventions to mitigate flood risks.

Overall, the paper underscores the need for a holistic and adaptive approach to fluvial flood risk management, one that integrates resilience-building measures, multi-use functions, advanced information systems, and robust hydrological methodologies.

2.3.61) In the research paper "Suffering with the River: Floods, Social Transition and Local Communities in the Ajoy River Basin in West Bengal, India" (2010), Researcher Abhik Chakraborty delves deeply into the multifaceted dynamics surrounding the Ajoy River and its interaction with local communities. The study employs a qualitative approach to capture the nuanced changes in the river's character over time and their consequences on the social fabric of the region.

Researcher exploration begins with an examination of how human activities, often carried out without scientific considerations, have impacted the Ajoy River's natural flow and behaviour. These activities encompass a range of practices such as irrigation methods, sand mining operations, and the construction of infrastructure along the riverbanks. The paper sheds light on how these activities have altered the river's course, flow patterns, and sedimentation rates, ultimately affecting its capacity to handle water during flood events.

A significant focus of the study is on the impact of embankments on the Ajoy River. While embankments are often constructed with the intention of mitigating flood risks, researcher discusses how these structures can inadvertently disrupt the river's hydrological processes. This disruption can lead to issues such as changes in water levels, increased sediment deposition, and the formation of breaches during floods. The paper delves into the complexities of embankment management and the challenges posed by relying solely on structural measures for flood control.

Furthermore, explores the environmental factors contributing to the river's changes, including soil erosion and deforestation within the Ajoy River basin. The loss of vegetation cover and soil destabilisation have led to heightened sedimentation rates in the river, reducing its carrying capacity and exacerbating flood risks during periods of heavy rainfall.

The study also reflects on historical flood events, notably highlighting major floods in 1978 and 2000. These events serve as critical milestones in understanding the river's evolving behaviour and the vulnerabilities faced by communities living in the basin. Chakraborty analyzes the repercussions of these floods on local communities, infrastructure, and the environment, providing insights into the social and economic impacts of such disasters.

Additionally, the paper delves into the gradual changes observed in tributaries like Hinglow and their influence on the main channel flow of the Ajoy River. Degeneration in tributaries can alter water flow dynamics, contributing to flood risks and environmental degradation downstream.

A key aspect discussed in the research is the relationship between land use/land cover changes and the behaviour of the Ajoy River. In conclusion, this paper provides a comprehensive examination of the complex interplay between human interventions, environmental changes, and the evolving character of the Ajoy River. The study underscores the need for holistic and sustainable approaches to river management that consider ecological resilience, community well-being, and long-term flood risk reduction strategies.

2.3.62) In the paper "An Information System for Risk-Vulnerability Assessment to Flood" by Subhankar Karmakar, Slobodan P. Simonovic, Angela Peck, and Jordan Black (2010), the researchers delve into a comprehensive framework for assessing risk and vulnerability associated with floods. The study integrates various components related to floods, including physical, economic, infrastructural, and social aspects, within a Geographic Information System (GIS) platform for enhanced analysis and decision-making.

The key components discussed in the paper include:

Physical Vulnerability: This aspect focuses on assessing the susceptibility of different areas to flooding. The researchers consider factors such as land cover, topography, and the extent of flood-prone areas. Additionally, the loss of productive ecosystems due to flooding is also factored into the physical vulnerability assessment.

Economic Vulnerability: The study evaluates the economic impacts of floods by quantifying monetary damages incurred. This involves assessing the direct costs associated with infrastructure damage, property loss, and disruption to economic activities caused by flooding events.

Infrastructural Vulnerability: Infrastructure vulnerability is assessed based on the damage and loss of critical assets such as roads, bridges, utilities, and other key infrastructure elements. The researchers quantify the impact of flood events on the functionality and resilience of these infrastructural components.

Social Vulnerability: Social vulnerability analysis encompasses the capacity of communities to cope with and recover from flood events. Factors such as community response mechanisms, preparedness levels, access to resources, and social resilience are considered in evaluating social vulnerability to floods.

The researchers emphasise the importance of considering critical facilities such as water pumping stations, school buildings, and healthcare facilities as focal points for assessing flood risk and vulnerability. These critical assets are vital for community well-being and are thus prioritised in the risk assessment process.

To conduct the risk-vulnerability assessment, the researchers employ a spatial analysis approach within a GIS framework. They create grid-based representations (6x6 square grids) to delineate flood-susceptible areas and overlay different layers of data, including physical, economic, infrastructural, and social parameters. This integrated analysis allows for a comprehensive understanding of flood risk hotspots, vulnerable communities, and critical infrastructure at risk during flood events.

Overall, the paper presents a systematic and multidimensional approach to flood risk assessment, leveraging GIS technology and incorporating diverse factors to enhance decision-making and resilience-building efforts in flood-prone areas.

2.3.63) In his research paper "Flood Susceptible Mapping and Risk Area Delineation Using Logistic Regression, GIS, and Remote Sensing" (2009), Biswajeet Pradhan delves into the intricacies of assessing flood-prone areas and delineating risk zones. The study employs a combination of logistic regression, Geographic Information Systems (GIS), and remote sensing techniques to achieve these objectives.

Pradhan begins by selecting six parameters deemed crucial for understanding flood susceptibility. These parameters likely include aspects such as topography, land use/land cover, soil type, rainfall intensity, proximity to water bodies, and slope gradient. Through logistic regression, a statistical modelling approach, Pradhan evaluates the relationship between these parameters and the occurrence of floods. This analysis allows him to assign relative weights to each parameter based on their significance in contributing to flood susceptibility.

The next step involves integrating the relative weightage derived from logistic regression into a GIS environment. GIS plays a pivotal role in spatial analysis and visualization, enabling the creation of detailed flood susceptibility maps and the delineation of risk areas. Pradhan likely incorporates remote sensing data, such as satellite imagery, to gather information on land cover changes, surface water bodies, and other environmental variables relevant to flood susceptibility.

A crucial aspect of methodology is the validation of the flood-susceptible mapping and risk area delineation. To assess the accuracy and reliability of the predictive model, Pradhan utilises the Area Under Curve (AUC) method. AUC analysis provides insights into the model's performance in predicting flood-prone areas, thus enhancing the credibility and utility of the generated maps for risk assessment and disaster management planning.

2.3.64) In their paper "Methods for the Evaluation of Direct and Indirect Flood Losses" (2008), AH Thieken, V Ackermann, F Elmer, H Kreibich, B Kuhlmann, U Kunert, H Maiwald, B Merz1, M Müller, K Piroth, J Schwarz, R Schwarze, I Seifert, and J Seifert delve into the intricate factors influencing direct and indirect flood losses. Their analysis spans various aspects, including residential buildings, agricultural losses, and transport disconnections, with a keen focus on assessing these losses in monetary terms.

One significant aspect discussed by the researchers pertains to the loss factors associated with residential buildings. They consider variables such as building height and building types to evaluate the extent of damage and subsequent financial losses incurred during flooding events. By categorising buildings based on these factors, the researchers can better understand the vulnerability of different structures to flood-related damages.

In addition to residential buildings, the paper also addresses agricultural losses resulting from floods. The researchers take into account various types of crops and their respective economic values to quantify the agricultural damage caused by inundation. This approach enables a comprehensive assessment of the impact on the agricultural sector, which plays a crucial role in the economy of flood-affected regions.

Moreover, the study examines the effects of flood-induced transport disconnections. Disruptions in transportation infrastructure, such as road closures or bridge damage, can have far-reaching consequences, affecting accessibility, emergency response, and economic activities. The researchers likely analyse the financial implications of these transport disruptions to gain insights into the indirect losses associated with flood events.

To facilitate their analysis and assessment of flood losses, the researchers leverage geographic coordinate data, allowing them to study the impact at a micro-scale level. This granular approach enables a detailed understanding of the spatial distribution of losses and helps in pinpointing areas most susceptible to flood-related damages.

Overall, the paper presents a methodological framework for evaluating both direct and indirect flood losses, incorporating factors such as building characteristics, agricultural impacts, and transport disruptions. By quantifying these losses in monetary terms and utilising geographic data for spatial analysis, the researchers contribute to a comprehensive understanding of the economic consequences of flooding and inform strategies for risk mitigation and disaster management.

2.3.65) In their paper "Urban Flood Vulnerability and Risk Mapping Using Integrated Multi-Parametric AHP and GIS: Methodological Overview and Case Study Assessment" (2008), Researchers Yashon O. Ouma and Ryutaro Tateishi delve into a comprehensive methodology for mapping urban flood vulnerability and risk. The study focuses on a specific municipality area and employs an integrated approach that combines Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS) techniques.

The researchers begin by identifying and selecting eight key factors responsible for urban flood vulnerability within the municipality area. These factors could include aspects such as topography, drainage patterns, land use and land cover, proximity to water bodies, infrastructure resilience, population density, historical flood data, and emergency response capacity.

To assess the relative importance of these factors in contributing to flood vulnerability, the researchers utilise the AHP method. AHP involves constructing a hierarchical decision-making framework and eliciting expert judgments to derive weightage values for each factor. This process allows for a systematic and structured approach to prioritizing the factors based on their significance in influencing flood vulnerability.

Once the weightage values are determined through the AHP matrix, the researchers integrate this information with GIS data layers, including flood-prone areas and land use/land cover maps. By overlaying these spatial datasets and applying the weighted factors, the study estimates flood risk levels across the municipality area.

The integrated multi-parametric approach enables a comprehensive assessment of urban flood vulnerability and risk. By considering multiple influencing factors and their weighted contributions, the researchers generate detailed flood risk maps that highlight areas of heightened vulnerability within the municipality. These maps can aid urban planners, decision-makers, and emergency responders in implementing targeted mitigation measures and disaster preparedness strategies.

Overall, the paper provides a methodological framework that leverages AHP and GIS techniques for effective flood risk mapping and vulnerability assessment in urban environments, offering valuable insights for enhancing resilience and adaptive strategies in flood-prone areas.

2.3.66) In their paper "Coastal Changes Predictive Modelling: A Fuzzy Set Approach" (2008), Researchers Thi Nguyen, Jim Peterson, Lee Gordon-Brown, and Peter Wheeler explore the utilisation of fuzzy set theory in predicting shoreline changes in Portland Bay, Victoria, Australia. The study emphasizes the adaptability, flexibility, and effectiveness of fuzzy set theory in constructing spatial models, particularly in addressing uncertainties inherent in coastal dynamics.

Fuzzy set theory, a mathematical framework that handles uncertainty by allowing elements to have degrees of membership rather than binary distinctions, proves valuable in coastal change predictive modeling. By incorporating fuzzy logic into the modeling process, the researchers can account for the gradual and uncertain nature of coastal transformations.

The research methodology involves analyzing time series data related to coastal parameters such as shoreline position, sediment deposition, erosion rates, and environmental variables. These data points serve as inputs to the fuzzy set model, which then generates predictive outcomes regarding future coastal changes.

One of the key strengths of the fuzzy set approach is its ability to handle imprecise or ambiguous data, common in coastal monitoring and prediction. The fuzzy logic framework allows for the representation of vague concepts and gradual transitions, enabling a more nuanced understanding of coastal dynamics compared to traditional binary models.

The study showcases the practicality of fuzzy set theory in capturing the complex and evolving nature of coastal environments. By harnessing the power of fuzzy logic, researchers gain insights into the potential trajectories of shoreline changes, aiding coastal management strategies, environmental planning, and risk assessment in coastal areas.

Overall, the paper highlights the significance of adopting innovative methodologies like fuzzy set theory to address challenges posed by uncertainties in coastal change prediction, demonstrating its applicability and efficiency in spatial modeling for coastal management and planning initiatives.

2.3.67) The paper "Flood Risk Assessment: A Methodological Framework" by Aimilia Pistrika and George Tsakiris (2007) provides insights into the intricate relationship between hazards, vulnerability, and risk, particularly in the context of flood risk assessment. The authors present a methodological framework that encompasses key concepts and proposals for effective flood risk management.

Firstly, the paper delves into the definition and interconnection of hazards, vulnerability, and risk in the context of floods. Hazards refer to the natural phenomena or events, such as heavy rainfall or storm surges, that can lead to flooding. Vulnerability encompasses the susceptibility of elements at risk, such as communities, infrastructure, and ecosystems, to adverse impacts caused by these hazards. Risk, on the other hand, arises from the combination of hazards and vulnerability, representing the likelihood and potential consequences of flooding.

Main focusing area in this research-

1) Flood risk mapping

2) Flood management plans

3) Three types of vulnerability- economic, social and cultural vulnerability discussed here. By preparing a flow chart the process of risk estimation from hazards to risk also discussed.

2.3.68) In the paper "Reinforcing Flood-Risk Estimation" by Researcher Duncan W. Reed (2002), the methodologies for estimating flood risk are extensively explored. The author delves into several key approaches, including flood frequency analysis, past flood data examination, paleo-flood analysis, and the consideration of past rainfall data. These methods contribute significantly to the understanding and assessment of flood risk.

One of the primary techniques discussed is flood frequency analysis, which involves analysing historical data related to flood occurrences. By studying the frequency and magnitude of past floods, researchers can establish statistical patterns and probabilities associated with different flood events. This analysis is crucial for predicting the likelihood of future floods and assessing their potential impacts.

The paper also highlights the importance of examining past flood data, which provides valuable insights into the characteristics and behaviour of previous flood events. Understanding the factors that contributed to past floods, such as river discharge, precipitation patterns, and land use changes, helps in identifying potential risk factors and vulnerabilities in flood-prone areas.

Furthermore, the author discusses the significance of paleo-flood analysis, which involves studying geological evidence and historical records to reconstruct past flood events. This method is particularly useful for assessing flood risk in areas where long-term data is limited or unavailable. By reconstructing paleo-floods, researchers can gain insights into the variability and magnitude of floods over extended periods.

Continuous monitoring and model development emerge as critical aspects of flood risk analysis in the paper. The author emphasises the need for ongoing monitoring of hydrological parameters, weather conditions, and environmental changes to improve the accuracy of flood risk assessments. Additionally, the development of robust models, including hydraulic models and hydrological simulations, enhances the capability to predict and evaluate flood hazards.

The methodology proposed by Reed also underscores the importance of considering both single-event data and long-term data sets. Single-event data provides detailed information about specific flood events, while long-term data allows for the analysis of trends and patterns over time, aiding in comprehensive flood risk assessment.

Author provides valuable insights into the diverse methodologies used in flood risk estimation, highlighting the importance of continuous monitoring, model development, and data analysis in enhancing our understanding of flood risk and improving resilience to flood events.

2.3.69) In their paper "Application of GIS in Flood Hazard Mapping: A Case Study of Gangetic West Bengal, India" (2003), researchers Joy Sanyal and Xi Xi Lu delve into the detailed analysis of flood hazards using a composite weighted index approach within a GIS framework. The study focuses on the Gangetic region of West Bengal, India, known for its susceptibility to flooding.

One of the primary methodologies employed in the research is the creation of a composite weighted index, which integrates various indicators related to flood hazards. These indicators include flood frequency, spatial extent of flooding, population density, and potentially other relevant factors. By combining these indicators using appropriate weights, the researchers generate a comprehensive flood hazard map in the GIS platform.

A notable aspect of the study is the use of micro-scale parameters, specifically the revenue village boundaries, as polygonal boundaries for the analysis. This finer level of spatial resolution allows for a more localised and precise assessment of flood hazards within specific areas, enabling targeted risk management strategies.

The composite map produced through GIS integration provides a visual representation of areas prone to high flood hazards, highlighting regions where multiple risk factors converge. This spatial analysis aids in identifying vulnerable zones, assisting authorities and stakeholders in prioritising mitigation and preparedness efforts.

Furthermore, the study delves into the classification of causes contributing to high flood hazard areas. By analysing the data within the GIS framework, researchers can identify underlying factors such as topography, land use patterns, hydrological characteristics, and human settlements that contribute to heightened flood risks in certain areas.

Researchers showcases the utility of GIS technology in flood hazard mapping, emphasising its ability to integrate diverse data sets, perform spatial analysis, and facilitate informed decision-making for flood risk management and disaster resilience efforts in flood-prone regions like Gangetic West Bengal.

2.3.70) In their article "Hydrometeorological Aspects of Floods in India," Researchers O. N. Dhar and Shobha Nandargi (2003) provide an in-depth analysis of the impact of tropical monsoon climate on flooding, particularly focusing on India within the context of South-East Asia. The researchers delve into various characteristics of the monsoon climate, including phenomena such as the break of the monsoon, El-Nino, and La-Nina, which significantly influence precipitation patterns and flooding in the region.

One key aspect of the research is the classification of India into four major groups based on flood characteristics. This classification helps in understanding the diverse flood patterns across different regions of the country, considering factors such as precipitation levels, river systems, and terrain features.

The article also delves into the analysis of flood hazard characteristics over a specific period, highlighting the years 1986-2000. By examining hydro-meteorological data from this timeframe, the researchers provide insights into the frequency, intensity, and spatial distribution of floods during this period. This analysis aids in understanding the temporal trends and variability of flooding in India.

An important component of the research is the correlation between climatic phenomena and the physiographic features of India. The researchers elucidate how factors such as topography, land cover, soil types, and river networks interact with meteorological conditions to influence flood dynamics. This holistic approach helps in comprehensively assessing the drivers of flooding in different regions.

Furthermore, the article discusses the role of the fluvial system in shaping regional hydrological characteristics. By examining river morphology, flow patterns, sediment transport, and floodplain dynamics, the researchers provide valuable insights into the interconnectedness between river systems and flooding in India.

The work contributes significantly to the understanding of hydro-meteorological factors influencing floods in India. Their comprehensive analysis of climatic patterns, flood characteristics, and regional hydrology sheds light on the complex dynamics of flooding in the context of India's diverse geographical and environmental settings.

2.3.71) Prof. Dhrubajyoti Sen in his article "Flood Hazard in India and management Strategies" (2010) is drawn an overviewed on Indian flood. Researchers classified the Indian flood into 3 major groups-

i) Atmospheric flood due to extreme rainfall or snow melt water.

ii) Tectonic flood due to land slide or tsunami.

iii) Technological flood due to failure of dam or embankment.

Researchers also emphasised on the flood region of India like Ganga basin region, Brahamaputra basin region, Central India, Coastal region and urban centres flood. In management concern the suggestion of NDMA, 2008 is analysed.

i) Prevention and protection to the flood

ii) Adaptation to existing flood situation

iii) Mitigation of flood related losses by insurance coverage

2.3.72) In their paper "Application of Gumbel's Distribution Method for Flood Frequency Analysis of Lower Ganga Basin (Farakka Barrage Station), West Bengal, India," researchers Kajal Kumar Mandal, K Dharanirajan, and Sabyasachi Sarkar (2021) conducted a thorough analysis of flood frequency using data from the Lower Ganga Basin, specifically focusing on the Farakka Barrage Station in West Bengal, India.

The researchers collected 72 years of maximum discharge data from the Farakka Barrage Station. Utilising this extensive dataset, they performed flood frequency analysis to understand the recurrence intervals and probabilities of various flood events in the region. For this analysis, they employed the Gumbel distribution method, a statistical approach commonly used for flood frequency analysis due to its ability to model extreme events and estimate return periods.

The results of their analysis demonstrated a strong correlation between peak discharge and gauge height data, indicating the suitability and effectiveness of the Gumbel distribution method for flood frequency analysis in the Lower Ganga Basin. This finding is crucial as it validates the use of this method for assessing flood risks and designing appropriate flood management strategies in the region.

By applying statistical techniques like the Gumbel distribution method to analyze long-term discharge data, the researchers contribute valuable insights into the flood characteristics and hydrological behaviour of the Lower Ganga Basin. Such studies are essential for enhancing our understanding of flood risks, improving flood forecasting and early warning systems, and supporting informed decision-making for flood risk management and mitigation measures.

2.3.73) In their recent study titled "Flood Susceptibility Mapping Using the Frequency Ratio (FR) Model in the Mahananda River Basin, West Bengal, India" (2022), researchers Arnab Ghosh, Malabika Biswas Roy, and Pankaj Kumar Roy aimed to assess and map flood susceptibility within the Mahananda River Basin.

The researchers employed a systematic approach by selecting and analyzing various factors associated with flooding. These factors could include topographic attributes, land cover characteristics, soil types, historical flood data, rainfall patterns, and hydrological parameters relevant to the Mahananda River Basin. By integrating these diverse factors, they were able to reveal the spatial distribution pattern of flood susceptibility across the basin.

To quantify the relationship between these factors and flood occurrences, the researchers utilised the Frequency Ratio (FR) model. This statistical model is widely recognised for its effectiveness in flood susceptibility mapping as it allows for the integration of multiple parameters to assess the vulnerability of areas to flooding events.

The outcome of their analysis was a detailed flood susceptibility map highlighting areas within the Mahananda River Basin categorized based on their susceptibility to flooding. This map serves as a valuable tool for various stakeholders, including government agencies, urban planners, and disaster management authorities. It provides crucial insights into areas at higher risk of flooding, enabling informed decision-making regarding land-use planning, infrastructure development, and disaster risk reduction measures.

Moreover, the researchers discussed the practical applications and implications of their findings. The flood susceptibility map can serve as a foundational resource for developing effective flood management plans, implementing mitigation measures, and enhancing emergency response strategies. Additionally, it contributes to advancing scientific understanding and research efforts focused on improving flood resilience and disaster preparedness in the region.

2.3.74) In their recent paper titled "Characterizing floods and reviewing flood management strategies for better community resilience in a tropical river basin, India" (2022), Researchers Susmita Ghosh, Md. Mofizul Hoque, Aznarul Islam, Suman Deb Barman, Sadik Mahammad, Abdur Rahman, and Nishith Kumar Maji delved into the historical context of floods within the Bhagirathi-Hugli River basin in India.

The researchers conducted a comprehensive analysis of flood occurrences in the region, categorizing floods into two main types: monsoon floods, which typically occur from June to September during the monsoon season, and non-monsoon floods, observed between January and May. They highlighted that non-monsoon floods can be attributed to factors such as the Farraka Barrage, while monsoon floods are primarily driven by substantial rainfall volumes.

A significant aspect of their study involved examining the characteristics of the river channel within the basin. This included measuring parameters like sinuosity and conducting river network analyses to understand the morphology and behaviour of the river system. Such analyses are crucial for assessing flood dynamics and identifying areas susceptible to inundation.

One noteworthy aspect discussed in the paper is the concept of "living with flood," which represents an approach to flood management that acknowledges the inevitability of floods in the region and focuses on strategies to coexist with them rather than attempting to entirely prevent or control them. This approach typically involves adopting measures such as flood-resistant infrastructure, early warning systems, community preparedness, and sustainable land-use practices that mitigate flood impacts while promoting community resilience.

The researchers' work contributes valuable insights into the flood dynamics of the Bhagirathi-Hugli river basin and provides a basis for reviewing and enhancing flood management strategies aimed at fostering better community resilience in the face of recurrent flood events.

2.4 Flood management

For flood management related literature review traditional flood management methods and newly adopted methods are included in this research. Few case studies related management methods are also selected in this area.

2.4.1) In their paper "Flood risk and shelter suitability mapping using geospatial technique for sustainable urban flood management: a case study in Palembang city, South Sumatera, Indonesia" (2023), researchers Muhammad Rendana, Wan Mohd Razi Idris, Sahibin Abdul Rahim, Hazem Ghassan Abdo, Hussein Almohamad, and Ahmed Abdullah Al Dughairi shed light on the escalating frequency of floods in recent times, particularly in regions with high population density like Palembang city. The increased vulnerability due to urbanisation and population concentration necessitates effective flood management strategies. The researchers employed an integrated approach combining the Analytical Hierarchy Process (AHP) with Geographic Information System (GIS) technology to assess flood risk and identify suitable locations for flood shelters. They considered multiple factors such as elevation, population density, slope, land cover, proximity to rivers, drainage density, and accessibility to roads in their analysis of flood-prone areas. By integrating these factors into a GIS platform and applying the AHP methodology, the researchers generated a flood risk map that classified areas into high, moderate, and low-risk zones. This classification is instrumental in prioritising areas for flood management interventions and resource allocation. One significant outcome of their analysis is the identification of areas highly suitable for flood shelters based on risk assessment. According to their findings, approximately 4.1% of the area falls into the highly suitable category for establishing flood shelters, while 19.4% of the area is moderately suitable. This information is crucial for urban planners and decision-makers to devise effective strategies for sustainable flood management and enhance the city's resilience to flooding events.

2.4.2) In their paper titled "Emergency Shelter Geospatial Location Optimization for Flood Disaster Condition: A Review" (2022), Researchers Reza Asriandi Ekaputra, Changkye Lee, Seong-Hoon Kee, and Jurng-Jae Yee critically evaluate traditional models used in emergency shelter development and propose a new approach. They highlight four key factors essential for effective optimization: optimization objective, decision variables, victim identification, and real distance. The researchers emphasise the importance of defining clear objectives, considering variables like population density and accessibility, identifying potential victims, and calculating real-time travel distances. To enhance accuracy, they use the K-means clustering algorithm to mitigate biases in location decisions. This approach aims to develop a robust geospatial optimisation model for emergency shelters during flood disasters, improving response strategies and disaster resilience.

2.4.3) The research conducted by Tsolmongerel Papilloud and Margreth Keiler (2021) focuses on assessing the vulnerability patterns of road networks to extreme floods using accessibility measures. Vulnerability in this context is evaluated through various factors such as the affected number of population, road length impacted by floods, average travel time during flood events, flood height, and other related parameters.

By combining these diverse factors, the researchers create a comprehensive spatial zonation mapping that illustrates the vulnerability of road networks in terms of accessibility. This mapping helps to identify areas where the road infrastructure is most susceptible to damage or disruption during extreme flood events.

The study also delves into both direct and indirect effects of floods on road networks. Direct effects may include physical damage to roads, bridges, and other infrastructure components, while indirect effects can encompass increased travel times, detours, or complete disruptions in transportation routes due to flooded areas.

Overall, the research contributes to a better understanding of how extreme floods can impact road networks, allowing for informed decision-making in disaster preparedness, infrastructure planning, and risk mitigation strategies.

2.4.4) Kabir Uddin and Mir A. Matin (2021) conducted a study on potential flood hazard zonation and flood shelter suitability mapping for disaster risk mitigation in Bangladesh using geospatial technology. They utilised Sentinel 1 Synthetic Aperture Radar (SAR) images to analyse flood hazard areas.

The researchers incorporated various factors such as flood area, elevation data, land use and land cover (LULC) patterns, landform characteristics, population density, distance to roads, and distance to settlements. These factors were used to create different layers that contributed to the flood hazard mapping process.

By integrating and analysing these layers, the researchers generated flood hazard maps that delineated areas prone to flooding. The flood potentiality was categorised into three distinct classes based on the severity and likelihood of flooding in different regions.

This study's findings provide valuable insights for disaster risk mitigation efforts in Bangladesh, aiding in the identification of high-risk areas and the suitability of locations for flood shelters. Geospatial technology plays a crucial role in such analyses, enabling a comprehensive assessment of flood hazards and supporting informed decision-making processes related to disaster management and resilience building.

2.4.5) In the paper "Crop Insurance Policies in India: An Empirical Analysis of Pradhan Mantri Fasal Bima Yojana" researchers Sandeep Kaur, Hem Raj, Harpreet Singh, and Vijay Kumar Chattu (2021) delved into the realm of crop insurance policies in India, focusing on an empirical analysis of the Pradhan Mantri Fasal Bima Yojana (PMFBY). Their study highlighted India's standing in the Global Hunger Index (2020), where the country ranked 94th out of 107 nations. This ranking sheds light on the challenges faced by farmers due to the lack of security and the high risks prevalent in the agricultural sector.

In the context of India, the researchers traced the evolution of crop insurance policies, noting that a pilot insurance program was introduced in 1979 by V. M. Dandekar, earning him the title of the father of crop insurance in India. Subsequently, in 1985, the Comprehensive Crop Insurance Scheme replaced the earlier model with modified features. The timeline progressed with the introduction of the Weather Based Crop Insurance Scheme in 2007-08, which incorporated weather indices into the insurance framework.

A significant development occurred in 2016 with the launch of the Pradhan Mantri Fasal Bima Yojana (PMFBY), which introduced new features and replaced all existing crop insurance schemes. The PMFBY aimed at providing comprehensive coverage and was implemented nationwide with an allocation of 55,000 crore rupees. Both public and private insurance companies participate in this scheme under the oversight of the central government.

The researchers highlighted the incorporation of modern technologies such as Remote Sensing, GPS, and GIS in the implementation of PMFBY. These technologies play a crucial role in securing scheme benefits and improving the efficiency and accuracy of crop insurance processes in India.

2.4.6) Researchers Mohit Prakash Mohanty, Sahil Mudgil, Subhankar Karmakar in the paper of “Flood management in India: A focussed review on the current status and future challenges” (2020) briefly discussed on the damage history of India and its neighbouring country. Total economic loss, lives losses are shown in graphical form. The whole India is classified into 5 flood prone zone and discussed each part flood concern and management process. The flood zones are-

i) Bhamaputra River region

ii) North-West region

iii) Ganga River region

iv) Central India and Decan region

v) Urban centers

In these work national and state level organisations work functions are discussed. In national scale- Central Water Commission, Ganga Flood Control Commission, Brahamaputra Board, National Disaster Management Authority etc. are work together. But a wide miss communication or gap is found out between national and state governance system in case of the flood management. Few important suggestions also highlighted-

i) Accepting the residual risk

ii) Improvement of governance

iii) Creation of central data base

iv) Capacity building

v) Adaptability capacity

2.4.7) Researchers Sayoni Mondal & Priyank Pravin Patel in the paper of “Implementing Vetiver grass-based river bank protection programmes in rural West Bengal, India” (2020) have shown the scenario of river bank in Indian context and with special reference to the West Bengal. Specialy due to monsoonal fluvial nature the river bank erosion is very common in this area. But structural measure like embankment construction is costly and harmful for natural fluvial conditions. So a non structural measure like vetiver grass plantation for protecting the river bank is studied in different parts of the West Bengal. By using this grass it is prove that it resist the erosion naturally and cost is also very less in comparison to structural based construction. In this study a cost benefit comparison is shown by setting an example. Few case studies are done in this study, one of them located in Ketia River at Kuthi Ghat village in Ghatal, West Bengal. More importantly vetiver grass gives an opportunity of community income which is helpful for perception development.

2.4.8) Chris Zevenbergen, Berry Gersonius and Mohan Radhakrishan in the article of “Flood resilience” (2019) emphasised on the resilience building. Mainly three types of resilience included i) engineering resilience ii) ecological resilience iii) socio-ecological resilience or adaptive resilience

Engineering resilience: This is being applied in case of architecture, planning and innovative technology to mitigate the flood problems.

Ecological resilience: Ecological resilience is the ability to return back the system in stable conditions. In case of the flood event due to storm surge and heavy rainfall the recovery of the system depends on ecological resilience.

Socio-ecological resilience: The concept of socio-ecological resilience has been defined as-‘the capacity of linked socio-ecological system to absorb the recent disturbance.

In this study briefly discussed about the limitations of quantifying the indicators and it highly variable and dynamic in nature. Case study chosen in Island of Dordrecht in Netherlands while is one of the best example of engineering design protected by ring like dike. Again in another case study-Can Tho in Vietnam region is the example of the adaptability- ‘living with flood’.

2.4.9) The paper "Living with floods through geospatial approach: a case study of Arambag C.D. Block of Hugli District, West Bengal, India" discusses the significance of Arambag block's location in relation to flood vulnerability in the Damodar and Dwarakesher interfluves region. The study employs Analytic Hierarchy Process (AHP) methodology to evaluate factors like elevation, inundation extent, road infrastructure, and settlement patterns. Using GIS tools, the researchers analyze these factors to identify optimal locations for flood shelters, aiding in disaster management and response strategies for the region.

2.4.10) In their article "Resilience in Flood Risk Management - A New Communication Tool" published in 2016, researchers Jelena Batica and Philippe Gourbesville focus on assessing the resilience status of eight study areas across Europe and Asia. Their approach involves using a macro scaling index to analyse the Flood Resilience Index. The researchers select these specific study areas to represent a diverse range of geographical and socio-economic contexts, allowing for a comprehensive analysis of resilience in flood risk management. By examining regions from both Europe and Asia, they aim to capture different approaches to flood resilience and draw meaningful comparisons. To evaluate the resilience status, the researchers develop a Flood Resilience Index, which serves as a communication tool for conveying the level of resilience in each study area. This index likely comprises a set of indicators or variables that are relevant to flood risk management and resilience, such as infrastructure robustness, community preparedness, early warning systems, emergency response capabilities, and recovery mechanisms. A scale is established to quantify the Flood Resilience Index, allowing for a standardized measurement across all study areas. This scale could range from low to high resilience, providing a clear representation of each region's ability to withstand and recover from flood events.

By employing this index-based approach and utilising a standardised scale, the researchers aim to facilitate meaningful comparisons and discussions regarding flood resilience among the selected study areas. This methodology likely enables policymakers, researchers, and stakeholders to identify strengths, weaknesses, and opportunities for improving flood risk management strategies and enhancing resilience in vulnerable regions.

Table 2.1 Flood resilience based index

Scale	Status
0-2 very low	No activity for flood risk management
2-3 low	Capacity building of human resources remains limited
3-4 medium	Implementation and improvement solutions is higher
4-5 high	A culture of safety

(Source- Batica and Gourbesville, 2016)

More importantly the limitations of the index based resilience study also discussed. Some assumptions, assignment weightage etc problems are identified.

2.411) The article "Environmental impact of Embankment beaching: a case study on lower Ajay River West Bengal in India," authored by D. Ghosh, M. Mondal, and M. Banerjee in 2015, analysis the consequences of embankment breaches and the sand splay effect resulting from embankment failures, particularly focusing on the lower Ajay River in West Bengal, India.

The researchers highlight the significant impact of embankment breaches on the surrounding environment, particularly on the Ajay River basin. They base their analysis on historical flood data, with a specific emphasis on the years 1978 and 2000, which were identified as the most flood-vulnerable years. These years witnessed high levels of flood activity and substantial sand splay effects.

The study reveals that the sand splay effect was particularly pronounced during the floods of 1978 and 2000. The maximum affected area due to sand splay reached up to 2.57 km from the source area in 2000, while the minimum impact was recorded at 0.38 km during the 1959 flood. This data underscores the significant variability in the extent of sand splay effects across different flood events.

Furthermore, the researchers observe a gradual decline in soil fertility attributed to the impact of sand splay. This highlights the broader environmental consequences of embankment breaches and flood events, impacting agricultural productivity and ecosystem health in the region.

The study also identifies the right bank of the Ajay River basin, spanning from Illambazar to Bhedia, as the most flood-vulnerable and heavily affected by sand splay. The analysis indicates that the highest proportions of the basin area experienced severe flooding during the 1978 flood (58.64% of the basin area) and the 2000 flood (52.82% of the basin area), illustrating the recurring challenges posed by flood events in this region.

Overall, the research underscores the complex interplay between embankment infrastructure, flood dynamics, sand splay effects, and environmental impacts. By examining historical flood patterns and their consequences, the study provides valuable insights for understanding and addressing flood risks and environmental sustainability in the lower Ajay River basin of West Bengal, India.

2.4.12) In their paper "Occupational Resilience to Floods across the Urban-Rural Domain in Greater Ahmedabad, India" published in 2015, researchers Nitin Srivastava and Rajib Shaw delve into the aftermath of floods, with a specific focus on economic vulnerability in the Greater Ahmedabad region of India.

The researchers highlight the significant impact of floods on economic activities, particularly on daily wage laborers who often face substantial challenges during flood events. They emphasise the loss of work and income experienced by these vulnerable groups due to flood-related disruptions.

A key aspect of the study is the exploration of community-based recovery strategies. This involves understanding how local communities, both in urban and rural areas, cope with and recover from the economic impacts of floods. The researchers likely investigate resilience-building initiatives within communities, such as the establishment of support networks, resource-sharing mechanisms, and alternative livelihood strategies.

Additionally, the paper underscores the importance of rural-urban communication and social networking in fostering resilience. Effective communication channels between rural and urban areas play a crucial role in coordinating response efforts, sharing information about flood risks and mitigation measures, and facilitating resource mobilisation during and after flood events.

The researchers adopt a quantitative approach, relying on statistical techniques to analyse the data and draw conclusions about the economic consequences of floods and the resilience strategies employed by communities. This likely involves gathering data on factors such as income loss, employment patterns, recovery timelines, community cohesion, and the effectiveness of resilience-building interventions.

By using quantitative data and statistical analysis, the study aims to provide empirical insights into the economic resilience of communities across the urban-rural spectrum in Greater Ahmedabad. The findings can inform policy recommendations, disaster risk management strategies, and community-based interventions aimed at enhancing occupational resilience and reducing economic vulnerability to floods in the region.

2.4.13) In their paper "Improved Management Options for Submergence-Tolerant (Sub1) Rice Genotype in Flood-Prone Rainfed Lowlands of West Bengal" published in 2014, researchers Malay K. Bhowmick, Madhab C. Dhara, Sudhanshu Singh, Manzoor H. Dar, and Uma S. Singh address the challenges posed by frequent floods in India and Southeast Asia, particularly focusing on flood-prone rainfed lowlands in West Bengal.

The researchers highlight the significant economic losses incurred due to the submergence of paddy fields during the monsoon season. To address this problem, they introduce the Sub1 gene into various rice varieties, creating submergence-tolerant rice genotypes. Notably, varieties such as Swarna Sub 1 and Sambha Mahsuri Sub 1 have shown promise for commercialisation due to their ability to survive under submergence conditions and exhibit improved yields in the post-submergence period.

The study involves conducting research programs at two sites in West Bengal: one at the Rice Research Institute in Chinsurah, Hugli, and another near Chinsurah-Baidyabati Chawak. These research programs were carried out in 2011, focusing on evaluating the performance of Sub1 rice genotypes under the humid tropical climate and clay loamy soil prevalent in the region.

The results of the research demonstrate the success of the project, with the Sub1 rice genotypes showing resilience to submergence conditions and maintaining better yield rates compared to non-submergence-tolerant varieties. This indicates the potential of Sub1 rice genotypes to mitigate economic losses caused by floods in flood-prone rainfed lowlands.

Overall, the research contributes valuable insights into improved management options for flood-prone areas, highlighting the importance of developing and promoting submergence-tolerant rice genotypes to enhance agricultural resilience and food security in regions vulnerable to flooding.

2.4.14) In the study titled "Development of village-wise flood risk index map using multi-temporal satellite data: a study of Nagaon district, Assam, India" conducted by S. V. Shiva Prasad Sharma, G. Srinivasa Rao, and V. Bhanumurthy in 2012, the researchers focused on assessing flood vulnerability and risk in the Nagaon district of Assam, India.

To evaluate flood vulnerability and risk, the researchers selected several factors such as flooded area, frequency of inundation over specific periods, damages to major roads, and land use and land cover (LULC) changes. Each factor was assigned a score value based on its significance in contributing to flood risk.

The study utilised multi-temporal satellite data, specifically LISS III imagery, to analyse the present status of infrastructure and land use and land cover in the study area. Using Geographic Information System (GIS) technology, the researchers conducted spatial analysis for each individual factor, examining the spatial patterns and distributions within the Nagaon district.

By combining the scores assigned to each factor, the researchers derived a final flood risk index for each village in the Nagaon district. This index map provided a comprehensive overview of the flood risk scenario, highlighting areas with higher vulnerability and potential impacts.

The use of satellite imagery and GIS analysis allowed for a detailed and spatially explicit assessment of flood risk, enabling stakeholders and decision-makers to identify priority areas for mitigation measures, infrastructure improvements, and disaster preparedness initiatives.

Overall, the study contributed valuable insights into understanding and mapping flood risk at the village level, leveraging remote sensing and GIS techniques to enhance flood risk management strategies in the Nagaon district of Assam, India.

2.4.15) In the paper "Need for Integrated River Basin Management in the Context of West Bengal Floodplains" by researchers Sujit Choudhury, Girija Sankar Chattopadhyay, and Deepankar Chakrabarti in 2010, the focus is on understanding and addressing floodplain management in the Bengal delta region, particularly in West Bengal.

The researchers begin by defining floodplains and examining the characteristics of floodplains within the Bengal delta. They highlight the agricultural suitability of floodplains, emphasising the fertile land and gradual increase in settlements within these areas.

A significant aspect of the study is the analysis of the integrated river valley project known as the Damodar Valley Corporation (DVC). This project, aimed at harnessing water resources for irrigation, power generation, and flood control, is statistically evaluated based on past records.

The researchers delve into the success stories and drawbacks of the DVC project, particularly in dealing with peak flood and low flood situations. They find that the DVC project has been successful in mitigating low peak floods but faces challenges during high peak flow events.

This analysis sheds light on the limitations of existing flood management strategies, especially in handling extreme flood scenarios. The researchers advocate for integrated river basin management approaches that consider the complexities of floodplain dynamics, water resource utilisation, and sustainable development.

By highlighting the strengths and weaknesses of the DVC project and emphasising the need for integrated river basin management, the study contributes to discussions on improving floodplain management practices in West Bengal and similar deltaic regions. It underscores the importance of balancing development initiatives with environmental resilience and disaster risk reduction measures in flood-prone areas.

2.4.16) In the "National Disaster Management Guidelines" published by the National Disaster Management Authority (NDMA), Government of India, in 2008, several key aspects of disaster management, particularly focusing on floods, are highlighted.

Firstly, the guidelines stress the importance of providing essential services during floods, including access to clean drinking water, medical facilities, and sanitation facilities such as latrines. These services are crucial for addressing the immediate needs of affected populations and reducing health risks during flood events.

Additionally, the government places emphasis on flood insurance for both property and crops, suggesting that insurance coverage should be based on the probability of flood occurrences. This approach aims to provide financial protection to individuals and communities against flood-related losses and damages.

Furthermore, the guidelines recommend improving the quality of channels and waterways to enhance flood management and reduce the impact of flooding. This includes measures such as dredging, embankment maintenance, and river training to ensure efficient water flow and minimise flood risks.

Moreover, the Ministry of Water Resources (MOWR) is highlighted as urgently advocating for the identification of floodplain areas. Identifying these areas is essential for implementing targeted flood management strategies, including land use planning, early warning systems, and infrastructure development to reduce vulnerabilities and enhance resilience in flood-prone regions.

Overall, the guidelines underscore the comprehensive approach required for effective flood disaster management, encompassing infrastructure improvements, risk assessment, emergency response planning, and financial protection measures. The focus on collaboration between government agencies, stakeholders, and communities is crucial for implementing these guidelines and mitigating the impacts of floods in India.Significant suggestions -

a) Collaboration of CWC and IMD for the prediction of rainfall and river gauge.

b) Data transmission through mobile.

c) Computer based comprehensive model development on hydrology.

d) Basin wise flood mitigation model development.

e) Damage assessment quantification on priority basis.

f) Advisory form for flood relief and route development.

g) Value addition- prediction by local language which is easy to understandable by the local people.

2.4.17) In their 2006 paper titled "Vetiver Grass for River Bank Protection," researchers D.J. Jaspers-Focks and A. Algera highlight the various advantages of using vetiver grass, particularly in the context of river bank protection and erosion control.

The study emphasises that vetiver grass serves as an effective anti-erosion measure, making it valuable for protecting river banks and dikes. One of the key advantages noted is the economic viability and environmental sustainability of using vetiver grass for such purposes.

Researchers delve into the impact of vetiver grass on the phreatic level, which refers to the groundwater level, under different conditions and seasons. They observe how the presence of vetiver grass influences the upgradation of the phreatic level, which is crucial for maintaining groundwater resources and ecosystem health.

The study specifically focuses on Southeast Asia, where vetiver grass plantation is seen as a means to improve groundwater levels, provide economically sustainable bank protection, and offer various other benefits. These benefits may include reducing the load induced by vessels along the river bank region, contributing to overall environmental resilience and economic stability.

Overall, the research highlights vetiver grass as a multi-functional and beneficial plant species for river bank protection, erosion control, and groundwater management. Its use is seen as a practical and sustainable solution, especially in regions like Southeast Asia, where environmental conservation and economic development are key priorities.

2.5 Summary of literature review

Numerous authors have examined the physical characteristics of the Ajay River basin and correlated them with the current landscape. Notably, many pioneers have concentrated on the Kunur River basin, a significant tributary of the Ajay basin (Bandhapadhoy, 2014; Roy, 2013). Additionally, research works have delineated the tectonic characteristics of the Ajay-Damodar interfluves region (Roy and Sahu, 2015), while others have analysed the tectonic and geomorphological behaviour in the Ajay basin area (Jha et al., 2011). Of particular relevance, several studies have investigated the hydro-geomorphological aspects and channel characteristics of the Bhagirathi-Hugli River (Guchhait et al., 2016). Moreover, researchers have focused on the geological attributes of the Chotanagpur plateau region and discussed its evolutionary processes (Ghosh and Guchhait, 2014; Singh, 1995). Many papers emphasises the use of geo-spatial techniques for river basin analysis (Jha et al., 2011), soil erosion studies (Roy, 2013), and morphometric character analysis (Prakash, 2016; Rai et al., 2014). The impact of human activities on channel characteristics and fluvial changes has been magnified in several works, particularly in the context of sand mining in the Ajay-Damodar River (Ghosh et al., 2016; Mandal, 2016). Notably, various Eastern Coalfields Limited (ECL) reports also depict changes in fluvial patterns in the Ajay-Damodar River.

Numerous researchers have developed diverse methodologies for spatial flood area prediction, with notable approaches including AHP-based weightage calculations and the use of geospatial platforms (Rimba et al., 2017; Rahamati, 2015). For spatial flood analysis, authors have employed software like HEC-HMS and HEC-RAS (Aryal et al., 2020; Martin et al., 2012), and they have validated their models to assess their suitability (Pradhan, 2009). From the results of spatial flood prediction, vulnerability and risk indices have been calculated, incorporating various socio-economic parameters and represented through spatial mapping techniques (Mahato et al., 2021; Nazeer and Bork, 2019). Flood impacts and historical overviews in the Ajay River basin have also been characterised in many studies. These analyses have emphasised the impact of sand splay over extensive regions (Roy, 2012; Mukhopadhyay, 2010).

In flood management, analyses of both structural and non-structural measures have been conducted. This includes the development of flood shelters, identification of evacuation routes, flood forecasting, etc. (Papilloud and Keiler, 2021; Mohanty et al., 2020). The 2008 National Disaster Management Guidelines have stressed resilience building, watershed-based management, and collaborative approaches between departments like CWC-IMD. For long-term sustainable flood management, researchers have worked on spatial flood zonation and the implementation of regulations in flood risk zones. They have also evaluated different management policies, regulations, and challenges within the Indian context. Noteworthy contributions include studies on crop insurance policy implementation (Kaur et al., 2021), submergence-tolerant seed development (Bhowmick et al., 2014), and the necessity of integrated river basin management (Choudhury et al., 2010). Some works have also analyzed the impact of embankment breaching in the lower Ajay River basin (Ghosh et al., 2015). Interestingly, Indian researchers have shown concern about strengthening embankments through ecological measures like vetiver grass cultivation and geo-textile engineering (Mondal and Patel, 2020).

2.6 Gap of the research

After reviewing the existing literature on various aspects of floods, few significant gaps are identified between the existing research and current challenges. This study aims to bridge this gap comprehensively. Studies about flood potential in the Ajay River mostly emphasise hydrological aspects, a noticeable gap in understanding the interconnection between floods and geomorphology. In the context of the Ajay River basin, which lies between the Mayurakshi and Damodar Rivers, there is a lack of research regarding the morphometric characteristics' impact on fluvial behaviour. Additionally, during flood events, the influence of adjacent rivers like the Mayurakshi and Bhagirathi-Hugli, and the effect of backflow from the latter into the Ajay River channel, remains unexplored. Even areas on the opposite side of the Bhagirathi-Hugli River experience flooding during these events, yet this aspect has received minimal attention.

Existing studies primarily rely on historical data to depict flood scenarios, with little emphasis on understanding the root causes of floods in the Ajay River. The role of tributaries in the lower catchment area of the Ajay River, variations in channel characteristics, and human encroachment on these channels have been largely overlooked. Furthermore, the Ajay River flows through diverse topographical conditions, but there's a notable absence of research on how these topographic changes affect spatial flood behaviour.

Most studies also focus on a particular model for spatial flood hazard prediction, often using past flood records as the basis. Few consider the impact of pre-monsoon and post-monsoon rainfall on flood dynamics, which is crucial for a comprehensive understanding. Additionally, the lack of a systematic approach to measure daily discharge in rivers like the Ajay impedes accurate spatial flood distribution predictions.

In terms of vulnerability assessment, existing literature predominantly assesses physical damages, with limited attention to social, economic, and environmental impacts. Micro-level studies on resilience capacity and its role in reducing flood risk are rare, and there's a notable gap in understanding how resilience can be cost-effective in flood management.

This study aims to fill these gaps by delving into understanding the fluvio-geomorphological aspects, exploring the causes of floods in the Ajay River with reference to sub-watershed hydrological potentiality, improving spatial flood hazard prediction methodologies, and conducting a comprehensive vulnerability assessment with a focus on resilience and cost-effectiveness in flood management strategies.

Chapter-3

Objective and Scope of Work

By the detaild study of the past literature and reviewing the present problems in the study area objectives are selected.

3.1 Objective

The objective of the present study are-

- To analyse the evolution of the hydro-geomorphological characteristics of the river basin.
- Assessment of potential flood vulnerability.
- Development of sustainable management solutions to tackle the same.

3.2 Scope of the study

The objective of the study is to be fulfilled by the scopes of the work as mentioned. Scope of the work may be divided into the following divisions.

- Physical and socio-economic characterisation of the basin area.
- Basin morphometric analysis.
- Analysis of the Spatio-temporal change of the hydro-geo morphological characteristics of the lower Ajay basin area.
- Analysis of the Land use and Land cover (LULC) change in the lower part of the basin area.
- Analysis of the past flood records by applying statistical methods.
- Flood potential area prediction by using different models.
- Analysis of the present vulnerability conditions.
- Comprehensive index development by including the physical, social and economic condition of the basin area.
- Analysis of the spatial risk pattern and vulnerability in relation to the existing flood resilience.
- Development of sustainable management solutions to take care of the vulnerability issues.

Chapter - 4

Methodology and Data Used

4.1 Methodology

Methodology refers to the systematic, theoretical analysis of the methods applied to a field of study. It encompasses the principles, tools, and procedures used to collect and analyse data, ensuring that the research is conducted in a structured, reliable, and reproducible manner.

4.1.1 Study of Physical characteristics of the Ajay River basin

The study of physical characteristics within a river basin is paramount for understanding flood dynamics effectively. In this research, physical data related to various parameters are sourced from secondary outlets and subsequently analysed within a Geographic Information System (GIS) platform to meet the objectives of the study. This data, crucial for flood analysis, forms the backbone of flood management strategies.

To delve into the physical attributes of the basin area, physical parameter maps are obtained from diverse sources and geo-referenced within the GIS environment. These maps, overlaid with the basin boundary, allow for the extraction of essential physical parameter data specific to the basin's region. For a comprehensive analysis of the basin's physical components, detailed physical maps are digitised within GIS platforms, ensuring accurate representation and characterisation.

Topographical parameters are meticulously studied using processed SRTM DEM data (30 m) to generate a contour map of the basin region, cross-validated with a topographical sheet (R.F 1:50000). Additionally, geological maps, fault lines, and soil maps are analysed to assess the basin's physical conditions comprehensively. Isopleth methods are employed to visualise broad topographical changes, depicting the long profile of the Ajay basin and its environs. Climatic parameters, including rainfall and temperature data sourced from IMD, are crucial for understanding the basin's hydrological dynamics. Climatic variation maps are generated within GIS software, utilising point-based rainfall data and interpolation methods to create isopleths that showcase spatial rainfall distribution across the basin. A similar methodology is adopted to represent groundwater scenarios, exploring their interaction with rainfall to control runoff. This spatial analysis is pivotal for understanding how changes in gradient and geological parameters influence surface geomorphology and channel characteristics, thus contributing significantly to flood risk assessment and management strategies.

4.1.2 Basin morphometric analysis

The study utilises SRTM DEM (Shuttle Radar Topography Mission Digital Elevation Model) data due to its reliability and reduced susceptibility to weather conditions, as highlighted by Kabite and Gessesse in 2018. This data, obtained from version 4.1 of the SRTM DEM database (accessible at http://srtm.csi.cgiar.org) with a resolution of 90 metre, is processed within the Arc GIS 10.0 platform for analysis.

The initial steps involved filtering the SRTM DEM data in Arc GIS to minimise errors. Subsequently, basin boundary delineation, channel network, flow direction analysis, and flow accumulation computations were carried out using the Arc Hydro tools within ArcGIS. The basin boundary extraction employed the snap pour point method, while channel extraction utilised polyline tools. Both layers were then re-projected to the UTM projection system with WGS 84 datum for consistency.

Morphometric analysis of the drainage basin was conducted using 5 sq. km grids along the basin boundary, with each grid assigned a FID (Feature Identifier) for calculations of relative relief, average slope, dissection index, drainage density, and drainage frequency. These calculated values were plotted against the FID points, and isopleths were generated using ArcGIS to visually represent the results.

Linear properties of the basin, derived from the DEM-extracted channel, were analysed using Strahler's method (1952) for stream ordering. Various parameters of the channels were graphically represented. Areal properties, such as the shape and size of the basin, were measured within ArcGIS. Relief properties, indicating the topographic characteristics, were assessed by analysing the contour pattern extracted from the DEM. A mean slope curve was plotted based on the extracted contour pattern, and the basin was divided into three segments- upper, middle and lower based on slope changes.

To further understand the role of landscape on morphometry, physical landscape maps were overlaid with the resulting morphometric data in GIS platform. This overlay provided insights into the basin's function, as depicted in Figure 4.1 of the study. Overall, the study leverages GIS technology to comprehensively analyse the physical characteristics and morphometry of the Ajay basin.

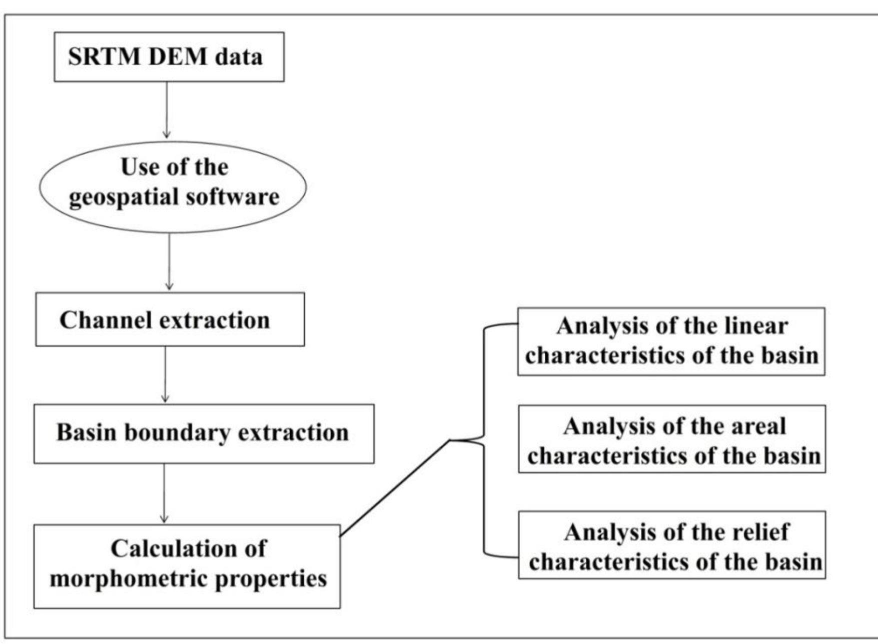


Figure 4.1 Flow diagram showing the method of morphometric analysis of the basin

(Source - Prepared by researcher)

4.1.3 Analysis of the channel characteristics in the study area

The study involves field studies and the use of various instruments to measure the channel characteristics of the lower segment of the river. A Total Station is employed at various points in the lower parts of the river to create a cross profile of the channel. This cross profile study reveals important features such as channel width, wetted perimeter, and the effect of sand quarrying. Measuring the cross-profile at various points also reveals the channel's intake capacity on a spatial scale.

In analysing the channel character, the flow path of the river at different points is measured. Using these flow path characteristics, the Sinuosity Index is calculated using the following equation – $SI = \frac{DO}{DE}$ (Eq. 4.1)

SI= Sinuosity Index, DO= observed distance of river channel flow, DE= Expected distance of channel flow (Leopold and Wolman, 1957)

To measure the sinuosity of the channel, the present channel length is measured at various stations, and the radius of curvature is also utilised to observe changes in the channel's characteristics. The study further explores the impact of human intervention, particularly in the lower part of the river. Analysing human intervention is crucial for understanding factors contributing to flood vulnerability (Gambo et al., 2024). Data from ECL reports on sand quarrying are collected and presented on a GIS platform, showing the spatial area of sand quarrying along the river. This indicates its influence on the channel characteristics. The sand quarrying areas also directly affect the morphology of the riverbed.

To analyse the effect of embankments on channel characteristics, overlay the channel profile data from 2017 and 2022 in the same frame to observe changes over time. Focus on regions with and without embankments to determine their impact on the channel profile. Thalweg shifting and river sinuosity near the embankment region and in areas without embankments are analysed. By using the topographical sheets and satellite image from different period's the embankment length is measured and graphically presented over time. The channel characteristics and embankment locations are pivotal for flood vulnerability analysis. However, significant shifts in the thalweg line are observed in the satellite image in different year, attributed to factors like bed sand quarrying.

Bhedia and Illambazar regions were chosen due to its significance of the major sand quarrying stations. Cross-profile data was collected at different time intervals to analyse thalweg shifting. These cross-profiles were overlaid along the same river line, and it graphically presented. The presence of paleo-paths is identified from the topographical sheets and it reveals the historical background of the river. Various types of bars in different parts of the river are identified and their areas measured, aiding in understanding river dynamics.

For the analysis of topographic variation in a river basin, a topographical sheet is used, which is prepared based on the GTS (Great Trigonometrical Survey) benchmark. The elevations extracted from the topographical sheet are referenced to this benchmark, ensuring consistency and accuracy in elevation measurements.

In contrast, the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) provides high-resolution global elevation data. While SRTM DEM is useful for broad-scale terrain analysis and hydrological modeling, it may have limitations in terms of local accuracy, especially in areas with dense vegetation, steep slopes, or water bodies where elevation errors can occur.

For detailed river cross-profile analysis, the leveling survey method is applied to obtain precise elevation measurements across the river section. Unlike the topographical sheet or SRTM DEM, which provide generalized elevation data, the leveling survey captures localised variations in riverbed and bank elevations with high accuracy. In such cases, arbitrary benchmarks (ABMs) are used instead of GTS benchmarks due to practical constraints. GTS benchmarks are often spaced far apart and may not be readily available within the study area. Therefore, ABMs are established based on easily identifiable and stable reference points in the field, ensuring that the survey remains consistent and reliable within the scope of the study.

Moreover, the study evaluates tectonic influences on channel patterns using Transverse Topographic and Asymmetry factors. These measurements are applied across the basin's upper, middle, and lower parts, highlighting tectonic impacts on the regional channel pattern. These assessments are crucial for understanding the complex interplay of natural and human-induced changes in the river basin, providing valuable insights for flood management and environmental planning.

4.1.4 Study of Socio-economic character

Socio-economic data refers to information related to social and economic factors within a specific area or region. This data is often collected and presented based on administrative divisions such as blocks or districts. The data can include aspects such as population demographics, income levels, education, healthcare facilities, infrastructure development, and other relevant socio-economic indicators. Since the socio-economic data is available at the administrative scale, the socio-economic analysis considers data at the block level, and the work is presented through block-level mapping. The use of the open source Census Report from 2011 allows for a comprehensive understanding of these socio-economic characteristics. By collecting and geo-referencing block maps within the Ajay basin region, researchers can analyse and visualise the socio-economic data in relation to the geographic area of interest. Cartograms, which are graphical representations of data using map-like visuals, can be employed to further interpret the socio-economic trends and patterns within the region.

Additionally, data on infrastructural facilities and development parameters are gathered from sources like the Institutional Strengthening of Gram Panchayats (ISGP), Program II, which is managed by the Panchayat and Rural Development Department of the Government of West Bengal. This data provides insights into the state of infrastructure and development initiatives within the Ajay basin area, contributing to a comprehensive socioeconomic analysis.

4.1.5 Flood potential area prediction by multi-criterion factor based methods

In this study, the spatial extent of flooding in the lower Ajay River basin is analysed using both qualitative and quantitative methods. Due to the limited availability of gauge stations in the Indian context, hydrological impacts cannot be accurately gauged solely through traditional quantitative methods. Therefore, qualitative approaches are adopted alongside available hydrological data to understand the spatial scale of flooding.

Qualitative methods involve weightage-based factor analysis, where past experiences and expert knowledge guide the selection of factors influencing flood distribution. These factors can vary based on the spatial scale under consideration. Initially, this qualitative approach aids in identifying potential flood-prone areas within the basin.

However, for more accurate and reliable results, quantitative methods are also integrated. Quantitative analysis utilises available hydrological data to assess the extent and severity of flooding. This data-driven approach provides a more concrete understanding of flood dynamics based on measurable parameters.

4.1.5.1 Flood area estimation by using AHP method

The lower segment of the river frequently experiences severe flooding, making it a significant area for study. This region has been divided into three parts based on changes in the main channel's break of slope, with the lower part chosen as the focus due to its history of flood occurrences. Hydro-geomorphological factors are considered, and a ranking-based weighted approach is applied for flood prediction, prioritising factors based on their significance in flood incidents within this specific area.

The study begins by defining the study area in the lower part of the Ajay basin and selecting nine flood-affecting factors. These factors are then classified and prioritised using a GIS platform, where a priority scale from 1 to the upper value indicates the potential flood hazards.

Altitude and slope data are derived from SRTM DEM data (30 m resolution) and reclassified based on flood potential, with higher slopes and altitudes indicating lower flood potential. Soil data collected from NBSS and LUP are classified according to USDA soil drainage quality, and reclassification is performed based on soil drainage conditions.

Drainage density is calculated from SRTM DEM data using a 5 sq. km grid, and choropleth mapping is conducted based on the calculated drainage density. The channel intake capacity is measured using primary data gathered with Total Station instruments, and spatial mapping is done to classify the basin based on carrying capacity, with lower carrying capacity indicating higher flood potential.

The distance from the river is determined by creating buffer layers from the main channel in the GIS platform and reclassifying based on flood potential. The nearest zones are considered high flood potentiality zones. Discharge data are extracted using HEC-HMS software at different junction points of the channel, and spatial discharge patterns are drawn in the basin region, with high discharge indicating high flood probability zones.

Weightage values are calculated based on expert and stakeholder opinions using the Saaty (1980) model, where a scale of 1 to 9 indicates relative importance. These flood factors are then rated, weighted, and checked for consistency using the Analytic Hierarchy Process (AHP) calculator, with comparison-based matrices drawn based on expert and stakeholder opinions and consistency ratios checked for each matrix.

Table 4.1 Saaty's scale of relative importance

Definition	Assign value	Explanation
Equal Importance	1	Two activities contribute equally to the objective
Moderate importance	3	Experience and judgment slightly favour one activity over another
Strong importance	5	Experience and judgment strongly favour one activity over another
Very strong	7	An activity is favoured very strongly over another
Extreme	9	The evidence favouring one activity over another is of the

importance		highest possible
Intermediate values	2,4,6,8	The values 2, 4, 6, and 8 in the AHP scale indicate increasing degrees of preference or importance between activities, ranging from a slight preference (2) to a moderate (4), strong (6), and very strong preference (8) for one activity over another.

(Source - Saaty, 1980)

The most consistent opinion of experts and stake holders is selected for input weightage in this study. Finally the average weightage value from expert's opinion and stakeholders are used as an input of weightage. Selecting experts for AHP matrix-based flood area prediction involves ensuring they have advanced degrees in relevant fields, practical experience in flood modelling, recognised contributions through publications, and proficiency in AHP, GIS, and data analysis. Additionally, they possesses regional expertise, an interdisciplinary understanding of socio-economic and environmental factors, and maintain an objective and transparent evaluation approach. This process ensures robust and credible expert input for accurate flood predictions. 9 reclassified layers are overlayed in the Arc GIS 10.1 platform and by using the raster calculator tools based on the weightage, the spatial zones are identified. Finally, the flood potential zones are determined and classified into three zones- High, moderate, and low flood potential zones (Figure 4.2). By overlayed block boundary and Panchayet boundary the area of flood potential zone is calculated. For reasonably expected result micro scale administrative unit can be used.

$$CR = CI/RI$$ (Eq. 4.2) (Mondal et al., 2023; Rahmati et al., 2016)

Where, CR- Consistency Ratio, CI is the consistency index, and RI is the random index whose value dependson the number (n) (Table 4.2)

The CI was calculated using the following formula:

$$CI = (\lambda - n)/(n - 1)$$ (Eq. 4.3)

Where n = number of parameters (i.e. 9) and λ = average value of the consistency vector.

Table 4.2 RI values according to the Number of factors (n)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

(Source - Saaty, 1980)

4.1.5.2 Fuzzy-AHP method for flood potential area prediction

By applying the Fuzzy set theory with the classic AHP, human ambiguity or judgment may be avoided. It's strengthened the judgment mathematically and resolves the uncertainty (Table 4.3) (Hoque et al., 2019). Triangular Fuzzyfication is used because it is easy to calculate. In case of uncertainty based prediction and depending on the decision makers opinion Triangular Fuzzy number is suitable for good result (Shapiro and Koissi, 2017; Baharom et al., 2014). Triangular Fuzzy number is defined as (a, b, c) where a≤b≤c (Kannan et al., 2013; Zimmermann, 2001).

First, the most consistent AHP matrix is converted into a Triangular Fuzzy set value. Then Fuzzy set values are de-fuzzified by the geometric mean calculation. Finally, the average value of the expert and stakeholder opinion is used to calculate the weightage.

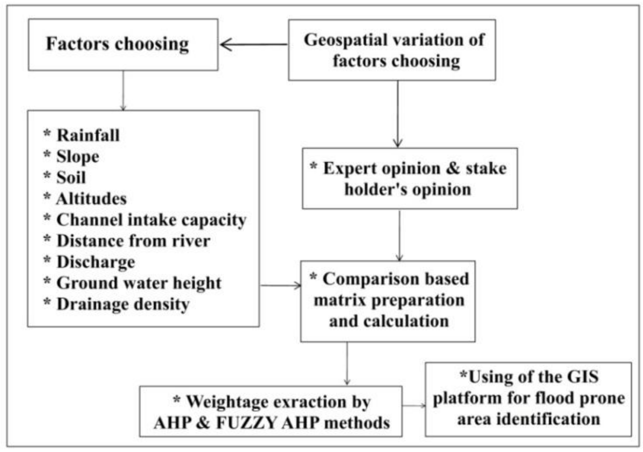


Figure 4.2 Flow chart to show the potential flood area identification by the AHP and Fuzzy-AHP method

(Source – Prepared by researcher)

Table 4.3 Linguistic variables for pair-wise comparisons of each criterion

Definition	Values assigned
Extremely strong	(9,9,9)
Intermediate	(7,8,9)
Very strong	(6,7,8)
Intermediate	(5,6,7)
Strong	(4,5,6)
Intermediate	(3,4,5)
Moderately strong	(2,3,4)
Intermediate	(1,2,3)
Equally strong	(1,1,1)

(Source - Hoque et al., 2019; Kannan et al., 2013)

Using the weightage values within the Arc GIS platform, reclassified layers are overlaid to delineate high, moderate, and low hazards potentiality zones (Figure 4.2).

In the AHP methodology, qualitative linguistic terms are converted into crisp numeric values following Satty's rules (1980), and the consistency rate is checked to validate the weightage values. In the case of Fuzzy AHP, the Fuzzy set theory is integrated with the AHP comparison matrix to reduce human ambiguity and strengthen mathematical reliability. This comprehensive approach ensures robustness in weightage calculation.

The flood potential area is identified by combining the outcomes of qualitative factor analysis and quantitative data analysis within a Geographic Information System (GIS) platform. This integration allows for a comprehensive assessment of flood-prone areas, taking into account both qualitative insights and quantitative measurements.

The study combines qualitative and quantitative approaches to gain a comprehensive understanding of flood dynamics in the lower Ajay River basin. While qualitative methods provide valuable initial insights, proper validation and physical field visits are essential for the practical application and verification of these methodologies. By integrating both approaches, the study aims to enhance our understanding of flood dynamics and contribute to more effective flood management strategies.

For validation, point data is collected using GPS. Data is gathered from different areas and overlaid on the predicted flood potential area. By comparing the model results with the point data of actual flood area, the suitability of the model is assessed. This comparison ensures that the model's predictions align with actual observations, confirming its reliability and practical applicability for flood management.

4.1.6 Prediction of flood potential area analysis by simulation based hydrological method

Quantitative methods are also utilised in the same area, particularly in the lower segment where gauge stations are present, allowing for the daily measurement of gauge height. Statistical methods are then applied using this data, specifically focusing on flood frequency analysis. The GIS platform is integrated with the resulting flood frequency data to analyse the spatial distribution of floods within the basin area.

4.1.6.1 Flood potential area prediction by historical data of flood gauge height in GIS platform

***4.1.6.1.1 Data sources and characteristics*:** The flood frequency analysis for the lower Ajay River relies on data from three gauge stations: Satkahonia, Budra, and Nutanhut. This data, along with open-access SRTM DEM data at 30 m resolution, is processed in the ArcGIS platform to extract topographic characteristics crucial for the analysis.

4.1.6.1.2 Flood Frequency Determination from Hydrologic Data: The Gumbel distribution is widely utilised for estimating extreme natural phenomena like storm rainfall, peak discharge, and low flows (Mondal et al., 2022; Malik and Pal, 2021). Increasing the sample size enhances its performance (Subramanya, 2015). This method is applied in this study for measuring flood frequency and magnitudes across various return periods. Using 40 years of peak gauge height data (Irrigation and Water Ways Government of West Bengal, 2015), the Gumbel distribution is employed for calculating flood magnitudes. Typically, it analyses the annual maximum flood, representing the peak flood within a year, as described mathematically in equation (Subramanya, 2015) (Eq. 4.4).

$$X_T = X_{av} + (K_1 \times SD) \quad \text{(Subramanya, 2015)} \qquad \text{(Eq.4.4)}$$

Where; X_T= value of variate with a return period

X_{av}= mean of the variate

SD = Standard deviation of the sample

K = Frequency factor expressed as

$K_1 = (y_T - y_n)/s_n$

$y_T = - [\ln.\ln (T/ (T-1)]$

T = Return period,

ln=Natural logarithm function
y_n= Reduced mean,
S_n= Reduced standard deviation

***4.1.6.1.3 Hazards estimation*:** From the SRTM DEM data, the topographic characteristics are represented. These topographic contours are delineated in ARC GIS software 10.1 using the SRTM DEM data.

The study adopts an inundation mapping approach based on spatial topographic elevation characteristics and water levels (Win et al., 2018). Using estimated river gauge heights and the recent topographic data, a model is built in the GIS platform for mapping inundation at various intensity levels. Based on different categories of flood magnitude data and elevation based data (SRTM DEM) of this present area the flood inundation mapping is performed using density slice tools in ENVI, an image classification based software. For analysis, the flood hazards in various intensity different magnitudes of scale are used. The extracted result is converted into polygon layers in the ARC GIS 10.1 software.

The lower Ajay basin is segmented three parts–Satkahonia to Budra, Budra to Nutanhut, Nutanhut to Katwa, based on available micro-topographic changes. The model is created for each segment and overlaid in the GIS platform. For instance, in the Satkahonia to Budra region, gauge data from Satkahonia and Budra are utilised to project flood inundation areas along this stretch. This method is repeated for the other segments, resulting in a more accurate flood analysis considering micro-topographic changes. The flood inundation areas are then overlaid on block boundaries and Panchayet boundary to analyse flood hazards and risks using the Arc GIS 10.1 platform.

4.1.6.2 HEC-HMS and HEC RAS application in flood area simulation and flood depth identification

Simulation-based discharge data were utilised for predicting spatial flood areas. Daily rainfall and Curve Number results were used into the HEC-HMS software to extract daily discharge data, which was then used to simulate flood areas in the HEC-RAS software. The impact analysis was conducted at the watershed scale to facilitate further flood management efforts.

4.1.6.2.1 Data preparation: The Ajay River lacks gauge stations for regular discharge measurements, necessitating simulation-based discharge estimation for flood potential area extraction in this study. Soil drainage properties were defined using micro region soil data from NBSS & LUP, while LANDSAT-5 imagery was employed to create a Land Use Land Cover (LULC) map in ERDAS Image 9.0. This software accurately processes LULC data and validates it through ground truth verification. The Soil Conservation Service Curve Number (SCS-CN) was determined based on soil hydrologic group and LULC characteristics, classifying soils into groups A, B, C, and D according to Table 4.4, with the Curve Number representing the combined influence of soil quality and LULC.

Table 4.4 Soil group according to SCS-CN

Soil group	Characteristics
A	Low run-off high infiltration in the USDA classification includes sand and sandy loamy

B	The moderate infiltration rate in the USDA includes silt and silt loamy
C	Low infiltration in the USDA classification include sandy clay loamy
D	High run-off potential in the USDA classification Clay loam, Silty clay, sandy clay

(Source - Soil Conservation Services, 1969)

4.1.6.2.2 Use of HEC-HMS software for discharge extraction watershed wise: In HEC-HMS software, the geo-referenced basin shape file and river channel are imported to prepare a basin model by dividing the basin into sub-basins based on channel characteristics.

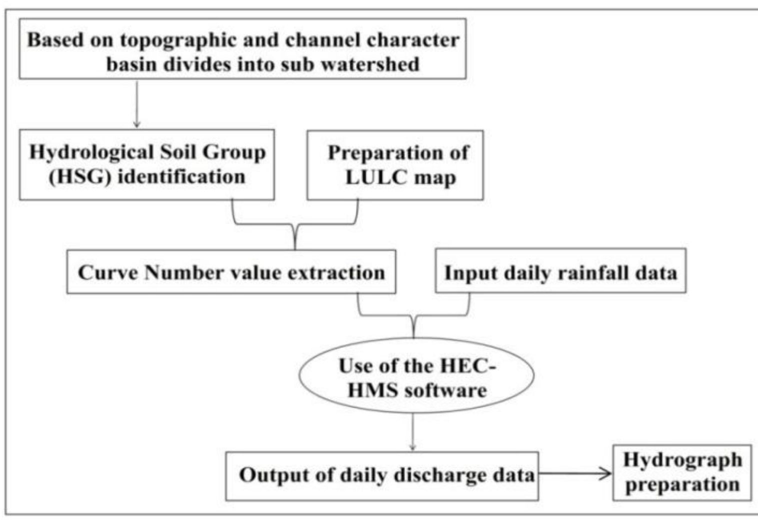


Figure 4.3 Frame work of discharge data extraction in HEC-HMS platform

(Source - Prepared by researcher)

Daily discharge simulation relies on curve numbers and daily rainfall data, extracting discharge data for each watershed and junction point. The simulation outcome includes data for each watershed area and junction point, enabling monitoring of rising and peak discharge trends, along with direct and base flow variations across seasons. Results are tabulated and graphed for easy identification of peak discharge, supported by a flow chart (Figure 4.3), aiding in the estimation of each tributary's impact and formulating flood control strategies.

4.1.6.2.3 Use of HEC-RAS software for flood plain simulation: The basin slope and topographic character extracted from the SRTM DEM data (30 m resolution). 1D model is performed using the DEM data and channel cross profile is drawn. 1 D model is run for extracting the cross profile character. Field cross profiles data arealso included with the simulated data. In this study 2D model is performed on the basis of the flow area of the basin. Finally, on the basis of daily discharge data through the channel profile flood plain mapping is prepared. Most significantly, by using the topographic character and extended flood plain the result of flood depth also simulated in the platform of HEC-RAS.

Both the results of flood plain mapping and flood depth are converted into a vector layer in ARC GIS 10.1 platform. Vector layers are easily overlayed on the block boundary and Panchayet boundary and spatial area of the flood is measured. In the case of the flood depth in each Panchayet area, the depth is overlaid and grids are drawn using the ARC GIS software. From the result of the flood depth on grid wise the average result of the flood depth is calculated for each Panchayet area (Figure 4.4).

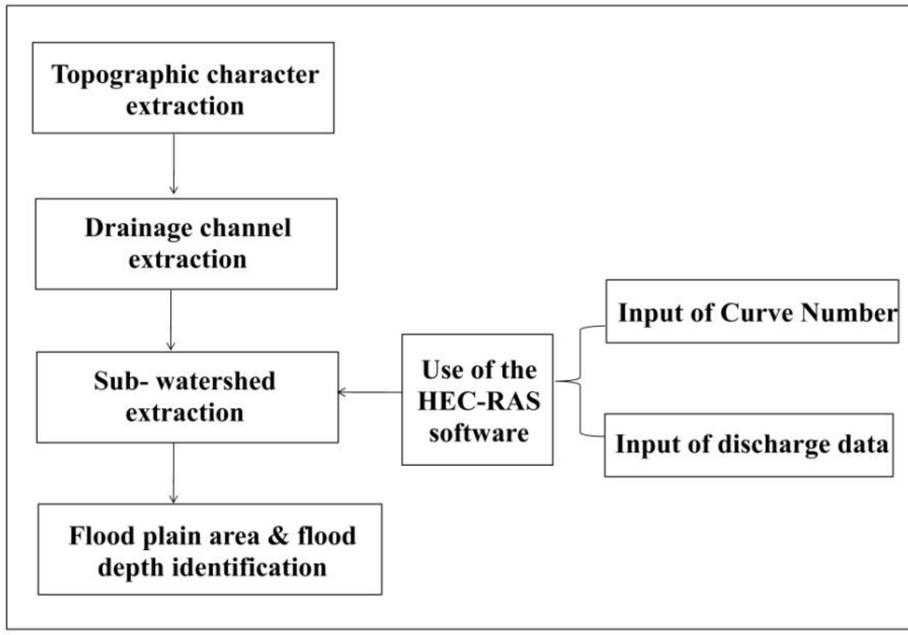


Figure 4.4 Frame work for flood potential area prediction in HEC-RAS platform

(Source - Prepared by researcher)

4.1.7 Validation of the model

Remote sensing and GIS is an essential tool for spatial analysis and now it is more cost-effective for the extracting spatial flood extent. Systematic validation with ground truth is necessary for final use of the model. Here over all accuracy is measured by following the error matrix (Eq. 4.5) and Kappa statistics (Eq. 4.6) are used for more specific judgment of the model.The error matrix is compared a simple relationship of known ground truth points with automated generated area. Over all accuracy only includes the diagonal values of matrix, whereas KHAT statistics include the non-diagonal elements of the error matrix as a product of the row and column marginal (Lillesand et al., 2004). Normally, both the values are used and in case of KHAT statistics can determine the significance of the matrix. The actual flooded area is visited and points are collected by GPS survey and few points are generated on the basis of secondary data. Both are overlaid on output map layers. On the basis of correct and incorrect points an error matrix is prepared by two categories-flood area points and non flood area points. According to objectives, the classified layer may increase. From this error matrix following the rules of overall accuracy, the major diagonal points are compared with the total number of points and following the KHAT statistics rules, the marginal row and column are included. The KHAT statistics (an estimate of KAPPA) value ranges from -1 to +1. There should be a positive relationship between reference data and generated data. In case of strong agreement, the values represents 0.8 (i.e. 80%) or greater than 0.8 (Congalton, 2001). In accordance with the qualitative methods of flood area extraction such as AHP, FUZZY-AHP and quantitative hydrological based methods-gauge height-topographic character based flood area, hydrological data simulation based flood area,all the cases these over all accuracy and KAPPA statistics are used for spatial area validation.

$$Overall\ accuracy = \frac{Sum\ of\ major\ diagonal\ cell}{Total\ number} \quad \text{(Eq. 4.5)}$$

$$\widehat{K} = \frac{N \sum_{i=1} Xii - \sum_{i=1}(Xi \times X_{+i})}{N^2 - \sum_{i=1}^{r}(Xi \times X_{+i})} \quad \text{(Eq.4.6)}$$

Where, $\widehat{K}$=Kappa coefficient

r = number of rows in the error matrix

Xii = number of observations in row i and column i (on the major diagonal)

Xi+ = total of observations in row i (shown as marginal total to right of the matrix)

$X+_i$ = total of observations in column i (shown as marginal total at bottom of the matrix)

N = total number of observations included in the matrix

4.1.8 Vulnerability, resilience and calculation of risk at micro level

In this study, flood vulnerability is approached from two main angles: physical vulnerability and socio-economic vulnerability, recognising that floods not only cause spatial hazards but deeply affect lives and livelihoods. Identifying resilience factors is crucial to mitigating vulnerability, which requires a robust monitoring system, continuous evaluation, research progress, and effective planning during flood conditions. Hazard assessment focuses on flood potential area and depth, while vulnerability assessment considers affected population and long-term socio-economic impacts. Developing a combined index aids in understanding overall risk, although quantifying socio-economic parameters poses challenges due to the lack of direct micro-level data. Therefore, an indirect approach is taken, recognising the complexity of flood vulnerability and adopting a deductive approach to identify key factors based on local flood behavior. Data availability is a critical criterion for parameter selection in vulnerability assessment.

4.1.8.1 Assessment of physical vulnerability

In this study, physical vulnerability to floods is assessed by considering three key components: the spatial area of the flood, the depth of the flood, and the population density within each Gram Panchayat area. The ratio of affected population is estimated by comparing the actual population density with the density in flood-affected areas.

***4.1.8.1.1 Flood potential area*:** To calculate the flood potential area, data from gauge height measurements and HEC-RAS software simulations are compared and validated with past data. To measure the flood area at the GP (Gram Panchayat) level, the simulated results are averaged. The vulnerability index for each Panchayat is determined based on the ratio of affected area to total area of GP. Since the results are provided on a ratio scale, it can be easily converted into a normalised scale from 0 to 1 for easier comparison.

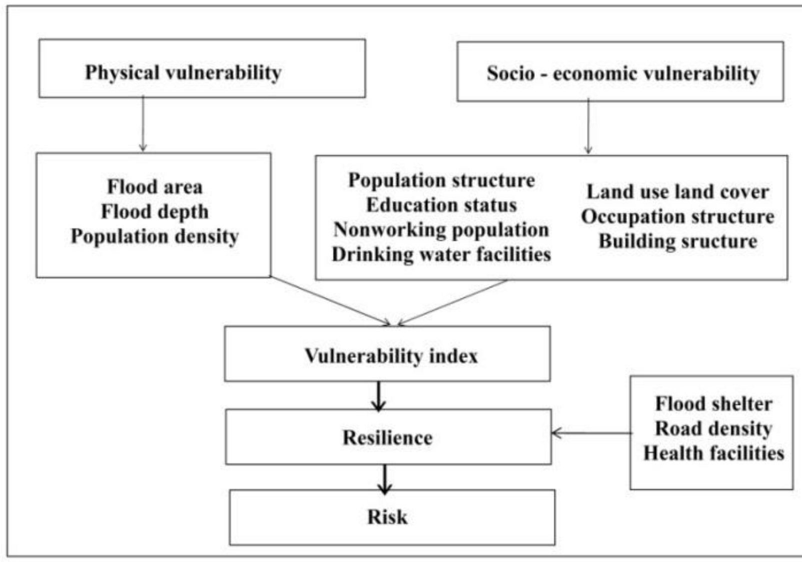


Figure 4.5 Flow chart to show the vulnerability Index calculation

(Source - Prepared by researcher)

***4.1.8.1.2 Flood depth*: ** Flood depth plays a critical role in vulnerability and risk assessment, with risk intensity being directly influenced by flood depth. However, since historical flood depth data is lacking, simulation-based results are used and validated through field studies. Depth measurements are collected from various points based on past flood experiences, and HEC-RAS software is employed to generate depth data based on topographic and hydrological inputs. The average flood depth is calculated for each Panchayat area, categorised into three groups using the quartile method, and assigned scores indicating high, medium, and low flood depth levels.

Table 4.5 Flood depth scale

Flood depth (m)	Scale
<0.875	0.33
0.875-1.25	0.66
>1.25	1

(Source - Calculated by researcher)

***4.1.8.1.3 Population density*: ** The calculation of population density within each Panchayat area involves dividing the total population by the area of the Panchayat, a method supported by Munyai et al. (2019). Population density is a crucial factor as it reflects the actual population pressure experienced in a given area (Suwanno et al., 2023). Using the Census of India data from 2011, the population density is classified into five categories, and vulnerability scores are assigned accordingly, with higher scores indicating areas of higher population density (refer to Table 4.6). By considering the results from these three components—spatial flood area, flood depth, and population density the actual physical vulnerability is estimated through averaging these scores.

Table 4.6 Categorisation of rural settlement as per population density

Population density/sq. km	Rank	Score
>850	1	1
451-850	2	0.8
251-450	3	0.6
101-250	4	0.4
<100	5	0.2

(Source - Census of India, 2011)

$$PV = (Fa+Fd+Pd)/3 \qquad \text{(Eq. 4.7)}$$

Where, PV= Physical Vulnerability, Fa= flood area in ratio, Fd= flood depth, Pd= population density score

4.1.8.2 Assessment of socio-economic vulnerability

The assessment of socio-economic vulnerability incorporated various parameters including demographic structure, literacy rate, and availability of drinking facilities, occupational structure, non-working and marginal population groups, as well as land use and land cover, and building types. For the qualitative analysis of factors influencing vulnerability, a structured expert opinion survey was conducted. A panel of ten experts was selected based on their expertise in various relevant fields. Selecting experts for the flood vulnerability opinions focuses on their relevant advanced degrees, professional experience, recognised contributions, project involvement, interdisciplinary knowledge, regional expertise, technical skills, communication abilities, and ensuring objectivity. This ensures reliable and comprehensive assessments.

Expert opinion is necessary for this work because it brings specialised knowledge, subjective evaluation capabilities, interdisciplinary perspectives, data interpretation skills, quality assurance, and facilitates a holistic assessment of vulnerability.

In this study, a scaling pattern ranging from 1 to 10 was utilised to assess the opinions of the ten experts across various qualitative factors influencing vulnerability. This scaling pattern enabled a thorough assessment of each factor based on expert opinions, with higher scores reflecting the increased significance or severity of the factor concerning vulnerability.

Overall, these rankings highlight the complex interplay of factors contributing to vulnerability. Understanding these perceptions can inform targeted interventions and policies aimed at reducing vulnerability and enhancing resilience among different groups and sectors in the study area.

Expert opinions are essential for capturing subjective view in qualitative factors because it offer contextual understanding, interpret ambiguous data, evaluate subjective factors, analyse complex relationships, leverage historical knowledge, identify emerging trends, and integrate seamlessly with quantitative data for a comprehensive vulnerability assessment.

Expert opinions are crucial for evaluating subjective factors that cannot be easily quantified. For example, factors like occupation structure, land use and land cover, demographic structure, and working status require an understanding that quantitative data alone may not capture accurately.

Experts bring their specialised knowledge and insights to the evaluation process. For instance, a social scientist may provide valuable insights into demographic trends and social vulnerabilities, while an environmental scientist may offer expertise on land use and infrastructure vulnerabilities.

By involving experts from diverse backgrounds such as social science (4 experts), civil engineering (1 expert), water resource management (1 expert), environmental science (2 experts), and statistical analyst (2 experts) a balanced and comprehensive perspective have been achieved. This ensures that various aspects of vulnerability and resilience are thoroughly examined.

Collaborating with experts from different fields promotes interdisciplinary collaboration, leading to a more holistic and well-rounded assessment. This interdisciplinary approach ensures that all relevant factors are considered and integrated into the analysis.

In summary, expert opinions are essential for their expertise, insights, qualitative data interpretation, risk mitigation, interdisciplinary collaboration, and quality assurance, all of which contribute to enhancing the accuracy, reliability, and comprehensiveness of vulnerability and resilience assessments.

Calculating rankings for qualitative data involves assigning numerical values to each category or factor based on expert opinions. Experts evaluate the factors and provide scores or ranks on a scale, often ranging from 1 to 10, where higher values indicate greater importance or impact. These scores are then averaged across all experts to obtain an overall ranking for each factor. This method allows for the quantification of qualitative data, making it easier to compare and analyse subjective information systematically.

By considering expert opinions alongside quantitative data, the vulnerability assessment becomes more holistic. It incorporates both objective data-driven analysis and qualitative expert insights, resulting in a more comprehensive understanding of vulnerability factors.

***4.1.8.2.1 Demographic Structure*:** Child population are ranked highest in vulnerability perception with an average score of 9.5, followed by females at 8.2, and others (rest of others) at 6.8 (Appendix H). This ranking suggests that experts view children as the most vulnerable group, possibly due to their dependency, limited ability to cope with disasters, and specific needs during crises. Females are also considered vulnerable, likely due to their societal roles and potential challenges during disasters. Experts also suggested including the disable population and old age population but unfortunately no data is available regarding this. So, in this calculation these parameters are not included. Research by Qasim et al. (2017) highlights that populations such as children, females, older individuals, and persons with disabilities are particularly vulnerable during flood events. However, at the micro-level, data on child (0-6 age group) and female populations are available through the Indian census. In this study, greater weightage was assigned to child population vulnerability, followed by female population vulnerability, and subsequently, other vulnerable population groups were considered.

Table 4.7 Demographic structure scale

Demographic structure	Rank	Scale
Child	1	1
Female	2	0.66
Other population	3	0.33

(Source - Calculated by researcher)

4.1.8.2.2 Land Use and Land Cover (LULC)**:** For calculating the economic vulnerability indirect way is adopted because no such data of financial details is published on micro scale. Due to flood hazards land use land cover is mostly affected so land use and land cover is considered as one of the important parameters (Munyai et al., 2019; Sharma et al., 2012). In case of land use land cover it is difficult to prioritised. So in this case expert opinion is carried for the ranking according to the vulnerability potentiality.

Experts ranked Settlement as the most vulnerable category with an average score of 8.8, followed by Agricultural land at 8.4, and others (water bodies, natural vegetation) at 6.4 (Appendix H). This ranking indicates that settlements are perceived to be highly vulnerable, possibly due to factors such as proximity to flood-prone areas, inadequate infrastructure, and population density. Agricultural land, although ranked slightly lower, is still considered vulnerable, likely due to its economic significance and exposure to environmental risks. To calculate the affect on land use land cover, firstly, the land use land cover map is prepared using the data of LANDSAT 8 data, (2018). Then flood potential area is overlaid on the LULC map and extracted the affected area in each type of LULC and converted into a ratio scale. According to vulnerability, the LULC is classified into three group-settlements, agricultural land and others. In other category water body and vegetation are included. In case of priorisation settlement area is considered more vulnerable and agricultural land and other groups respectively.

Table 4.8 Scale for LULC class

LULC category	Rank	Scale
Settlement	1	1
Agricultural land	2	0.66
Other	3	0.33

(Source - Calculated by researcher)

4.1.8.2.3 Occupation**:** The average scores indicate the ranking of occupations based on vulnerability perceptions. Agricultural labourers are ranked highest with an average score of 8.7, followed closely by cultivators at 8.2, and others (service sectors) at 5.9. This ranking suggests that experts perceive agricultural labours and cultivators to be more vulnerable compared to those with other occupations. This vulnerability assessment could be due to factors such as income instability, reliance on weather-dependent livelihoods, and limited access to resources.

In evaluating occupational vulnerability, agricultural laborers are deemed to be more affected compared to cultivators, service sector workers, and the unemployed (Sajilesh, 2021;

Srivastava and Shaw, 2015). The rationale behind this distinction lies in the long-term impacts, particularly for those without land who solely rely on labour for survival. Census data related to occupational structure is utilised and transformed into a ratio scale format, allowing for a combined score to be derived based on priority considerations. This approach helps in understanding and quantifying the vulnerability of different occupational groups in the study area.

Table 4.9 Scale for occupational structure

LULC category	Rank	Scale
Agricultural labour	1	1
Cultivators	2	0.66
Others	3	0.33

(Source - Calculated by researcher)

***4.1.8.2.4 Working Status*:** Non-working individuals are perceived as the most vulnerable group based on the expert rankings, with an average score of 9.1, followed by marginal workers at 7.4, and others (non-specific working status) at 5.9 (Appendix H). This ranking reflects the vulnerability associated with non working population, including financial instability, lack of access to resources, and limited social support. Marginal workers are also considered vulnerable due to their precarious employment conditions and limited resilience.

The non-working population, typically economically disadvantaged, experiences heightened vulnerability during flood events (Munyai et al., 2019). Their economic status often inhibits quick recovery post-flood, underscoring their increased susceptibility. In this assessment, maximum weight is assigned to the non-working population, followed by marginal working population, with the other group receiving minimal weightage. Given that the data is presented as percentages, it is converted into a ratio scale and standardised for inclusion in the vulnerability analysis.

Table 4.10 Scale for non working population

LULC category	Rank	Scale
Non working population	1	1
Marginal workers	2	0.66
Other	3	0.33

(Source - Calculated by researcher)

***4.1.8.2.5 Education status*:** In assessing socio-economic vulnerability, literacy percentage is a crucial factor, as highlighted by Qasim et al. (2017). This study calculates the illiteracy percentage from the literacy rate data, recognising that literate individuals are generally more informed about flood-related risks and respond better during and after flood events. Since literacy data is typically presented as a percentage in census records, it can be easily standardised for scoring purposes, reflecting education level as a ratio scale in the final calculation.

***4.1.8.2.6 Drinking water supply*:** Moreover, rural areas in India often face challenges with drinking water supply. Data from household census studies categorise drinking water supply into three types: within the premises, nearby (within 0-200 meters), and far from the premises (over 200 meters) (House listing & Housing Census, 2011). During floods, access to clean water becomes critical, particularly if water sources are located far from residences. Hence, the availability of drinking water supply facilities is a significant parameter in socio-economic vulnerability assessments. Utilising the percentage data from the 2011 census, this factor is considered on a ratio scale, with higher vulnerability assigned to locations where drinking water supply is far from residences, followed by nearby locations, and within the premises as the least vulnerabale.

Table 4.11 Scale for drinking water supply according to distance

Drinking water supply distance	Rank	Scale
Away	1	1
Nearby premises	2	0.66
In the premises	3	0.33

(Source - House listing & Housing Census, 2011)

4.1.8.2.7 Building types: Using census household data, the building condition parameter is assessed based on the type of wall material used in constructions (Munyai et al., 2019). The wall quality is categorised into three groups: mud walls, other materials like wood or bamboo, and concrete walls. Mud walls are deemed the most vulnerable, followed by other materials and then concrete walls. This scoring system is straight forward when the data is in ratio scale format, allowing for easy standardisation and calculation using simple priority methods.

Table 4.12 Scale for building types

Building category	Rank	Scale
Mud house	1	1
Wood and bamboo	2	0.66
Concrete	3	0.33

(Source - Calculated by researcher)

Finally, the result of the socio-economic vulnerability is framed by averaging the result of the combined seven mentioned parameters.

$$SEV=(Dt+Ed+Df+Lulc+Ot+Nw+Bc)/7 \quad \text{(E.q 4.8)}$$

SEV=Socio-Economic Vulnerability, Dt=Demographic structure, Ed- Education status, Df-Drinking water facilities, , Lulc= Land use land cover, Ot-Occupational structure, Nw= Non-working population ratio, Bc=Building condition

4.1.8.3 Assessment of Vulnerability

In this study equal importance is given for physical and socio-economic factors. So, combining both physical and socio-economic vulnerability, an equal weighting is applied to each in this research to calculate the final vulnerability value. The vulnerability index is prepared using a simple additive model, and the spatial pattern of vulnerability is then analysed using GIS platform (Figure 4.5).

4.1.9 Risk management and estimation of resilience capacity

In the context of flood management, this study emphasises resilience-based sustainable management plans over structural approaches. A cost-benefit analysis is integrated, measuring relative costs and resilience potential through both quantitative and qualitative methods.

For flood shelter analysis, existing shelters are quantified based on their resilience in risk reduction. A hypothetical increase in shelter numbers is then considered to gauge resilience potentiality. Total construction costs are calculated, and the multipurpose utilisation of shelters is discussed for resilience enhancement.

Regarding road networks and health care facilities, existing infrastructure and hypothetical expansions are assessed for their impact on resilience. Road density and health centre counts per Gram Panchayat (GP) are measured against population density to determine resilience scopes, applying a class-based statistical method for ranking.

Qualitative discussions include topics such as agricultural damage assessment, resilience via insurance coverage, and the potential reduction in risk volume by converting traditional housing to more resilient structures. Analysing government schemes alongside past census data can help predict future risk trends and identify essential resilience capacities.

The resilience factors like flood shelters, health centres, and road density were chosen for this study but can vary based on spatial and temporal scales. Flood shelter resilience is determined by the ratio of affected population to shelter availability in each Panchayat, classified into quartiles for scoring (Table 4.13).

Table 4.13 Score of flood shelter

Affected population/ Number of flood shelter	Score
0-2737	1
2737-6371	0.75
6371-10094	0.50
>10094	0.25

(Source-Calculated by researcher)

The calculation of health facilities resilience involves counting the number of health centers in each Panchayat area and assessing their coverage relative to the affected population. Based on the population ratio to health centers in each Panchayat, quartiles were determined (Table 4.14). Scores were then assigned according to these quartile values, aiding in the evaluation of health facility resilience.

Table 4.14 Health facilities score

Total population /number of health centre	Score
0-4872	1
4872-6110	0.75
6110-10618	0.50
>10618	0.25

(Source-Calculated by researcher)

The road network's resilience is crucial for effective rescue operations and the distribution of relief materials during floods. In this study, the presence and density of roads within each Gram Panchayat were assessed, although the condition of the roads was not evaluated. Using ISGPP data, road networks were mapped and overlaid with Panchayat boundaries in a GIS platform. Road lengths were measured for each Panchayat area to determine road density. Quartiles were then derived from the road density data for each Panchayat area, and scores were assigned based on these quartile values, as outlined in Table 4.15.

Table 4.15 Road density score

Road density km/km^2	Score
< 0.30	0.25
0.30-0.39	0.50
0.39-0.52	0.75
>0.52	1

(Source - Calculated by researcher)

Calculating the average value from these three components provides an overall resilience calculation, offering insights into management and response capabilities during floods. The resilience result helps to assess infrastructural facilities across different Panchayat areas. Basic primary facilities essential for an area are considered in resilience calculations, such as the presence of flood shelters crucial for saving lives, road facilities aiding in reaching shelters and distributing relief materials, and health centers essential for managing health hazards and post-flood health problems. The affected population and the availability of health centers reflect the minimum support needed for survival. So, a case study on flood shelter development locations is identified based on government buildings, specifically high school locations. Additionally, the road network is also shown for two risk-prone GPs.

4.1.10 Calculation of risk

Calculating the risk involves assessing the ratio between vulnerability and resilience. A risk value greater than 1 indicates a higher risk level, while a value less than 1 suggests comparatively lower risk due to higher resilience. The study shows that the Panchayats are currently at risk and require the development of resilience measures to mitigate this risk. The final risk assessment is presented in the GIS platform to analyze its spatial characteristics.

This visualisation aids in understanding the areas most susceptible to risks and helps in formulating targeted resilience strategies.

4.1.11 Analysis of existing structural resilience

This study delves into the crucial assessment of embankment conditions, with a specific focus on predicting the probability of seepage. During floods, drainage conditions often become choked, leading to embankment collapse. Therefore, a key aspect of this assessment involves analysing the soil texture and grain size to accurately predict seepage conditions.

To evaluate seepage through the embankment, permeability calculations are conducted. This process involves gathering soil samples from various locations along the embankment's sides, with a particular emphasis on areas with a history of embankment failure. Three samples are collected from each side: one from the top of the embankment and two from the sides.

The collected soil samples undergo a sieve method to determine their grain size distribution. This analysis helps in understanding the soil quality and identifying whether it falls into categories such as sandy, clayey, or silty. A critical criterion is applied during this analysis, where soil with less than 12% passing through a 75-micron sieve is categorised as sandy soil.

In the case of sandy soil, the study employs the Allen Hazen (1911) empirical formula (Eq. 4.9) to calculate the permeability of the soil (as mentioned in Murthy, 1992). This formula is a well-established method for estimating the permeability of sandy soils based on their grain size distribution.

By following these steps and methodologies, the study aims to provide a comprehensive understanding of seepage probability through embankments, especially in areas prone to embankment failure, facilitating better-informed decision-making and risk management strategies.

$$K = CD_{10}^{2} \qquad \text{(Eq. 4.9)}$$

Where, K is in cm per sec, D_{10} is the effective size of grain in cm. C means a factor varies from 100 to 150. But it is a very empirical study in nature. This empirical study gives a rough idea.

4.2 Data used and sources

The methodology employs both primary and secondary data. Primary data is collected directly through methods such as field surveys, interviews, and experiments. Secondary data is gathered from existing sources like academic journals, books, and online databases, official data base providing a comprehensive basis for analysis.

4.2.1 Secondary data collection

The secondary data are collected from various sources and the details of data sources, uses of the data are explained by tabulation form (Table 4.16).

Table 4.16 Details of secondary data used and sources

Data used	Details of data	Source
Rennel's Map (1779)		Collected from the book 'The Provinces of Bengal situated on the west of the Hugli River; with the Maharatta Frontier', National Library
Toposheet 1:50,000	73 M/6,73M/10, 73M/11, 73M/14,73M/15,79A/1, 79A/2 (2005-06)	Survey Of India
Satellite Image, 2018 & 2022	LANDSAT-8 WRS path-139 WRS row-44 (8.11.2018), (6.12.2022)	Open source data retrieved from USGS GLOVIS USGS GloVis (Global Visualization Viewer) is a web-based tool provided by the United States Geological Survey (USGS) for accessing satellite imagery and geospatial data.
Satellite Image 1991	LANDSAT-5 WRS path-139, 140, WRS row- 43, 44 (8.1.1991)	Open source data from USGS GLOVIS
Satellite Image, 2000 & 2001	LANDSAT-5139, 140, WRS row- 43, 44 (10.1.2001)	Open source data from USGS GLOVIS
Satellite Image, 2007	LANDSAT-5139, 140, WRS row- 43, 44 (4.1.2007)	Open source data from USGS GLOVIS
Satellite Image	Liss III	Jadavpur University
Google earth image		Google earth pro
Geological map	Birbhum, Bardwan Geological map, (R.F- 1:250000)	Published by Geological Survey of India, 2001
Geological map	Geological and mineral map of Jharkhand, (R.F- 1: 50000)	Published by Geological Survey of India, 2013
Geological map	Geological and mineral map of West Bengal, (R.F- 1: 2000000)	Published by Geological Survey of India, 2010
Soil data	Soil map- Bihar-Jharkhand, West Bengal 1:50000, 1987	NBSS & LUP
Geomorphological map	Basin area	Indian Geo-platform of ISRO Thematic map geomorpholocal, 2005-06

Data used	Details of data	Source
		ISRO (Indian Space Research Organisation) is India's national space agency, responsible for developing space technology and conducting space missions.
SRTM DEM data	54_08, 90 m & 30 m resolution	Retrieved from –http//srtm.csi.cgiar.org
Ground water data	Ground water year book West Bengal & Andaman	Central Ground Water Board, Ministry of Water Resource, Govt. of India
Gauge height data and others hydrological data and flood data	Irrigation report, 2005-2015	Govt. of West Bengal, Irrigation and Waterways
Gauge height data and others hydrological data and flood data	Data collected from gauge station –Budra, Satkahonia, Nutanhut for the periods of 1978-2017	Under- Govt. of West Bengal, Irrigation and Waterways
Disaster management data	District Disaster Management & Action Plan, Bardwan, 2015-16	District Disaster Management Authority, Burdwan, West Bengal
Disaster management data	Multi hazards District Disaster Management Plan, Birbhum, 2016-17, 2018-19	District Disaster Management Sect ion, Birbhum
Flood history	Sechpatra (2000-2010)	Govt. of West Bengal, Irrigation and Waterways Department
Panchayet Boundary map and infrastructural data in panchayet like roads, school building, hospital etc.	Map and data of each Panchayet within the study area, ISGP (Institutional Strengthening of Gram Panchayats)	Panchayet and Rural Development, Govt. of West Bengal, Planning and monitoring through GIS https://prd.wb.gov.in/projects/6c39ec04-68e9-4294-ad96-7ed3116ab6a8
Census data	Census of Bardwan, Birbhum, 2001, 2011	Census data
House listing & Housing census data, 2011	Birbhum, Bardwan district , Household amenities data	*https://censusindia.gov.in/2011census/* /HLO/HL_PCA/Houselisting-housing-HLPCA.html
Rainfall data	Grid data (0.25°×0.25°) of IMD	Jadavpur University
Rainfall and temperature data	Station wise daily data within the study area (Ketugram, Bhatar, Illambazar)	Agro-meteorology, Govt. of West Bengal
Crop insurance data	Premium calculation data of 'Pradhan Mantri Fasal Bima Yojana'&'Bangla Fasal Bima Yojana'	pmfby.gov.in &wbxpress.com/bangla-fasal-bima-yojana-bfby-scheme/

(Source - Prepared by researcher)

4.2.2 Primary data collection

Primary data collection method and its purposes are explained in the form of tabulation (Table 4.17)

Table 4.17 Details of primary data used and sources

Collection of data	Purposes	Using methods
Cross profile of the river	To analyse the river condition- Channel width depth, analysis of the thalweg shifing etc.	Leveling survey by Total station and Auto level
Wetted perimeter data	To analyse the river character	By measurement instrument
Length and area measurement of bars	To analyse the bed morphology	Measurement of the length and width
Soil sample collection from embankment	Sample collection for analysis for checking the seepage	Sheiv analysis
Stake holder opinion	For the flood prediction model development	By questionnaire data collected regarding the flood factors
Expert opinion	For the flood prediction model development and ranking the socio-economic factors of vulnerability	By questionnaire data collected regarding the flood factors
Ground point data collection	To validate the spatial flood model	Field visit and point data collection by GPS, for validate the spatial Flood model.
Ground point data collection	To validate the flood depth	Field visit and data collection by GPS and flood depth by marking point and verbal data from villagers experience during post flood

(Source - Prepared by researcher)

4.2.3 Name of the software and tools are used in this work

Table 4.18 Software and tools used

Name of the software	Microsoft office 2017, Arc GIS 10.0 & Arc hydro, Erdas Imagine 9.0, HEC-HMS 4.2, HEC RAS 5.0.3, Surfer DEM, ENVI, Google earth pro, Adobe photo shop, Mendeley
Name of the tools used	Auto level, Total station, GPS, Indian standard sieve

Chapter 5

Characteristics of the Study Area

5.1 Location

The Ajay is one of the important river basins of eastern India and serving as a significant important tributary of the Bhagirathi-Hugli River. Originating from the Chakai block area at an elevation of 330 metres above sea level in the Jamui district of Bihar, it flows across the undulated terrain of the Chotonagpur plateau and floodplain areas. The river finally confluences on the right bank of the Bhagirathi-Hugli near Katwa at an elevation of 10 meters above sea level in Bardwan district. This river basin extended ($23^0 24^/$N to $24^0 36^/$N and $86^0 16^/$E to $88^0 6^/$E) 6235 sq. km area spanning of the three states of India- Bihar, Jharkhand and West Bengal. The basin is nourished by several tributaries, including the Partho, Jayanti, and Sarath in the Chotanagpur Plateau area. As it progresses beyond the plateau, the Hinglow stream merges into the main channel of the Ajay River. Notably, important tributaries like the Kunur, Tumani, and Khandar join the Ajay River in its lower course. The river's journey traverses undulating terrain characterised by hard crust Granite Gneiss and reddish lateritic tracks, culminating in its entry into the Ganga Brahmaputra Delta (GBD) region, where it merges with the Bhagirathi-Hugli River. The Ajay River system relies heavily on monsoon and seasonal rainfall, which significantly influences its flow patterns throughout the year.

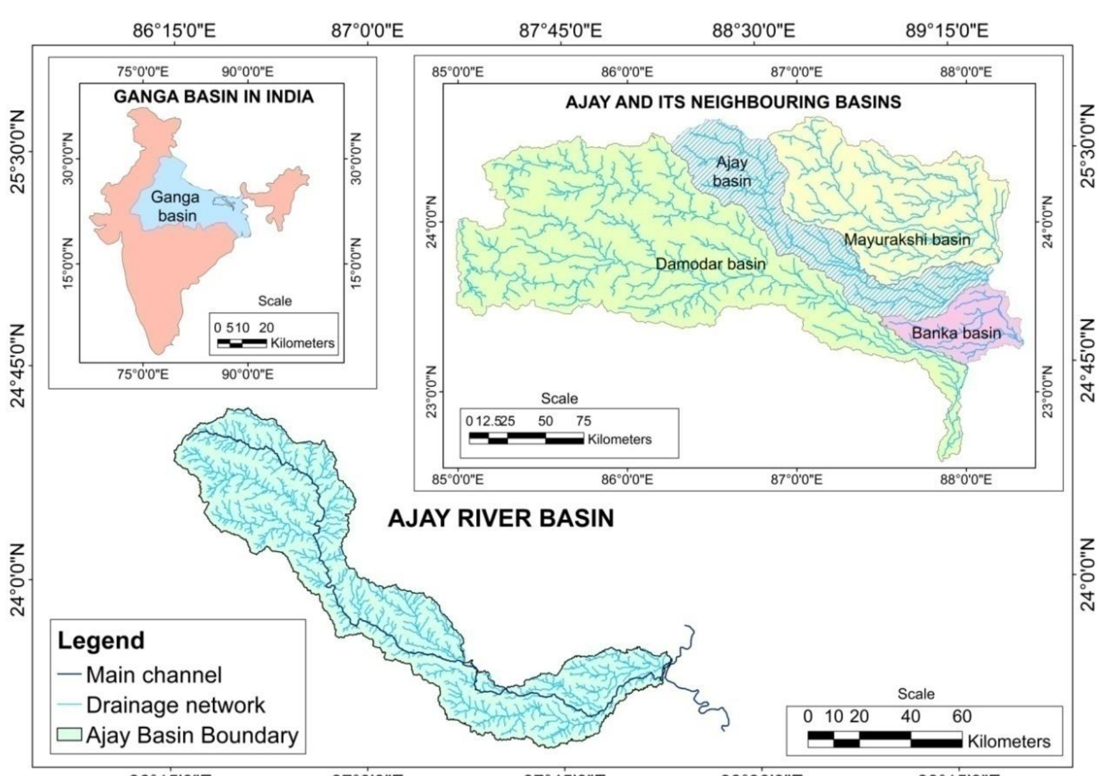


Figure 5.1 Location of the Ajay basin in India and its neighbouring basin

(Source- Maps of India and SRTM DEM data, 30 m)

Ajay is located between the adjoining basins of Damodar in the south and Mayurakhsi in the north (Figure 5.1). These three rivers flow parallel to each other. Due to similarities in terrain character and climatic control, almost similar kinds of flowing patterns and nature are observed in these three major rivers in eastern India. Some important heritage sites are also located along the Ajay River. In the upper catchment area, the holy place Deogarh and after that, the birthplace of poet Joydeb is located and now this place is famous for Joydeb Kenduli. Most importantly, Bolpur which now stands for the educational heritage of India is located in the Ajay basin area. Along with these heritage sites, the location of the archaeological site-Pandu Rajar Dhibi near Aushgram-I proves the floridity of the Ajay River and Bengal. Following the break of slope along the longitudinal profile of the main channel (Table 5.1), the whole river basin is divided into three parts: upper, middle, and lowers (Figure 5.2).

Table 5.1 Identification of break of slope in longitudinal profile

Distance in km	m	Ratio
0	330	
3.5	310	1;175
7.15	290	1;182.5
16.65	270	1;475
27.9	**250**	**1;562.5**
42.56	230	1;733
59.91	210	1;867.5
78.43	190	1;926
100.43	170	1;1100
122.5	150	1;1103.5
141.85	130	1;967.5
161.41	110	1;978
180.98	**90**	**1;978.5**
200.69	70	1;985.5
223.66	50	1;1148.5
253.66	30	1;1500
285.28	10	1;1581

Bold mark denotes the break of slope zone

(Source-Contour prepared from SRTM DEM data, 30 m and toposheets 1: 50000)

The upper basin area stretches from the origin to the Sikatia barrage and the middle area stretches from Sikatia to Illambazar, while the lower part is marked from Illmbazar to Katwa (Figure 5.2). Along with longitudinal profile characteristics, low average slope, relief pattern, wide flood plain, and most interestingly, the past flood records are considered for these divisions. Upper catchments cover 1936 sq. km, middle catchments cover 2563 Sq. km, and lower catchments cover 1736 Sq. km area. The total length of the channel is about 288 km. In the upper courses, the main channel of the river is flowing almost 30 km under the Archean basement, 150 km covers the middle course over the lateritic track and carboniferous sediment, and in the lower course, the river is flowing about 108 km on the quaternary sediment deposition. Evolutionary history reveals the existence of the paleo-path and human intervention in the lower course of the basin area. Due to the presence of the tropical monsoon climate, during the lean season, the river flows in a sinuous pattern with base flow. But in the peak season, the river's flowing pattern is totally changed, and frequent floods are observed in the lower part of the basin. During most of the period, the river flows with a base flow, exhibiting the sediment features of bars. Due to siltation in wide floodplain areas and fertile soil character, the lower part of the basin is densely populated. During the flood scenario, vulnerability is gradually increasing. Therefore, studying the river characteristics and analysing vulnerability during floods is significant for better management solutions.

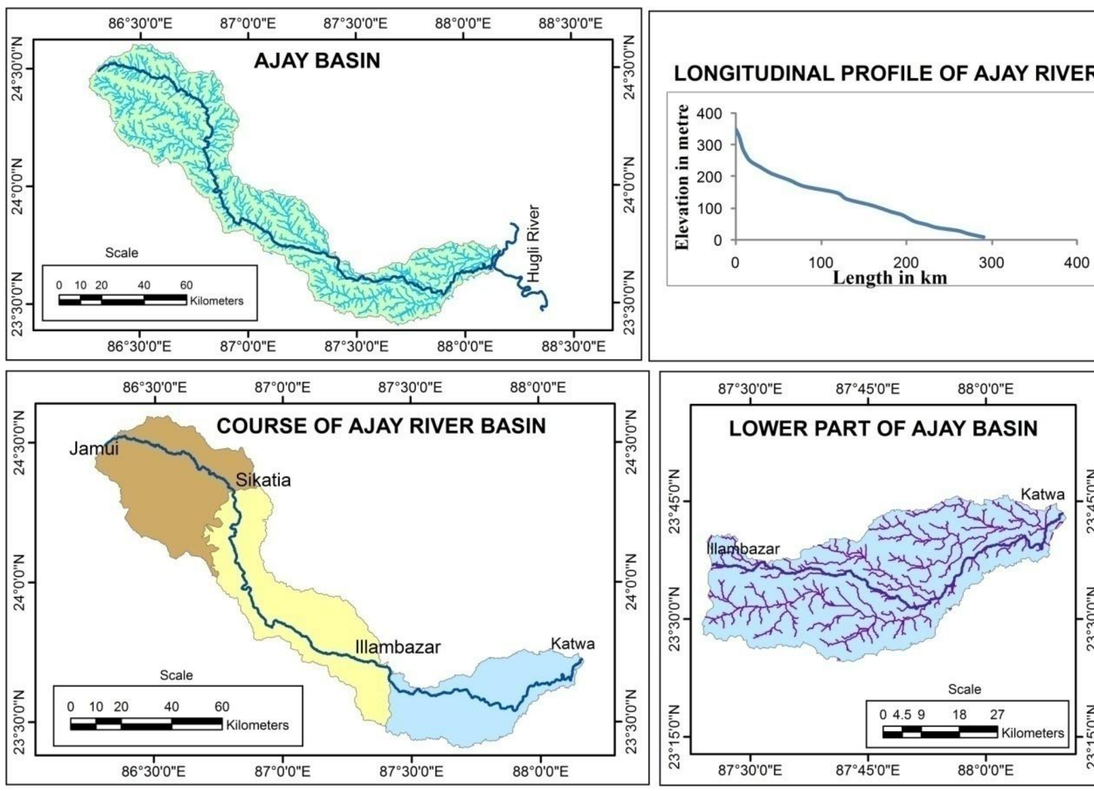


Figure 5.2 Study area: Identification of lower part of Ajay basin following the break of slope in longitudinal profile

(Source-Contour map generated from Topographical Sheet 1: 50000 and SRTM DEM, 30 m)

5.1.1 Administrative setting in the study area

The whole basin area lies within six districts. The upper and middle catchments area covers Jamui, Giridih, Deogarh, Jamtra, and the lower catchment area includes Birbhum and Bardwan (Figure 5.3). Flowing through Bihar and Jharkhand, it enters West Bengal near Chittaranjan. Thirty-nine blocks of the above-mentioned districts cover the whole basin area (Figure 5.3). For analysis, the flood vulnerability and its problems are focused on the lower part of the basin area, which comprises 11 blocks (Figure 5.4). For micro scaling, the analysis of flood vulnerability in Gram Panchayat is considered as a unit of study. A total of 80 Gram Panchayats are present in the lower part of the basin area. Concerning the basin area, 9.22% is covered in Bihar, 46.48% is covered in Jharkhand, and West Bengal encompasses 44.29% of the area. The basin area is divided according to natural basin divides. Converting the natural boundary to an administrative area is a difficult task, but here, the administrative boundary is compared with the basin boundary to identify the location of risk factors and estimate the risk intensity. Nowadays, watershed-wise basin resource mobilisation and management of the river basin are more effective than administrative boundaries. In this work, the natural boundary is identified as per the river course for the study of the river's nature, flood area estimation, etc., and the resulting factors are combined with the administrative boundary at the micro-level (Figure 5.4).

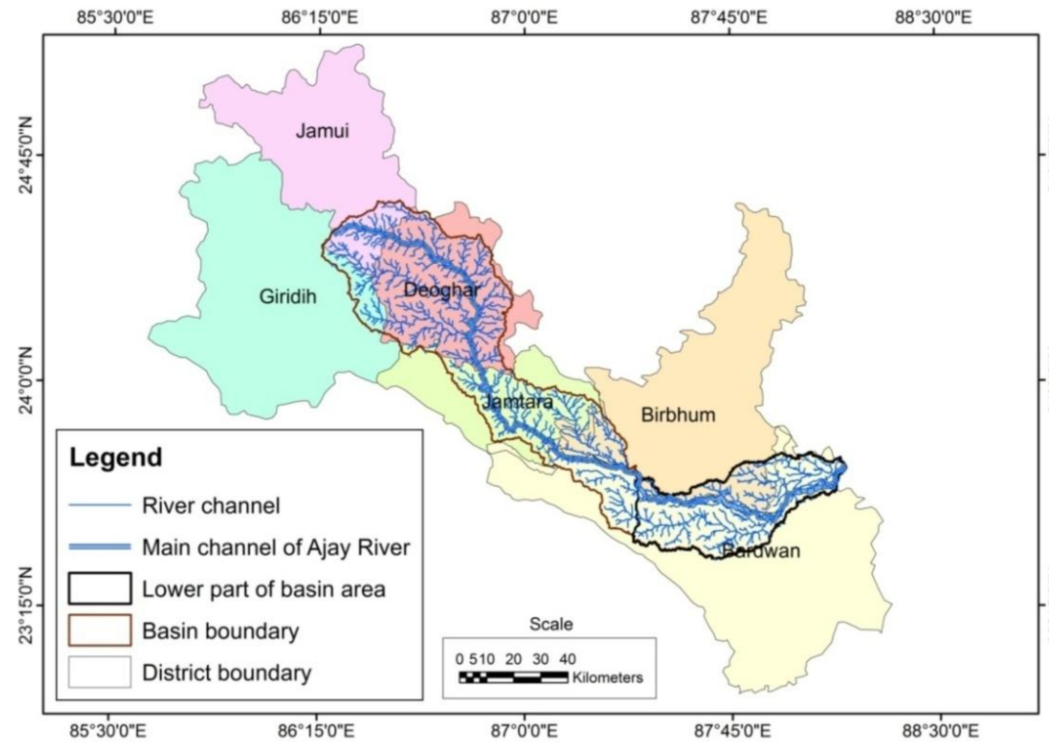


Figure 5.3 Ajay basin area on the district boundary map

(Source- District Census Hand Book, 2011)

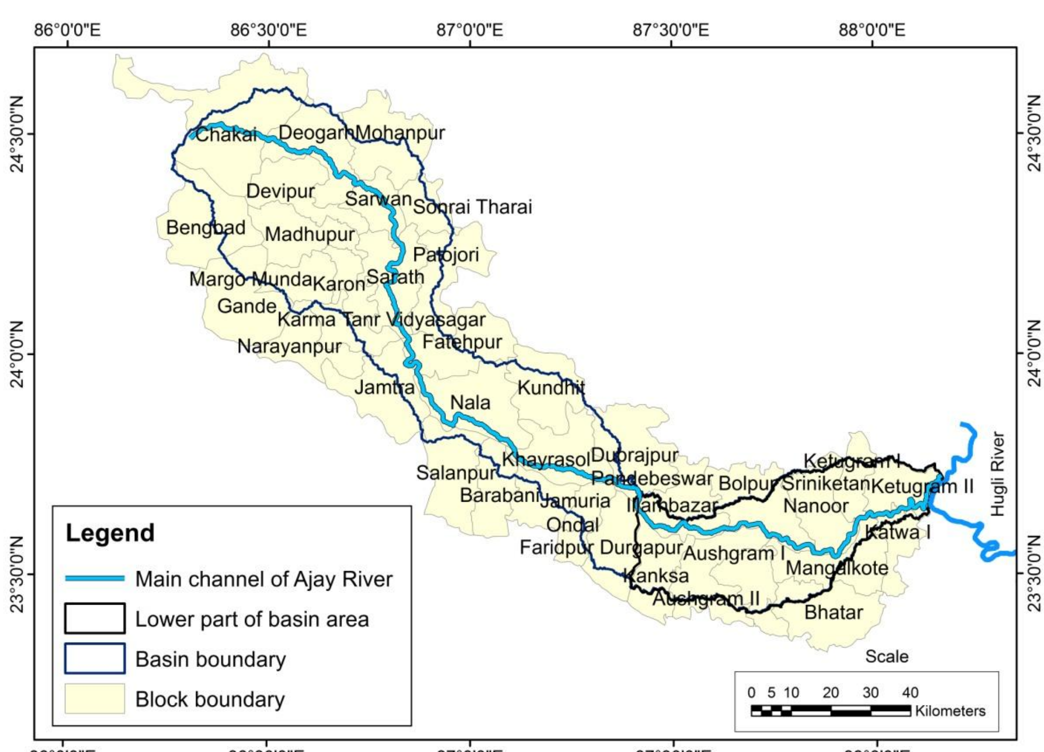


Figure 5.4 Ajay basin area on block boundary map

(Source- Block map collected from District Census Hand Book, 2011)

5.2 Study of physical characteristics of the Ajay River basin

Rivers are integral components of the hydrological cycle, functioning through the interaction of surface hydrology and subsurface flow. The flow of water in rivers is determined by the physical environment of the area, with geological strata, climatic conditions, and soil formation playing crucial roles. Groundwater formation, influenced by geological characteristics and rainfall patterns, also influences river flow. The lithological structure and soil composition of an area dictate the character of river channels, which varies spatially.

The Ajay River is a significant watercourse in eastern India, originating from an undulating plateau area and flowing through the Rarh Bengal region before joining the Bhagirathi-Hugli River in the alluvial aggradational plain. This diverse physical landscape contributes to the varied character of the river. Ajay, along with Mayurakshi, Damodar, and Kangsabati, are major tributaries of the Bhagirathi-Hugli River on its western side, all relying on southwest monsoon rainfall. Seasonal rainfall and soil characteristics significantly influence land use and land cover patterns, with historical data indicating the river's flood-prone nature during the monsoon.

The Ajay River carries a substantial sand load due to its geological and pedological attributes. The sand load deposited in the riverbed flushes during the monsoon season, impacting the Bhagirathi-Hugli River system (Niyogi, 1984). Previous research by pioneers has explored characteristics of alluvial deltaic regions and the rolling topography of plateau regions (Singh, 1995; Roy, 2012). A comprehensive study of the physical environment and channel characteristics can contribute significantly to solving flood problems and ensuring the proper utilisation of basin resources.

5.2.1 Geology

The upper part of the basin is covered by the old series of metamorphosed Granitoid gneiss that formed in the Archean period, also known as Chotonagpur gneiss or Bengal gneiss, which is characterised by fine foliation of schistose plains (GSI, 2013). Few pockets of land are composed of Gondwana sandstone formed in the Gondwana super group and few areas are interrupted by conglomerate during the Talcher formation (Table 5.2). The presence of a few residual monadnocks that have survived erosion and date back to the Gondwana period plays a significant role in the hydrology of the Ajay River basin. These geological formations, located in the middle part of the basin, serve as crucial watershed divides.

The monadnocks contribute to the origination of important tributaries such as the Higlow and the Kunur. These tributaries emerge from these elevated areas and flow into the Ajay River, influencing the river's drainage pattern and water distribution. By acting as water divides, these monadnocks help in segregating the drainage systems of the Damodar basin (Sarkar et al., 2015). This affects the overall hydrological dynamics of the region, impacting water availability, soil moisture, and potentially controlling flood behaviour. The significance of these formations lies in their role in shaping the riverine landscape and supporting the hydrological network within the basin. The interfluves region of the Ajay-Damodar stands on the Ranigaunge coal bed, which formed in the Gondwana period (Figure 5.5). The presence of lineaments and fault lines (Figure 5.6) indicates that the whole basin experiences tectonic activity in a regional context. A vast area of the basin is covered by hard crust Laterite formed in the Cainozoic age. In the lower part of the basin, a vast area is composed of recent alluvium comprising sand, silt, and clay under the Ganga-Kosi formation. In the lower part of the Ajay River basin, three major geological formations have been identified. Mainly, the

Nutanhut formation lies within the dissected alluvial tract. The Katwa surface belongs to the flood plain of the Ajay River and its tributaries. Lastly, the Diara surface belongs to the newer formations of the alluvial track and meander belt (Sarkar et al., 2015). These formations play a critical role in the geomorphology and hydrology of the region, influencing factors such as soil characteristics, water retention, and flood patterns. Understanding these formations helps in managing land use, agricultural practices, and flood control measures within the basin.

Table 5.2 General stratigraphic Sequence of the Ajay basin

Age	Formation	Lithology
Quaternary (Holocene)	Ganga-Kosi formation Sijua formation Panskura formation	Sand, silt and clay (Soft sediments, unoxidised) Soft rock (Sediments with oxidised)
Cainozoic	Laterite	Hard crust
Lr. Gondwana (Upper Carboniferous to Permian)	Barakar Formation Karharbari Talcher	Sandstone, Grit, Shale, Carbonaceous Shale and Coal Shale and Sandstone Sandstone, Shale, Boulders and Conglomerates
Unconformity		
Archaean (Lower to Upper Proterozoic	Chotanagpur Granite Gneiss Complex Unclassified Meta Sedimentatries	Quartz vein, Breciatted Quartz and Pegmatites, Biotite and Quartz biotite granite gneiss Amphibolite, Hornblende Schist and Epidiorite

(Source- GSI, 2013)

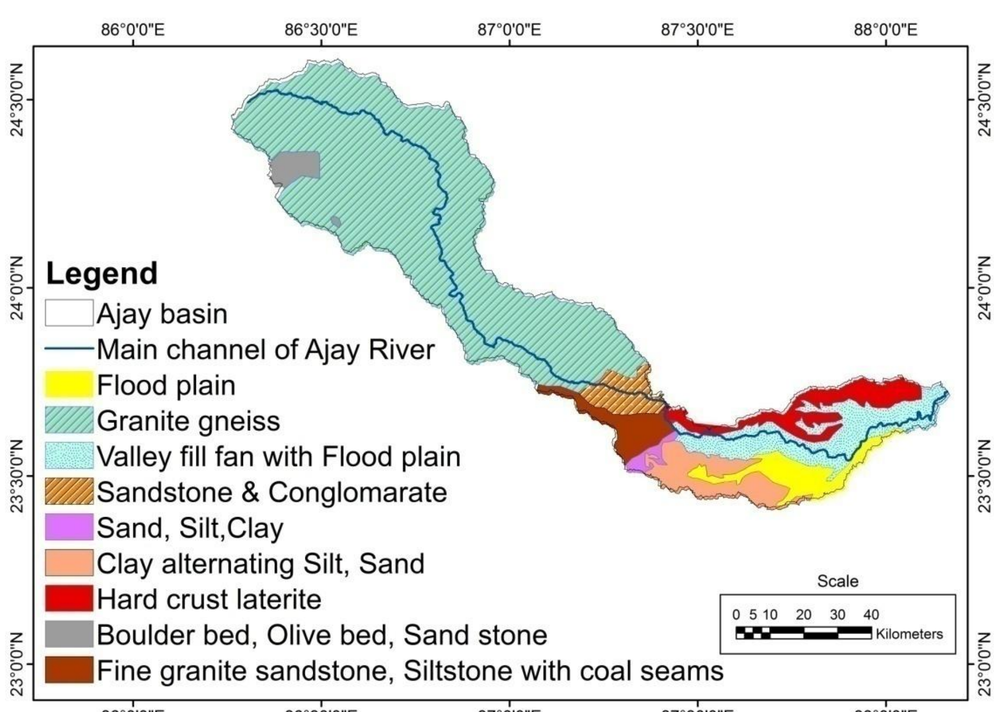


Figure 5.5 Geological setting of the Ajay basin

(Source- GSI, 2013)

5.2.2 Tectonic setting of the basin and its surroundings area

The basin has a rich tectonic history, marked by significant geological events. Particularly noteworthy are the Archean rocks, which have witnessed three generations of fold movements during the Satpura formation (Niyogi, 1984). However, during the Gondwana formation, a major fault line became prominent. In the study area has identified three major basement fault lines, as depicted in Figures 5.6-5.8. These major fault lines include the Chotonagpur Foot hill Fault, Medinipur-Farraka Fault, and Damodar Fault. The Chotonagpur Fault line acts as a boundary separating the peninsular block in the west from the Laterite upland in the east. Similarly, the Medinipur-Farraka Fault line divides the Laterite upland in the west from the Bhagirathi-Ajay-Damodar plain in the east. Lastly, the Damodar Fault line plays a crucial role in delineating the old Ganaga plain from the new Gangetic flood plain (Ghosh et al., 2015; Singh, 1995). This emphasis on the geological and tectonic features provides a solid research background for understanding the basin's structural complexities.

The Ajay basin area experiences significant seasonal and geological influences that affect groundwater levels and river dynamics. In the pre-monsoon season, groundwater levels in the lower Ajay basin are typically 4 to 8 metres below the surface. During the monsoon season, increased rainfall causes these levels to rise dramatically to between 0 and 4 meters. The middle part of the basin contains the Gondwana sand bed, a highly permeable layer. This sand bed allows for rapid groundwater recharge during the rainy season, contributing to a substantial rise in groundwater levels. This rapid recharge is a significant factor in seasonal flooding in the lower basin. Lineaments and faults in the basin area play a crucial role in groundwater recharge. These geological structures act as secondary permeability for water movement, particularly during the rainy season. They enhance the permeability of the basin, facilitating the infiltration of rainwater into the groundwater system. This increased infiltration significantly boosts groundwater levels during periods of heavy rainfall. The Gondwana fault lines have a significant impact on the Ajay River's channel characteristics. These fault lines influence the river's flow patterns, leading to asymmetric channel flows. This asymmetry manifests in uneven flow distribution and variations in erosion and sediment deposition along the river. Sharp changes in the main channel slope, caused by the fault lines, enhance sediment trapping in the lower basin region. This sediment trapping alters the river's sediment load and morphology, contributing to the complexity of flood dynamics. The combination of rapid groundwater recharge and geological influences leads to frequent flooding in the lower basin. As groundwater levels rise during the monsoon season, the ground becomes saturated, resulting in surface runoff and flooding. Sediment trapping in the lower basin further complicates the flood scenario by altering the river's capacity to transport sediment downstream. The Ajay basin area is heavily influenced by seasonal rainfall and geological features. The Gondwana sand bed in the middle part of the basin supplies a significant volume of sediment to downstream regions, affecting the channel's morphology, decreasing the channel intake capacity, and increasing the risk of flooding.

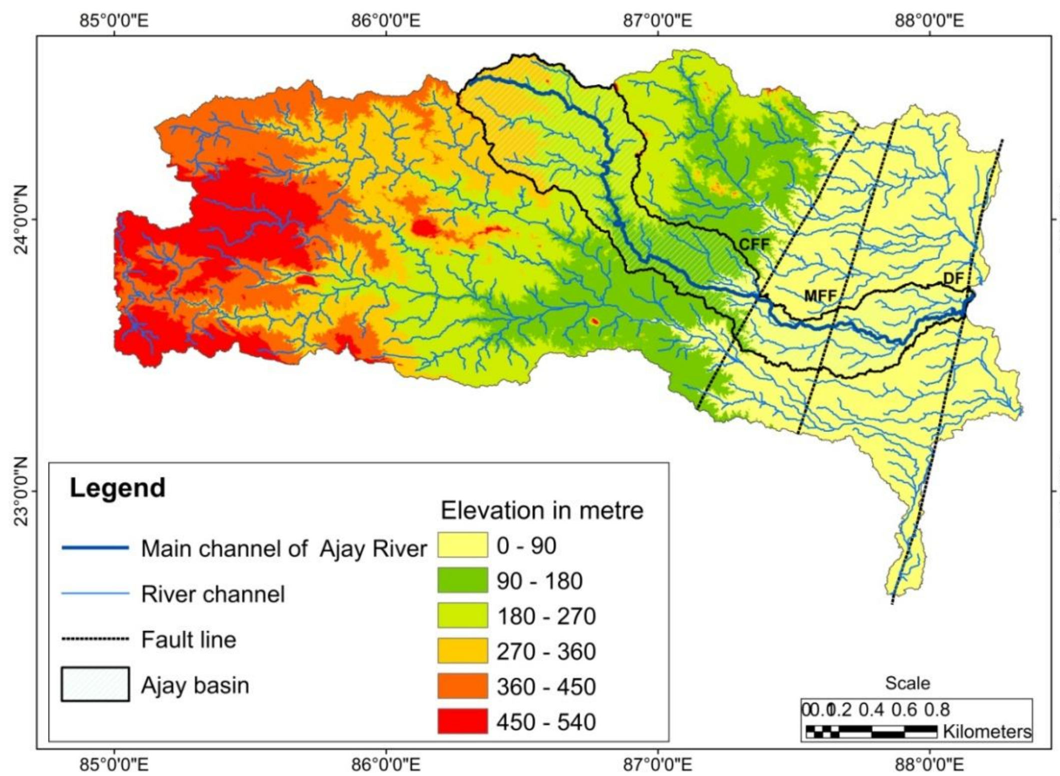


Figure 5.6 Tectonic set up in the Ajay and its surroundings basin CFF – Chotonagpur Foot-Hill Fault, MFF- Mednipur-Farraka Fault, DF- Damodar Fault

(Source-Ghosh et al., 2015; Singh, 1995)

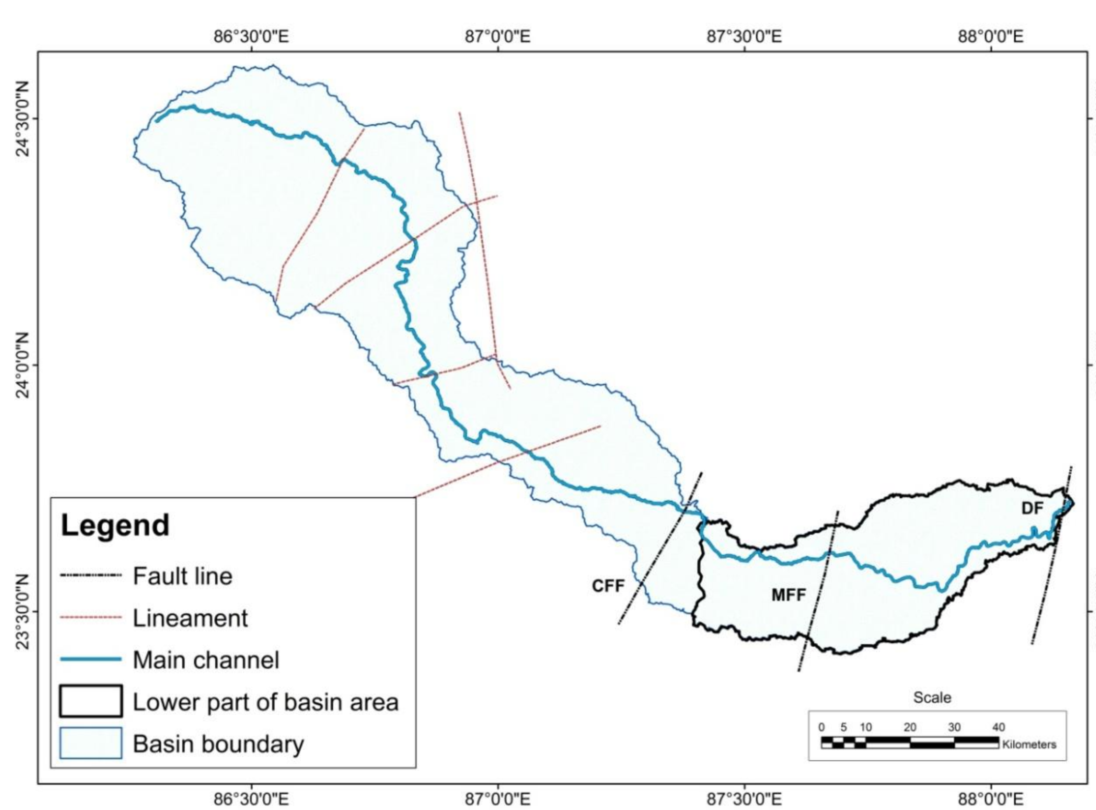


Figure 5.7 Fault and lineament in the Ajay basin

(Source- GSI, 2001, 2013)

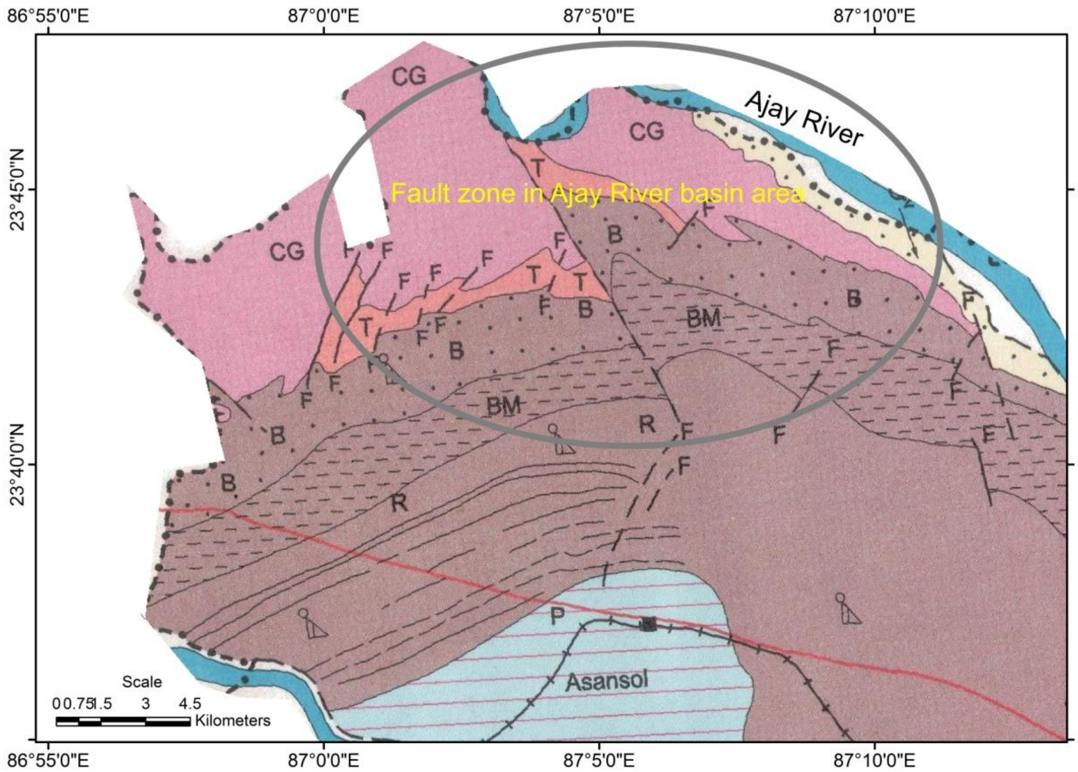


Figure 5.8 Major fault line in the Ajay-Damodar interfluve region

(Source- GSI, 2013)

5.2.3 Geomorphology

The upper part of the basin is characterised by degradational landforms resulting from high erosion prone, coinciding with a network of channels. The area exhibits high absolute and relative relief, leading to soil washout and sheet erosion, resulting in gully marks and the formation of monadnocks with undulating landforms. Subsequently, as absolute and relative relief decrease, monadnocks diminish, but gully marks persist, classifying this area as an erosional plain (Table 5.3). The high soil erosion prone in the upper region contributes to a high sediment-carrying load in the lower part of the region, forming a vast aggradational plain with less diverse landforms. However, the aggradational nature of the landforms also contributes to the diversity of the river channel character in this region (Figure 5.9). Notably, the presence of a wide floodplain with meandering channel flow and sand bar deposition on the riverbed is depicted in micro-aerial photographs.

Table 5.3 Areal coverage of geomorphic units

Geomorphic setup	Area in sq. km	Area in percent
Erosional plain with Monadonock	2250	36.08
Erosional plain	1900	30.47
Depositional plain	2085	33.44

(Source: Calculated by the researcher)

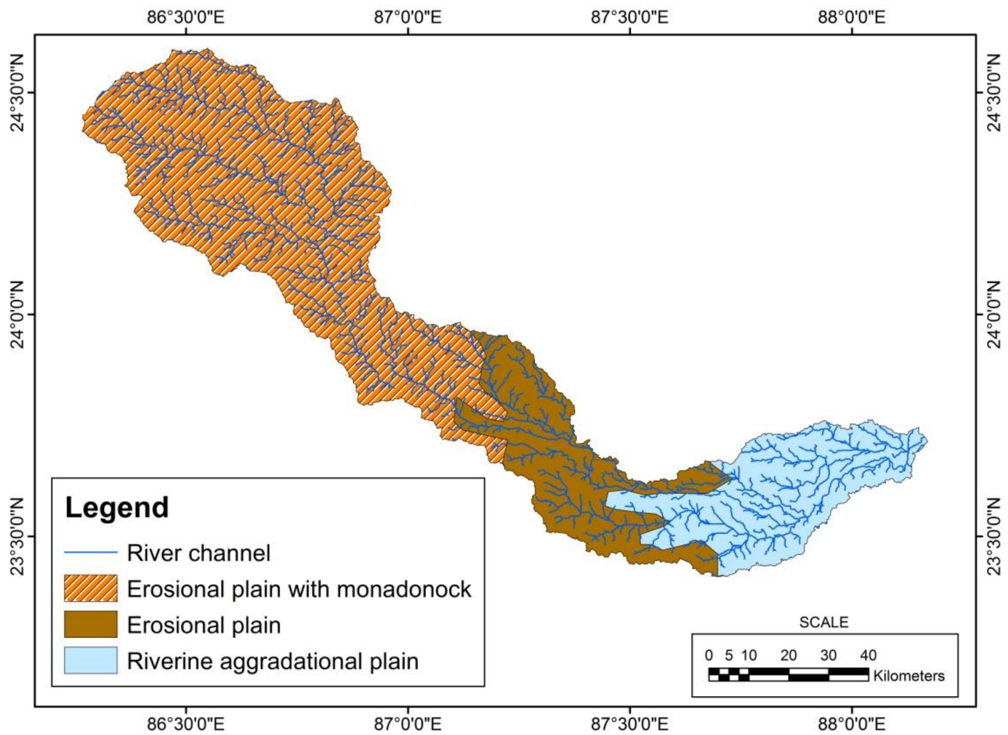


Figure 5.9 Geomorphic units in the Ajay basin

(Source-Thematic Map of ISRO, 2005 & Niyogi, 1984)

5.2.4 Topography

The upper part of the basin is integral to the Chotonagpur plateau, rendering it rugged and undulating in character. Initially, near the main channel's origin, landforms exhibit an average height of about 350 m to 400 m. However, this elevation gradually diminishes towards the confluence region, aligning with the Bengal delta at an elevation of approximately 20 m. The diverse topography leads to its classification into five distinct categories (Figure 5.10).

A comprehensive overview of the Ajay basin's physiography and its regional context reveals that the upper segment belongs to the Chotonagpur erosional plain, while the lower segment lies within the Bengal deltaic region. All rivers in this area converge into the Bhagirathi-Hugli River, functioning as tributaries to the same. The origin segment showcases rugged topography due to high first-order stream density and erosion, resulting in both high relative and absolute relief. Conversely, the subsequent areas experience a decrease in both absolute and relative relief due to variations in parent geology.

In the Bengal deltaic region, the terrain exhibits a more homogeneous and flat character. Analysis of river flow direction indicates a topographic slope from northwest to southeast (Figure 5.11).

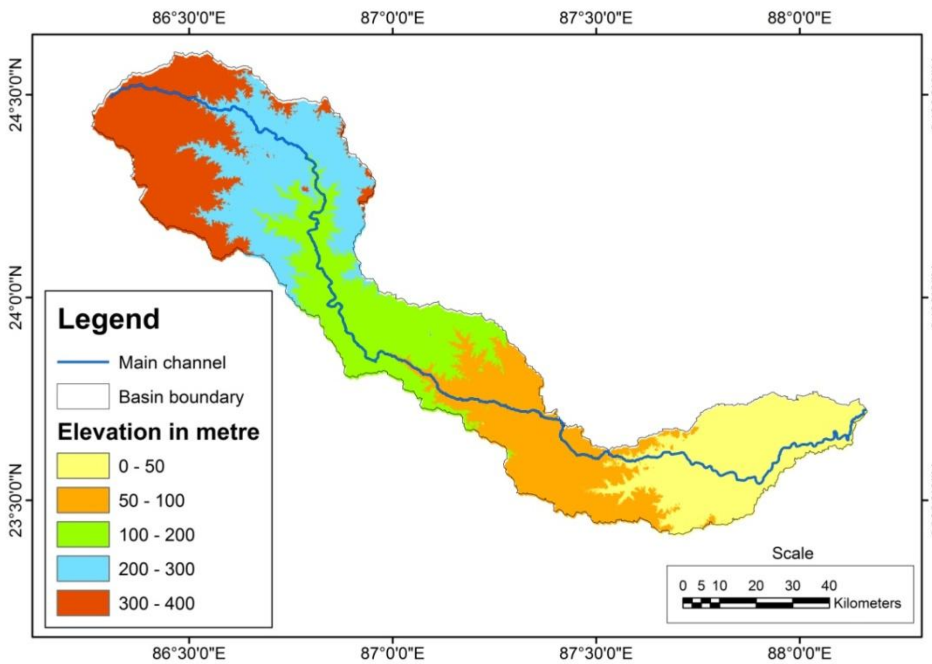


Figure 5.10 Broad physiographic divisions of Ajay basin

(Source- SRTM DEM data, 30 m)

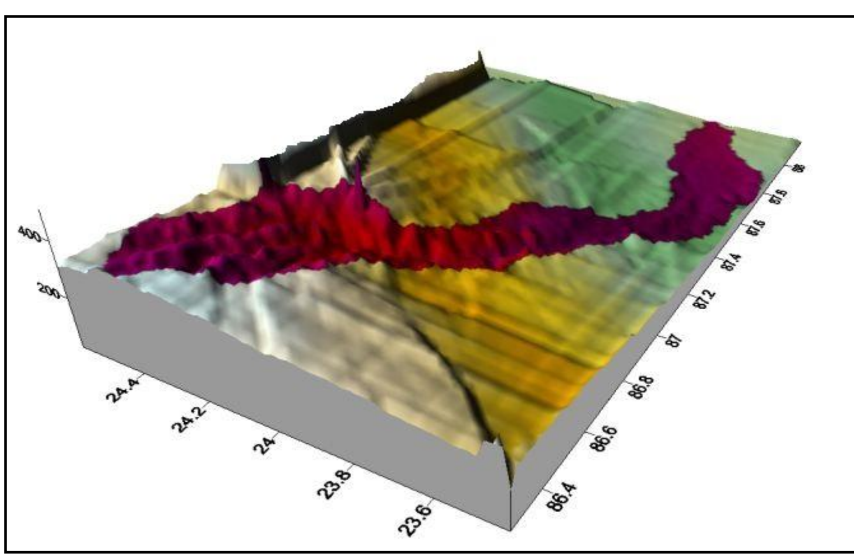


Figure 5.11 Topographic view of the Ajay basin

(Source- Prepared by researcher using SRTM DEM, 30 m)

5.2.5 Analysis of the drainage characteristics of the basin

The construction of the Sikatia Barrage over the main channel marks a pivotal point. Beyond this point, Ajay receives enrichment from one of its significant tributaries, Hnglow, near Pandabeswar in West Bengal. The tectonic system of the Gondwana periods guides the basin's formation from the Sikatia Barrage up to the upper region of the Hinglow River (Niyogi, 1984). Notably, a dam is constructed on Hinglow River to enhance irrigation facilities. Upon the confluence of the Hinglow River in the lower part of the region, the tributary Kunur merges into the main channel from the right side (Figure 5.12). In the lower basin, tributaries are drained through lower ground levels relative to the main channel. Specifically, the Khandar (Kana Ajay) faces difficulties in entering the main channel due to its lower section and depth. During monsoon periods, these tributaries function as distributaries, leading to inundation in pockets of the Lower Ajay region. The significant tributaries, such as Hinglow and Kunur, contribute a large volume of discharge to the lower segment of the Ajay basin. This increased discharge impacts a vast area, including the Bhagirathi interfluves region.

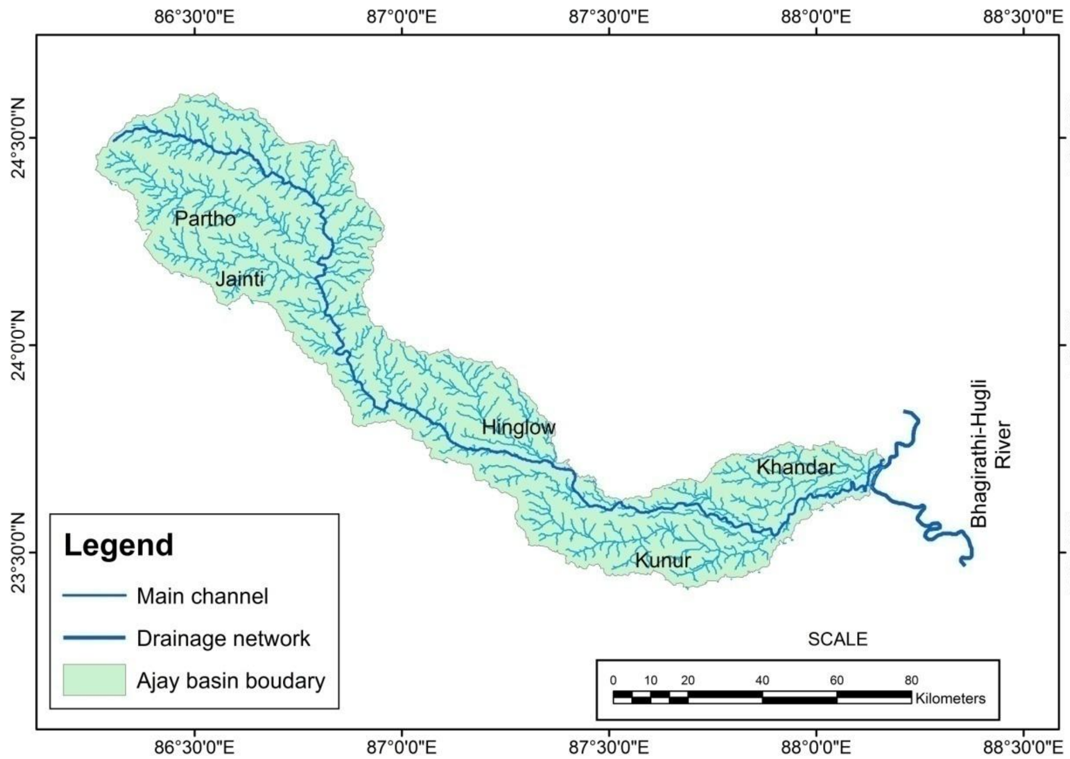


Figure 5.12 Drainage network in the Ajay basin

(Source- SRTM DEM 30 m, and Topographical sheets 1:50000)

5.2.6 Soil

Soil formation in the basin region results from the intricate interplay of geology and climate. This interaction has given rise to a diverse array of soils, reflecting the variability in geological compositions and climatic conditions. A soil taxonomy study based on the NBSS & LUP map series has identified major 5 soil types in the basin region (Figure 5.13).

In the upper region, situated under the Archean Gneiss basement with a moderate slope and a tropical climate, skeletal types of loamy soil prevail. These soils are well-drained and exhibit a loamy texture. Conversely, the lower region features clayey soil under the basement of old and younger quaternary depositions, characterised by a gentle slope. This soil type tends to be moderately to poorly drain and is susceptible to moderate to high levels of flooding (NBSS & LUP, 1987). Additionally, red to yellow soils are found in some areas of the old alluvium tract, displaying moderate drainage but prone to erosion.

Previous studies have identified two types of lateritic soils in the basin area, distinguished as upper unit (50 to 200 cm thick) and lower unit (200 to 300 cm thick) (Singh, 1995). Alluvial soil in the lower part of the Ajay basin area has a high capacity to retain water due to its composition. When combined with poor drainage quality, this can lead to stagnant water conditions and increased flood potentiality. The soil's water retention properties make it prone to water logging.

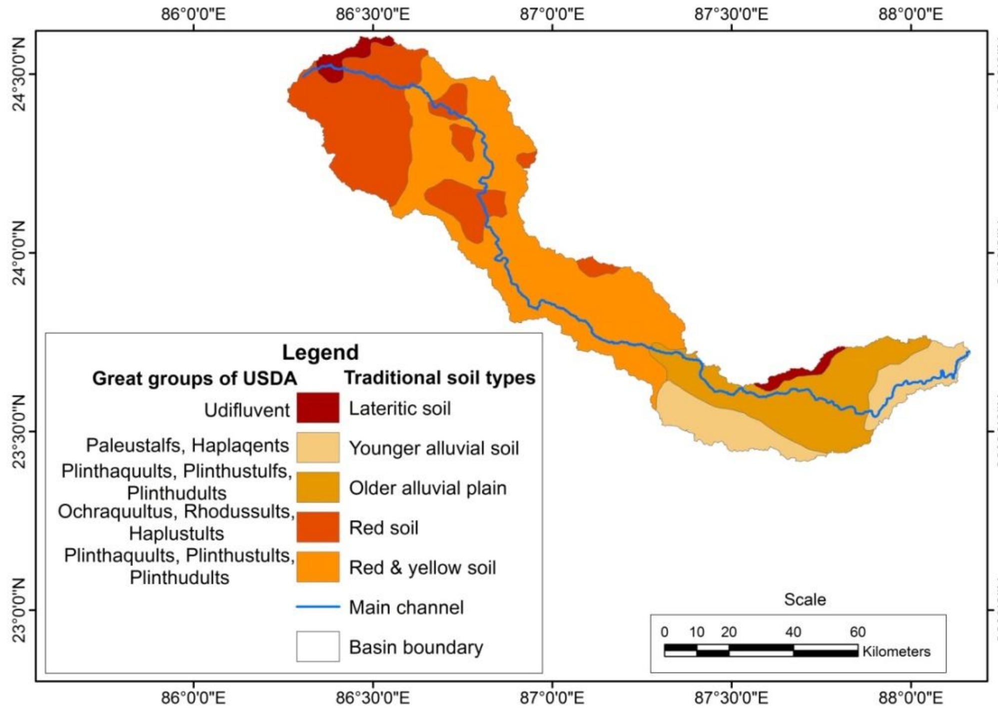


Figure 5.13 Soil map of Ajay basin

(Source- After Niyogi, 1984 and NBSS & LUP soil map Bhar & Jharkhand, Birbhum, Bardwan)

5.2.7 Climate

The region falls under the Tropical Humid Climate with a dry winter season ('AW') and a humid summer with a mild winter ('CW') according to Köppen's classification system (Jha et al., 2011), indicating a tropical monsoon climate. The entire basin experiences substantial rainfall during the monsoon season, typically from June to September or early October, while the remaining months receive comparatively less precipitation. Monsoons contribute to over 80% of the annual rainfall, with frequent flooding occurring due to monsoon outbursts and local depressions over the Bay of Bengal in September and early October (Mukhopadhyay, 2010). Rainfall distribution varies significantly across the basin, with Deogarh recording the highest yearly average rainfall and Jamtara the lowest (Figure 5.14 & 15). The basin exhibits high yearly variation in rainfall, indicating a higher probability of floods. Analysis of rainfall-temperature patterns reveals that maximum temperatures in the upper, middle, and lower basin regions occur during April-May, while peak rainfall is observed in August-September. The region is often impacted by depressions originating in the Bay of Bengal, resulting in fluctuations of heavy rainfall. Such events can lead to significant increases in river discharge, with reports of up to 30 cm of rainfall occurring in the basin over 3-4 days, elevating peak discharge levels by 3-5 metres (Bandyopadhyay, 2018). Moreover, the average humidity in the basin remains relatively high, ranging from 62 to 67% (Niyogi, 1984).

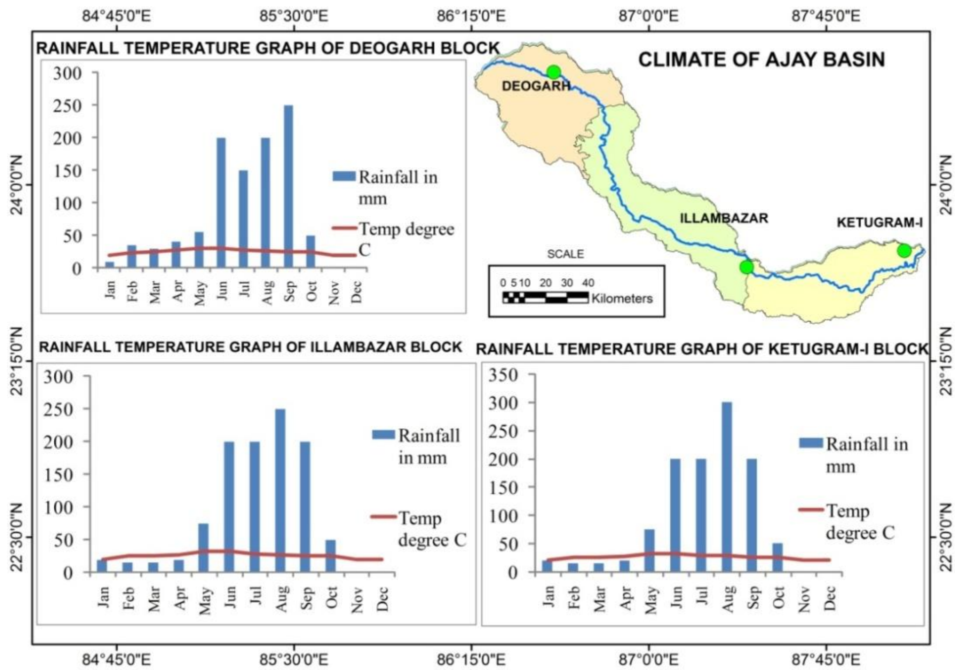


Figure 5.14 Climatic scenario in the Ajay basin region at various locations

(Source-IMD rainfall and temperature data last 10 years average)

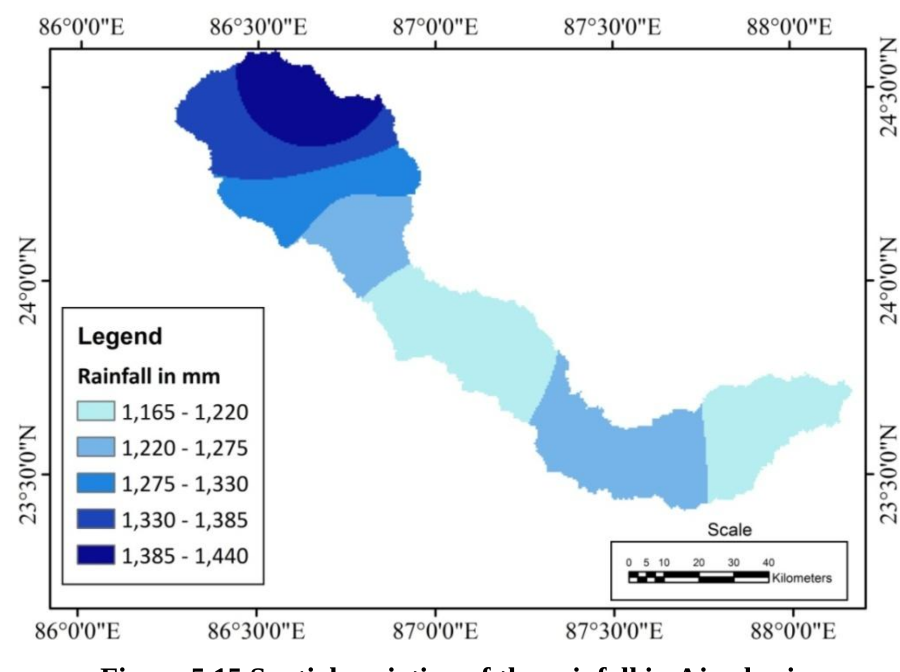


Figure 5.15 Spatial variation of the rainfall in Ajay basin

(Source- IMD, last ten years rainfall data)

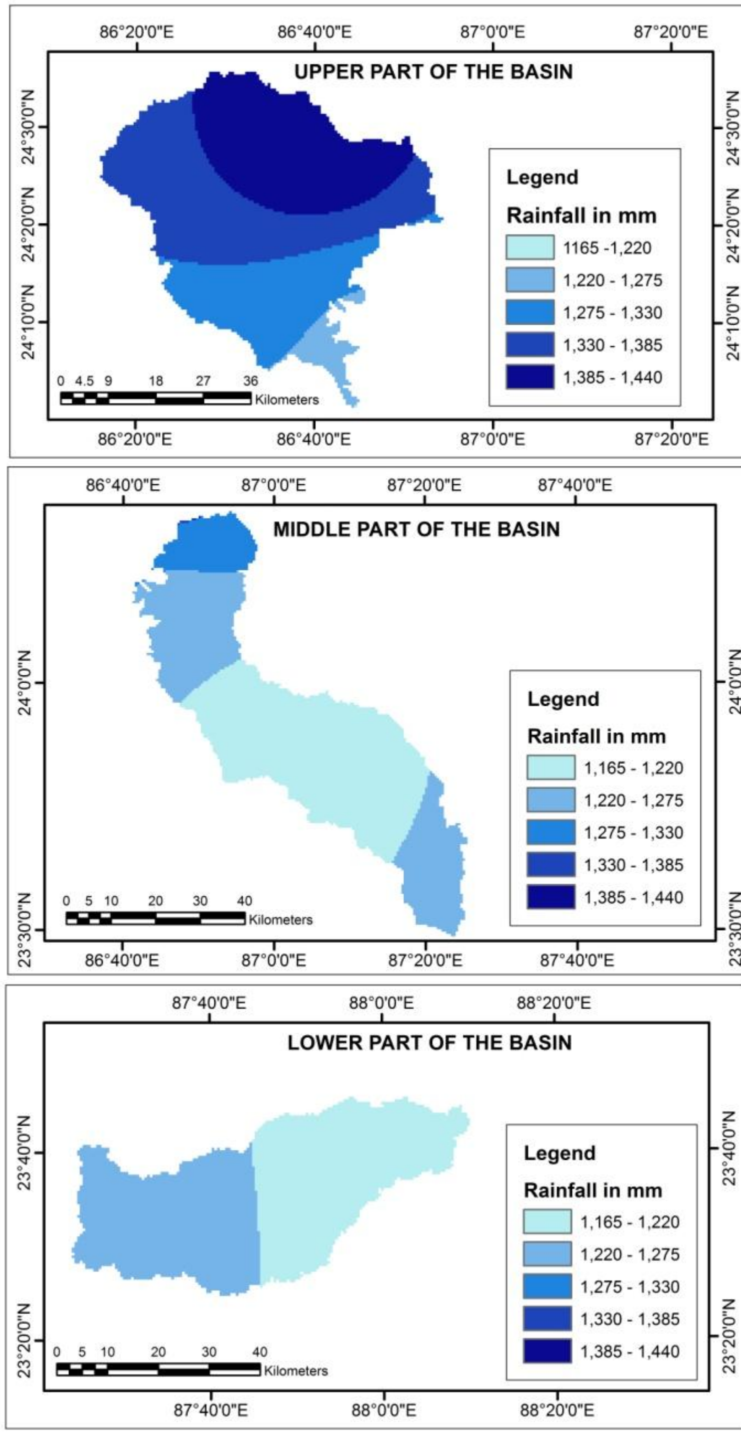


Figure: 5.16 Comparison of spatial variation of the rainfall in Upper, middle and lower part of Ajay basin area

(Source- IMD, Average rainfall data)

The Ajay basin area experiences an average yearly rainfall ranging from 1165 mm to 1440 mm. The upper part of the basin receives comparatively higher rainfall, while consecutive rainfall patterns are observed in both the middle and lower parts of the basin (Figure 5.16). Due to the formation of deep depressions over the Chotanagpur plateau, a large volume of water release from the upper catchment area. This influx of water, combined with the characteristics of the drainage network, significantly impacts the lower part of the basin.

In the lower part of the Ajay basin, the combination of alluvial soil and poor drainage exacerbates the flooding situation. Alluvial soil retains water effectively but drains slowly, leading to water logging and stagnation.

When the upper and middle parts of the basin experience heavy rainfall, the excess water flows downstream, overwhelming the lower basin's drainage capacity.

5.2.8 Ground water

The upper part of the basin predominantly consists of hard crust granite and gneiss, with some areas containing Gondwana sediments. Groundwater recharge primarily occurs through secondary porosity created by fractures and weathering processes in this region.

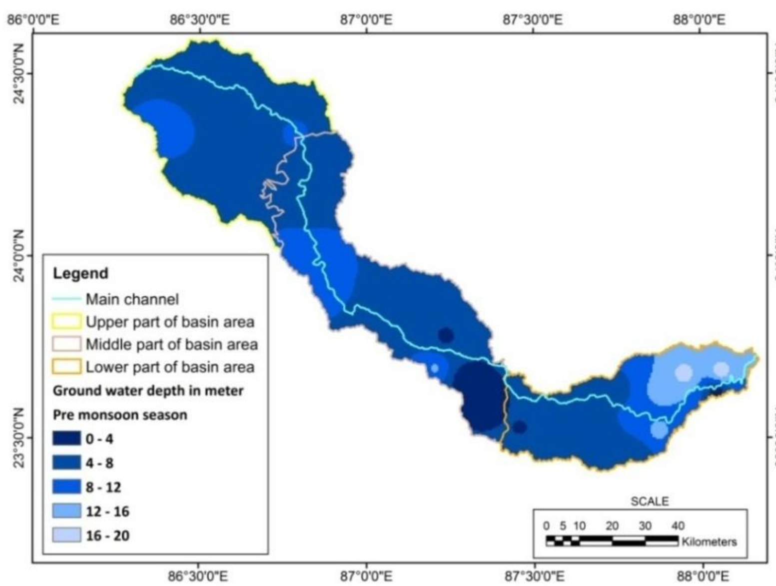


Figure 5.17 Ground Water Table depth in Pre-monsoon periods in Ajay basin

(Source-CGWB report, 2014-15)

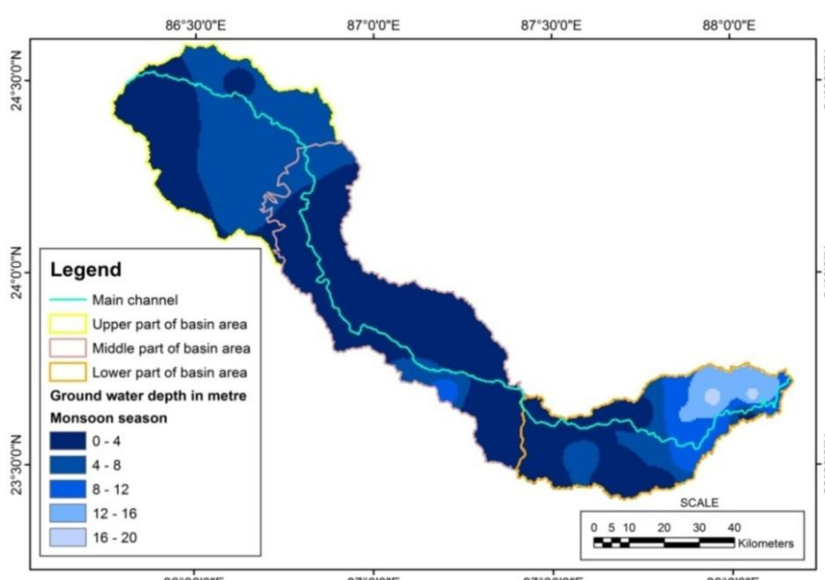


Figure 5.18 Ground Water Table depth in monsoon periods in Ajay basin

(Source-CGWB report 2014-2015)

The aquifers here are mainly unconfined or semi-unconfined, with an average groundwater table height of about 5 metre during the pre-monsoon period (CGWB, Jamtra, & Deoghar districts, 2013).

The Ajay basin area experiences significant seasonal variations in groundwater depth due to the influence of monsoon rains and the geological characteristics of the region. In the pre-monsoon season, groundwater depth ranges from 4 to 8 meters below the ground surface (Figure 5.17). During the monsoon season, the groundwater depth decreases significantly to between 0 and 4 meters (Figure 5.18).

The middle part of the basin contains the Gondwana sand bed, which is highly permeable and allows for rapid recharge of groundwater during the rainy season. This geological feature leads to a substantial rise in groundwater levels.

The rapid groundwater recharge during the monsoon season causes the water level to rise considerably. As the groundwater level approaches or exceeds the ground surface, the soil becomes saturated. Excess rainwater, unable to be absorbed by the saturated ground, results in surface runoff, contributing to flooding in the lower basin area. This phenomenon is particularly evident in the vast area of the lower basin, where the rise in water levels leads to recurrent flooding during the monsoon season.

5.3 Analysis of morphometric characteristics in the Ajay basin using geospatial techniques

5.3.1 General overview

The river basin is a fundamental unit for studying and planning due to its hydrological and topographic relationships (Hajam et al., 2013). For effective river basin management, understanding topographic control, geological setting, and drainage patterns is crucial. The morphometric analysis of a drainage basin in relation to its current topographical framework is particularly significant as it quantifies the basin and relates drainage characteristics to present landforms (Pandey et al., 2011). This analysis serves as the primary step in preparing plans for a basin area. It also reveals the balance between matter and energy within the system (Hajam et al., 2013) and provides insights into the hydro-geological conditions of the basin, especially in un-gauged rivers (Kabite & Gessesse, 2018).

The integration of geospatial techniques and remote sensing data within the GIS field is more advanced and efficient compared to traditional methods (Dash et al., 2019). Traditional methods based on toposheets are time-consuming, expensive, and often challenging to accurately assess all parameters. Conversely, geospatial platforms offer a more streamlined, cost-effective, and time-saving approach. Additionally, the GIS platform facilitates easier correlation estimation among parameters based on specific objectives (Kumar, 2013). The creation of different thematic layers within GIS serves multiple purposes and aids in further analysis.

The traditional observation method using topographical sheets is particularly cumbersome in vast areas, especially in rugged terrain where contour patterns and drainage networks rapidly change and are complex in nature. Geospatial techniques excel in delineating targeted basins and acquiring various hydrological parameters such as drainage density, drainage length, and basin shape, which are critical for analysing river basin characteristics.

Horton (1945), Strahler (1952), Miller (1953), Melton (1957), Shreve (1969), and other esteemed earth scientists have extensively studied the principles of morphometric characteristics of river basins, correlating morphometric parameters with underlying geology and surface geomorphological conditions. Their work has highlighted the profound impact of litho-geological conditions within basins on morphometry and sought to establish connections with current drainage conditions. Therefore, a thorough understanding of a river's hydrological characteristics necessitates morphometric analysis. Currently, watershed management and prioritisation based on morphometry within a GIS platform are pivotal aspects of research (Ahmed & Rao, 2015). For sustainable management concerning fluvio-geomorphic hazards such as floods, erosion, and sedimentation in the Ajay River Basin, morphometric analysis emerges as a key tool for grasping the river's fundamental dynamics (Withanage et al., 2014). Importantly, the river basin has been segmented, and potential hazards have been delineated for each section. Previous studies on river morphometry largely focused on specific parts of the basin or sub-watersheds. The primary objective of this study is to quantitatively analyse basin morphometry and hazard zonation in the Ajay River basin, considering its current litho-geological conditions and leveraging remote sensing data within a GIS platform for reliability, cost-effectiveness, and time efficiency. This study draws upon secondary data, including geological stratification analysis and drainage network assessment. It serves as a foundation for future research in this basin area and establishes a vital database for planning purposes.

Morphometry analysis encompasses three key aspects of a basin: linear, areal, and relief properties (Horton, 1945). In this chapter, these properties of the entire Ajay River basin are comprehensively analysed using DEM data.

5.3.2 Linear properties of the basin

The linear aspect of river basins pertains to the channel pattern and open link drainage network, encompassing the analysis of stream order, stream length, bifurcation ratio, and stream number, among others.

5.3.2.1 Stream order

'Stream order is a measure of a stream's position in the tributary hierarchy (Leopold et al., 1970). Strahler's hierarchical method (1952), a modified version of Horton's method (1945), is used to determine stream order. According to Strahler, first-order streams originate from finger-tip channels, and at the junction of first-order streams, second-order streams form. This hierarchical pattern continues (Figure 5.19).

5.3.2.2 Bifurcation Ratio

The bifurcation ratio illustrates the branching pattern, calculated as the ratio between the number of streams of a given order and the number of streams of the next higher order (Schumm, 1956). It is represented as Rb = Nu / (Nu + 1), where Nu is the number of streams of a given order and Nu+1 is the number of streams of the next higher order.

5.3.3 Areal properties of the drainage basin

The areal properties of a drainage basin, crucial in morphometric analysis, include drainage density, drainage frequency, and the geometric shape of the basin. These parameters influence storm hydrographs, peak flood characteristics, river flow, and flood patterns (Hajam et al., 2013; Nag & Laheri, 2011).

5.3.3.1 Geometric shape of the basin

The basin's geometric shape is a vital areal parameter, reflecting its functional characteristics like water flow, peak flow, and basin lag time.

5.3.3.2 Elongation ratio (Re)

Re is the ratio of the diameter of a circle with the same area as the basin to its maximum length (Schumm, 1956). A low Re indicates a highly elongated basin with high erosion and sediment yield potential.

5.3.3.3 Circularity ratio (Rc)

Rc, defined by Miller (1953), is the ratio of basin area to the area of a circle with the same perimeter. Rc near 1 indicates an ideal circular basin, while values close to 0 signify elongation.

5.3.3.4 Form factor(Ff)

Ff, the ratio of basin area to the square of its length (Horton, 1932; Nongkynrih & Hussian, 2011), indicates basin circularity (high Ff) or elongation (low Ff).

5.3.3.5 Fitness Ratio (Rf)

Rf measures channel lengths compared to basin perimeters, while Rw signifies the sinuous nature of the river (Pareta & Pareta, 2011).

5.3.3.6 Wandering Ratio (Rw)

Wandering ratio is the ratio between main channel length and basin straight line length (length of basin inlet and outlet) (Pareta & Pareta, 2011). It indicates the sinuous character of the river.

5.3.3.7 Drainage frequency

Frequency denotes streams per unit area, reflecting litho-geological conditions, while density is stream length per unit area, influenced by precipitation, vegetation, and geology.

5.3.3.8 Drainage density

Drainage density means the length of the stream per unit area. Drainage density reflects the precipitation effectiveness, vegetation cover and geology of the area. Working on drainage density, drainage channel length has been measured in the GIS platform, and by using the extracted channel length per unit of area, isopleths have been drawn to show the variation of the drainage density.

Drainage density (DD) =Length of the channel/area (Eq. 5.1)

The flow pattern of the river and base flow are directly related to drainage density and frequency. Flood frequency and peak flood also depend on drainage density and frequency (Carlstone, 1963).

5.3.4 Relief properties of the drainage basin

Relief properties encompass vertical dimensions like relative relief, average slope, dissection index, and hypsometric curve, indicating erosion intensity and basin development stage.

5.3.4.1 Relative relief

Relative relief is the difference of minimum and maximum relief in a unit area. For Ajay River basin 5 Sq. km grid has drawn in the GIS platform and results are also represented by isopleths by using ARC GIS tools.

5.3.4.2 Average slope

The average slope is the areal expression of slope distribution. For average slope calculation, the Wentworth average slope method is used on the basis of a 5 sq. km grid and DEM-generated contour crossings per unit of area. The final result is also represented by the isopleths drawn on the platform of ARC GIS. Average slope (Θ) (following Wentworth, 1930) (Pareta & Pareta, 2011).

Average slope $=\underline{(N\times I)/k}^{\tan^{-1}}$ (Eq. 5.2)

N=Number of contour crossing per mile or kilometer, I= interval of contour k=constant 3361 for mile grid and 636.6 for kilometer

5.3.4.3 Dissection index

Dissection Index is a ratio of the relative relief to the absolute relief (Dove Nir's 1957). Dissection index is one of the important indicators to analyse the stage of the erosion cycle (Farhan et al., 2015). Grid method adopted for computation of dissection index.

Dissection index (DI) =Relative Relief /Absolute relief (Dove Nir’s, 1957) (Eq. 5.3)

5.3.4.4 Slope along main course of river

In morphometric aspect, slope not only indicates the landform's characteristics but also reveals the operation of geomorphic processes and equilibrium in river conditions. It is measured by the ratio of the vertical interval to the horizontal equivalent (Sen, 1993). Both the parameters contour and length is measured in GIS platform.

Tangent of Angle of Slope, $\tan \theta = VI/HE$ (Eq. 5.4)

Where, θ =Slope angle in degrees or radians, VI= Vertical Interval (height difference between two points) HE= Horizontal Equivalent (horizontal distance between the two points)

5.3.4.5 Hypsometric curve

"A hypsometric curve is used to show the proportion of the area of the surface at various elevations above or below a given datum" (Sarkar, 2009). It is also known as Area-Height curve, which reveals the actual areas between two successive contours; hence, the horizontal axis represents area in terms of percentage of total area and the vertical axis shows height (Singh, 2006). The hypsometric integral indicates the stage of the basin development. The hypsometric curve analyses the volume of removed mass over a long period of evolution of the basin and geomorphic balance (Biswas et al., 2014). According to Strahler (1964), the hypsometric curve also indicates the stage of erosion.

5.3.5 Analysis of the linear, areal and relief properties in Ajay basin

According to Strahler's stream order method, the Ajay River basin exhibits a 5^{th} order characteristic (Figure 5.19), accompanied by a gradual decrease in the number of streams as the order increases (Table 5.4). Typically, in minimally structurally controlled rivers, the bifurcation ratio ranges between 3 to 5 (Strahler, 1964). However, in the Ajay River basin, the average bifurcation ratio stands at 4.4 (Table 5.4), indicating a homogeneous pattern within the basin (Babu et al., 2016). Notably, the maximum bifurcation ratio occurs between 4^{th} and 5^{th} order streams. Potentiality of overland flow is high in between 4^{th} and 5^{th} order streams (Hajam et al., 2013). A low bifurcation ratio can elevate flood potential as it restricts water from spreading out, potentially leading to increased accumulation (Kulkarni, 2013). Observing an inverted linear trend in the relationship between stream order, number of streams, and stream length aligns with 'Horton's law of stream number' (Figure 5.20), indicating a robust correlation between these variables. The strong correlation coefficient of 0.886 between stream order and number of streams further emphasises this relationship.

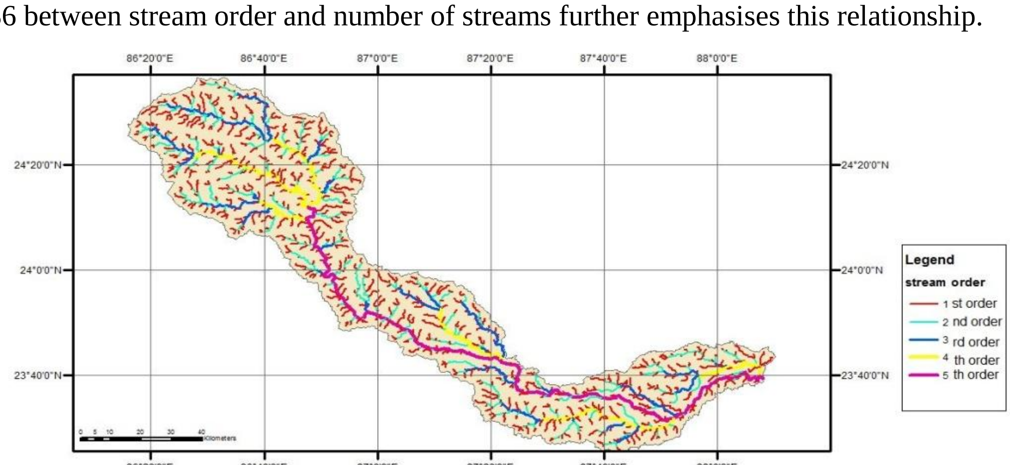


Figure 5.19 Stream order by Strahler's method

(Source-Stream line data extracted from SRTM DEM, 30 m data)

Table 5.4 Calculation of stream ordering

Stream order	Number of stream	Bifurcation ratio	Total length of the stream in km	Length ratio
1st Order	315		290	
2nd Order	120	2.62	270	1.07
3rd Order	30	4	266	1.01
4th Order	6	5	177	1.50
5th Order	1	6	175	1.01
	Total stream number=472	Average bifurcation ratio=4.4		

(Source-Calclated by researcher)

An inverse linear trend (Figure 5.20) is evident between stream order and length, with a notably high correlation coefficient of 0.925, indicating a strong relationship between these variables. This trend suggests that as the stream order increases, individual stream lengths tend to decrease, reflecting the hierarchical nature of the river network. Conversely, a positive trend is observed in mean stream length (Figure 5.20), indicating a gradual increase in channel length with higher stream orders. This trend aligns with expectations as streams of higher orders typically amalgamate and lengthen downstream, contributing to an increase in mean stream length as order increases.

Together, these trends offer valuable insights into the spatial distribution and connectivity of streams within the Ajay River basin, highlighting the dynamic nature of its river network.

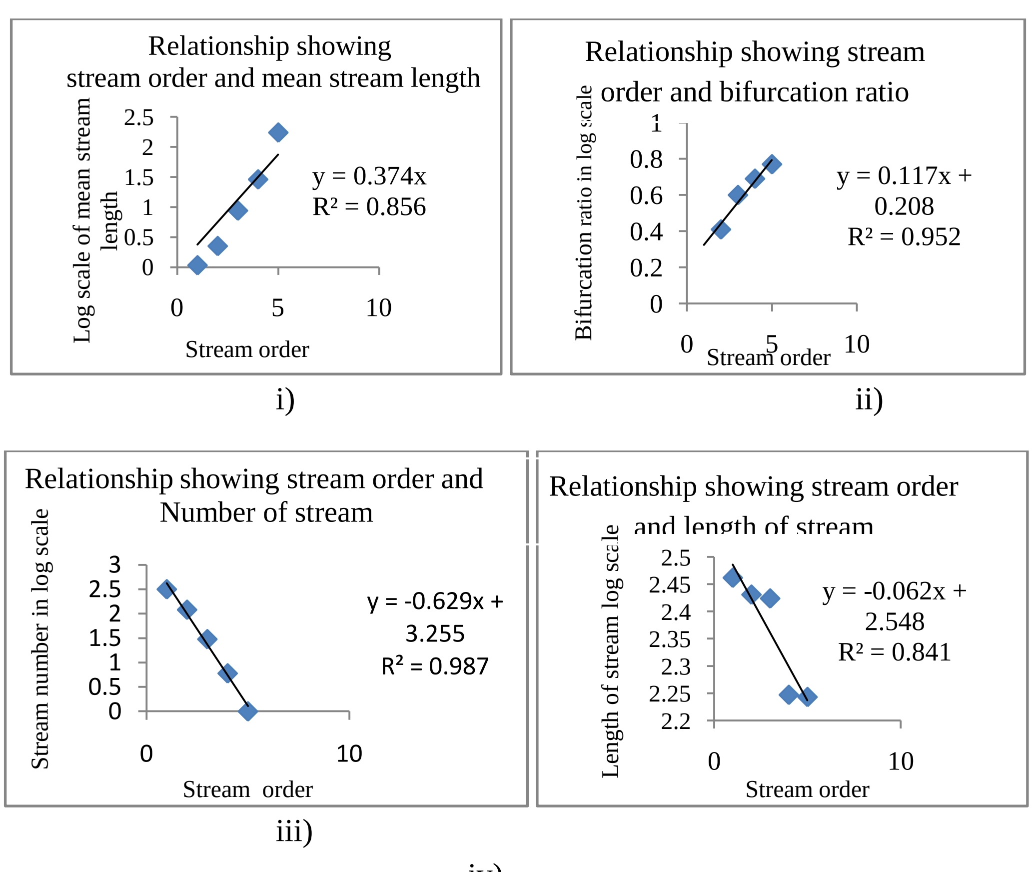
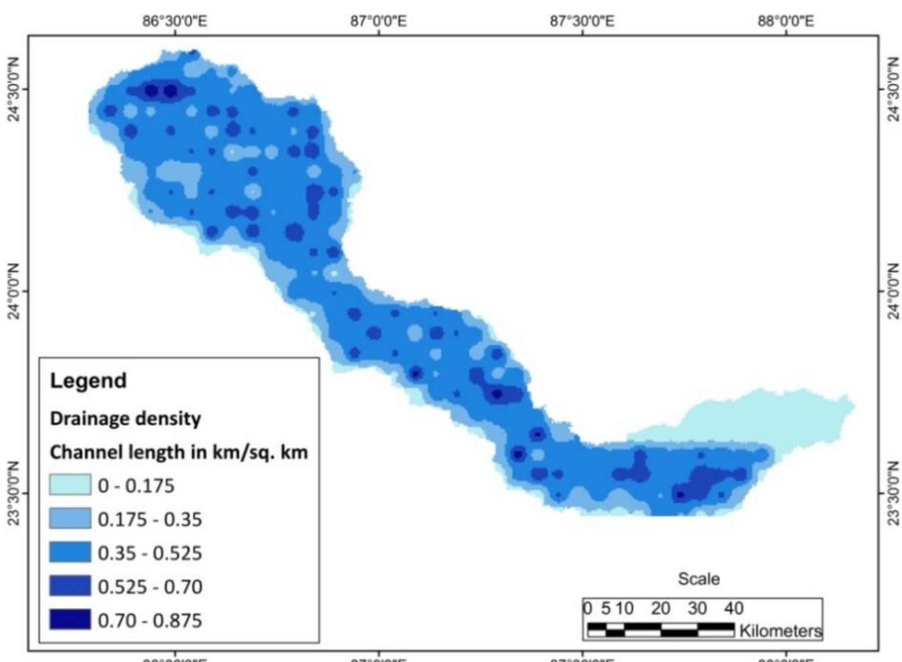
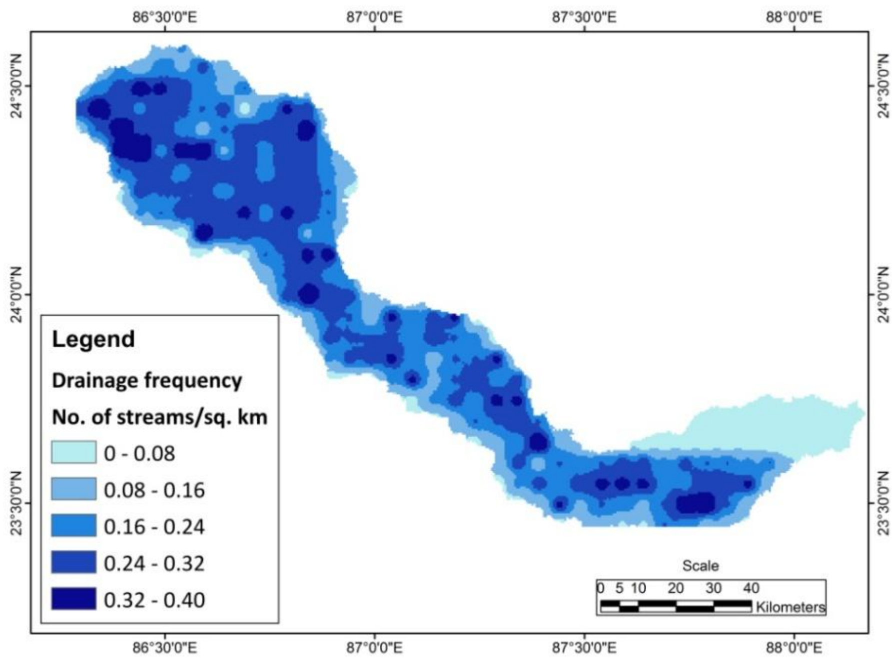


Figure 5.20 i) Linear relation of Stream number with stream order ii) Mean stream length with stream order iii) Bifurcation ratio with stream order iv) Stream length with stream order (Source-Prepared by researcher, After Leopold et al. 1957)

The well-aligned relationship between stream order and channel characteristics in the Ajay River basin reflects its present topographic and geological conditions. The basin's elongated character (categorised as 0.14) (Table 5.5) signifies low peak flows over extended durations and susceptibility to erosion (Farhan et al., 2015). Similarly, the circularity ratio of 0.16 (Table 5.5) indicates a highly elongated basin with high permeable subsoil conditions (Dash et al., 2019). Typically, circular basins exhibit higher runoff amounts compared to elongated basins, which tend to have moderate to low runoff. The form factor of 0.14 (Table 5.5) further confirms the basin's elongated character and low peak flow durations (Farhan et al., 2015). The maximum stream frequency of 0.39 per sq km suggests a low relief and flat topography in the basin area. Areas with high drainage density and frequency in the lower part of the basin correlate with lower flood areas, as low drainage density and frequency are related to flood-prone areas. The high correlation coefficient of 0.96 between drainage density and frequency indicates the channel character's alignment with the landscape (Nag & Laheri, 2011). About 70% of the basin area has very low relative relief (Table 5.6), although residual low-lying hills exist in some pockets (Figure 5.22.i). The basin's relatively low average slope contributes to its flood potential, especially in the lower part where sedimentation rates increase due to a breakdown in the main channel slope (Figure 5.22.iii) (Table 5.7). The poorly dissected nature of the Ajay River basin suggests an older stage in the erosional cycle (Figure 5.22.ii). The low dissected values (Table 5.8) and hypsometric integral of 0.383 (Appendix A) indicate that the basin is in the late mature stage, transitioning toward an older stage of evolution (Figure 5.23). The landscape study and contour patterns reveal residual erosional plains with monadnocks in some areas, along with dominant flat topography across the basin.



i)



ii)

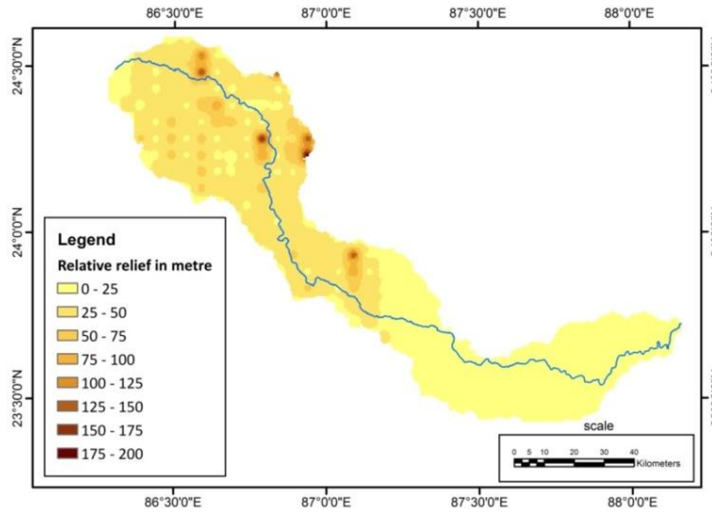
Figure 5.21 i) Drainage density map of Ajay River basin ii) Drainage frequency map of Ajay River basin

(Source- River channel data extracted from SRTM DEM, 30 m and toposheets 1:50000)

Table 5.5 Calculation of morphometric properties

Parameters	Law	Result in Ajay River	Remarks
Elongation ratio (Schumm, 1956)	$Re = \frac{2\sqrt{A/\Pi}}{lb}$ A=Area of the basin lb =Length of the basin	A=6235 sq. km lb=205 km Elongation ratio=0.434	As the result is <0.5 so basin is very elongated.
Circularity ratio (Straheler, 1964)	$Rc=4\Pi A/P^2$ A=Area of the basin P=Perimeter of the basin	Perimeter=696.25 km Circularity ratio 0.161	As the value is very close to 0 so the basin is very much elongated.
Form factor (Horton, 1945)	$Ff=A/lb^2$ A=Area of the basin, lb=Length of the basin	Form factor 0.148	Close to 0 indicates the elongation of the basin
Fitness ratio (Melton, 1957)	Rf = cl/p cl= Main channel length, P= Basin perimeters	Cl=290 km P=696.256 km Fitness ratio 0.41	Measure the topographic fitness
Wandering ratio (Smart & Surkan, 1967)	Rw = cl/lb cl=Main channel length, lb=Basin length	Wandering ratio 1.41	Sinous in character
Basin relief (Schumm,1956)	Maximum relief in basin-Minimum relief in basin	390 metre	Change of the relief

(Source-Calculated by reseacher)



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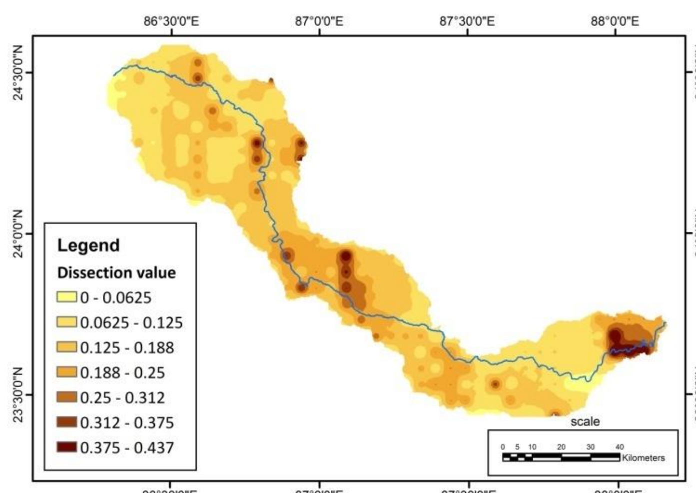

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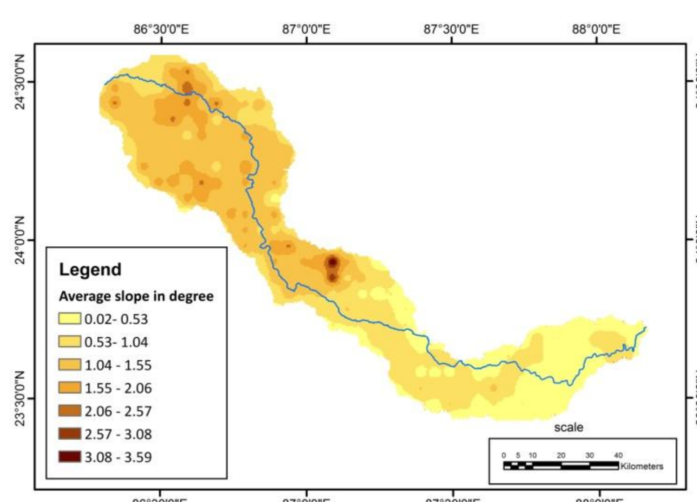


iii)

Figure 5.22 i) Relative Relief map of Ajay basin ii) Dissection map of Ajay basin iii) Average slope map of Ajay basin

(Source-SRTM DEM, 30 m, Toposheets 1:50000)

Table 5.6 Areal coverage of relative relief zones

Relative relief in metre	Percentage of area cover
0-25	70
25-50	22.4
50-75	4.4
75-100	0.4
100-125	0.8
125-150	1.2
150-175	0.4
175-200	0.4

(Source-Calculated by reseacher)

Table 5.7 Areal coverage of dissection index

Dissection value	Area of percentage
0-0.0625	12.8
0.0625-0.124	32.8
0.124-0.187	31.6
0.187-0.249	10.8
0.249-0.312	7.6
0.312-0.374	1.6
0.374-0.437	2.8

(Source-Calculated by reseacher)

Table 5.8 Areal coverage of average slope

Average slope in degree	Percentage of area cover
0.02-0.53	24
0.53-1.04	37.6
1.04-1.55	22.4
1.55-2.06	12
2.06-2.57	3.2
2.57-3.08	0.4
3.08-3.59	0.4

(Source-Calculated by reseacher)

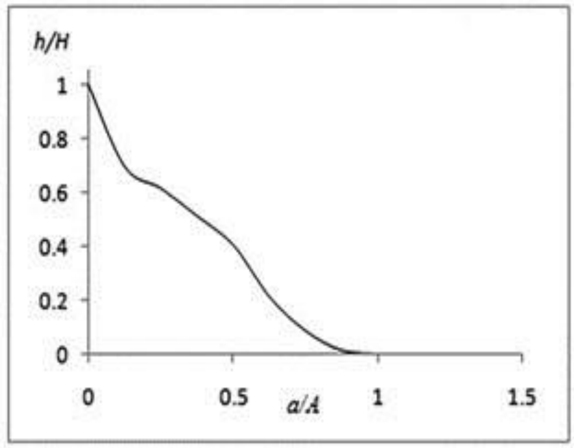


Figure 5.23 Hypsometric curve

The Y-axis (h/H) represents relative elevation, where: H is the maximum elevation within the drainage basin, h is the elevation at a specific point in the basin. The X-axis (a/A) represents relative area, where: A is the total area of the drainage basin and a is the area of land that lies above a given elevation (h) Willgoose & Hancock, 1998

(Source-SRTM DEM, 30 m, Toposheets 1:50000)

5.3.6 Morphometric analysis in upper, middle and lower part of the basin

Dividing the Ajay River basin into upper, middle, and lower parts based on topographic variations and slope breaks allows for a micro-scale study of morphometry, reflecting changes in river characteristics (Figure 5.24). This approach is especially significant given the basin's varying litho-geological and climatic environments.

The elongation ratio in the upper part is 0.31, while in the middle and lower parts; it is 0.19, indicating a higher degree of elongation in the latter parts. The gradient also varies across these sections, with the upper part having a gradient of 2.27, compared to 0.46 in the middle part and 0.42 in the lower part.

The upper part, characterised by a high relief ratio, comprises an erosional plain with monadnocks underlined by resistant granitoid rocks. Conversely, the lower part consists of a floodplain area with low relief and flat topography. The middle part, structurally weak with fault lines and unconformities, lies between Archean hard crust series and Gondwana sedimentary strata.

The hypsometric integral in the upper, middle, and lower parts respectively indicate their erosional cycle stages: youth (0.667), mature (0.49), and old (0.31). This stage-wise analysis aligns with the underlying rock structures, where the upper part exhibits erosional resistance due to granitoid gneiss, while the middle part features Gondwana sedimentary strata, and the lower part comprises Tertiary sedimentary beds.

The impact of basin morphometry extends to river channel behavior, especially in the lower part characterised by meandering flow with low average slope and relief, leading to sediment trapping and increased erosion. Human activities like embankment construction and sand quarrying further impact river health and morphology, affecting channel carrying capacity and sediment deposition rates. Incorporating basin geometry and geomorphic considerations alongside flood prediction and runoff estimation enhances the accuracy of results and aids in understanding river dynamics and responses to environmental changes.

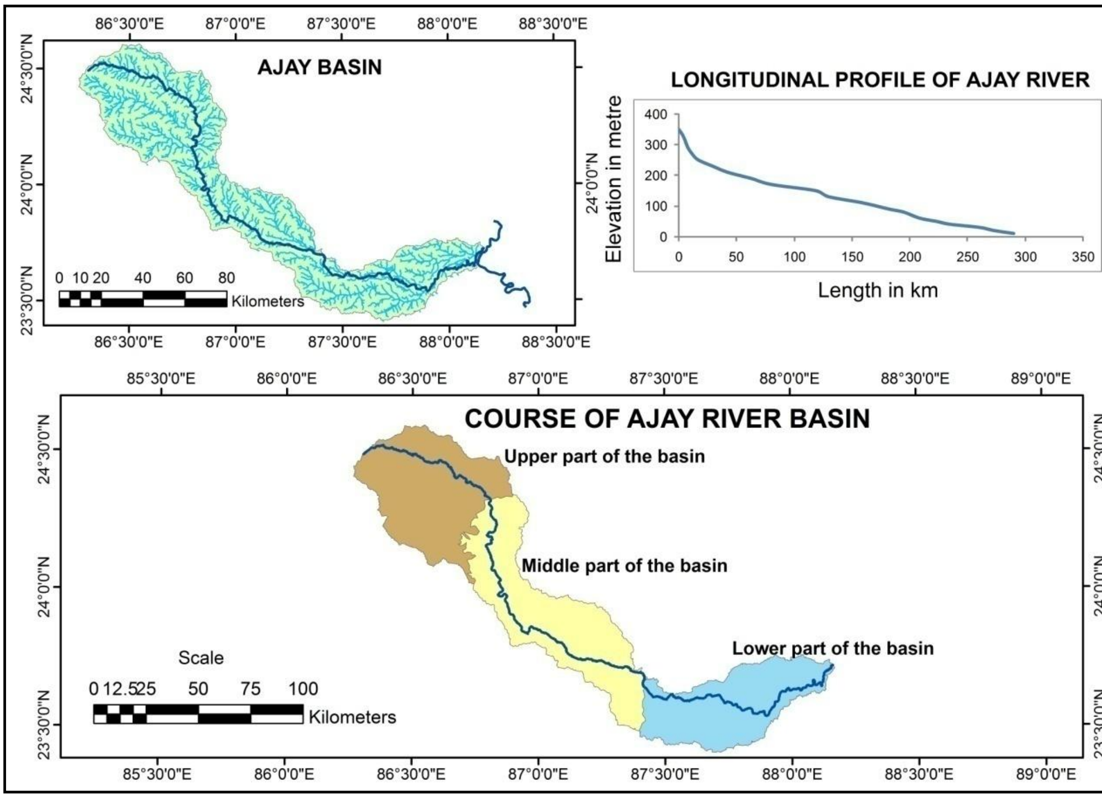


Figure 5.24 River course divisions along the basin slope

(Source-Basin boundary and channel data extracted from SRTM DEM, 30 m)

The drainage morphometric study plays a crucial role in understanding the characteristics of a river basin and is instrumental in geo-environmental management. Currently, making decisions regarding basin resource utilisation, flood control, water resource management, and land use planning requires a strong foundation of geo-hydrological knowledge, with morphometry providing fundamental insights into the natural unit. The hypsometric curve is particularly valuable as it depicts the basin's evolution and geomorphic balance over an extended period. Utilising geospatial techniques for morphometric analysis has proven to be highly satisfactory and efficient. The analysis of the Ajay drainage system reveals its dendritic nature, indicating a homogeneous underlying structure. Large portions of the basin feature low relief and slope, making them prone to flooding and conducive to high rates of sediment deposition. Human activities such as embankment construction have contributed to increased sediment deposition, leading to river bed aggradation and the formation of stable sandbars, which in turn heightens the risk of flooding. Parameters like the hypsometric integral and dissection index indicate that the basin is in the old stage of the erosional cycle, with some erosional residue present. A holistic approach to basin morphometry analysis is ideal, although in certain instances, dividing the basin for a more detailed study may be beneficial.

This work serves as a foundational step for further research and future planning initiatives focused on the Ajay River basin, providing valuable insights for sustainable management and mitigation strategies.

5.4 Analysis of the channel properties in the lower part of Ajay River

5.4.1 General overview

The study of the fluvial cycle and stages is crucial for understanding how processes and forms interact in river systems. The Ajay River, flowing through a tropical, humid region with seasonal flow variations, demonstrates complex channel responses shaped by sediment supply, water energy, and topographical factors.

During peak seasons, the Ajay River transports a significant amount of sediment from its upper reaches, influencing channel formation. Sediment size variations further impact channel morphology. Accumulation of sediment in the downstream region due to high supply alters energy balance, leading to diverse channel formations and bed landscapes.

The basin's composition, including metamorphosed granitoid gneiss in the upper part, a hard crust lateritic belt in the middle, and a flood plain in the lower part, alongside fault lines and lineaments, reflects tectonic influences on the river basin. Notably, lineaments along the Hinglow track in the middle part suggest tectonic control.

Geomorphologically, the upper and middle parts exhibit erosional processes, while the lower part is marked by depositional features. Hypsometric integral of 0.383 is indicating that the basin lies mature to old stage with monadonoks and aggradational plains.

Analysing flood control and lower channel dynamics is crucial, given the diverse bed channel character and high flood risk in the lower Ajay River. This area requires detailed examination due to its alluvial plain nature and varying channel characteristics, impacting flood management and river channel dynamics significantly.

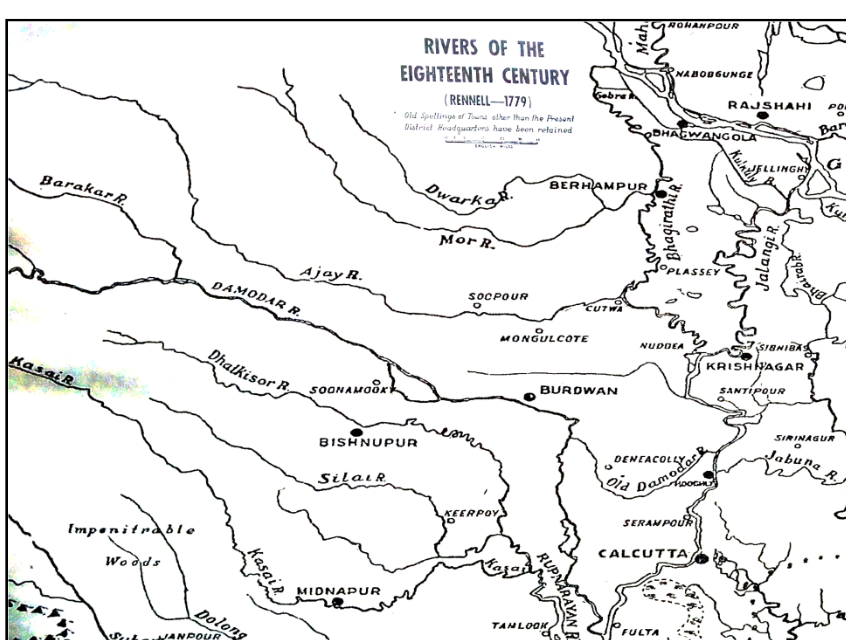


Figure 5.25 River Ajay in the Rennel's Map, 1779

(Source - National Library)

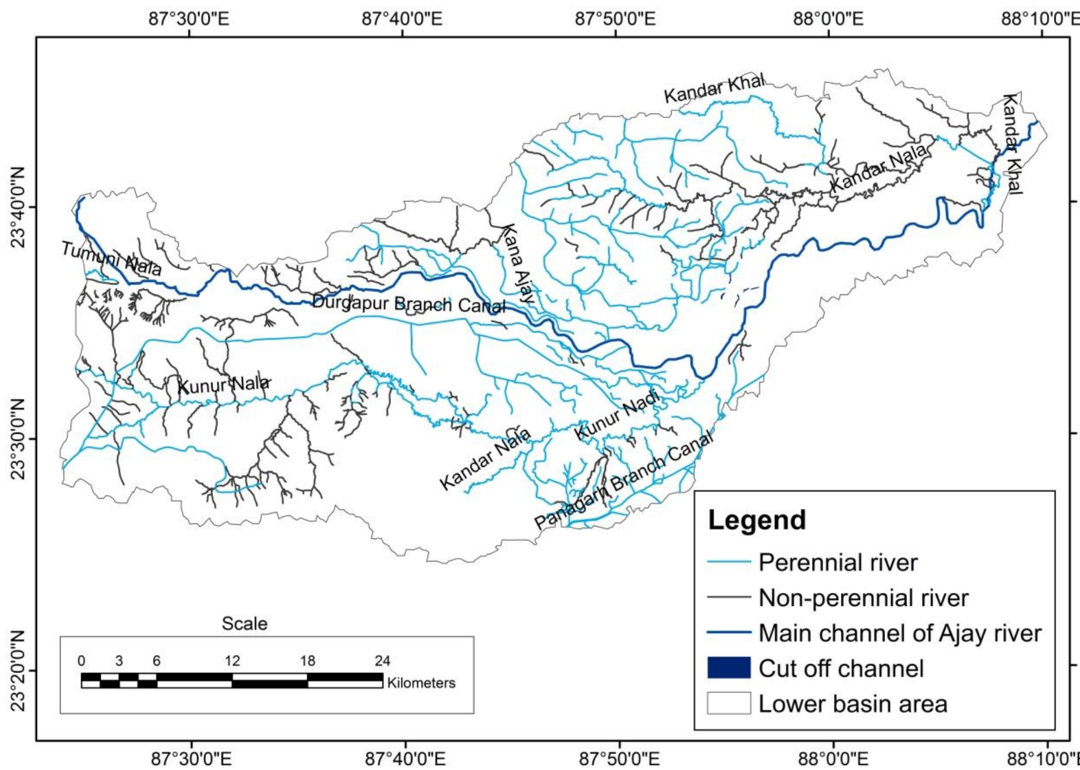


Figure 5.26 Present drainage systems in the lower part of Ajay River basin

(Source-Topographical sheet, 1: 50,000)

The historical mapping of the Bengal river channels, particularly the Ajay River, provides significant insights into the region's past and its relation to human civilisation. Renel's map in 1779 (Figure 5.25) and subsequent more detailed maps like the Bengal-Bihar-Orissa map in 1874–75 showcase the prominence of the Ajay River channel. Archaeological surveys conducted during 1965–70 shed light on the ancient agro-based civilisation in Aushgram II, now known as Pandu Rajar Dhibi, situated in the floodplain of the Ajay River. This civilisation from the Chalcolithic period holds a rich history, highlighting the importance of fertile soil and water resources in sustaining human settlements (Banerjee, 2012).The presence of well-developed agriculture and usable machinery indicates the technological advancement of this ancient civilisation. Similar contemporary civilisations were also found along the neighboring Mayurakshi River, such as Jakherdanga in Birbhum. Studying paleo-evidence allows us to bridge the past with present river conditions (Figure 5.26), offering a clear understanding of the river's dynamics and its historical significance in supporting human life and development.

5.4.2 Channel character of the lower Ajay River

The significant variation in channel width observed in the lower Ajay basin has implications for the channel carrying capacity and overall hydrological dynamics. Typically, river channel width tends to increase gradually with the length of the river. However, in the case of the Ajay basin, this variation is pronounced, as seen in the stark contrast between widths near Bhedia (approximately 700 m) and Katwa (only 250 m) (Figure 5.27). Local geological features, such as the presence of outcrops and lateritic bed conditions, play a crucial role in causing such wide variations in channel width. These geological factors can influence the river's erosional and depositional processes, thereby impacting its width. Additionally, historical embankment construction, particularly during the Zamindari periods, has contributed to the discontinuous nature of the river's embankments. This discontinuity in embankments can further exacerbate channel width variations, as it may lead to changes in flow patterns and sediment transport along different stretches of the river. Understanding these factors contributing to channel width variation is essential for effective river management and planning, especially in areas prone to flooding or sediment deposition. It underscores the complexity of river dynamics and the need for comprehensive approaches to river basin management.

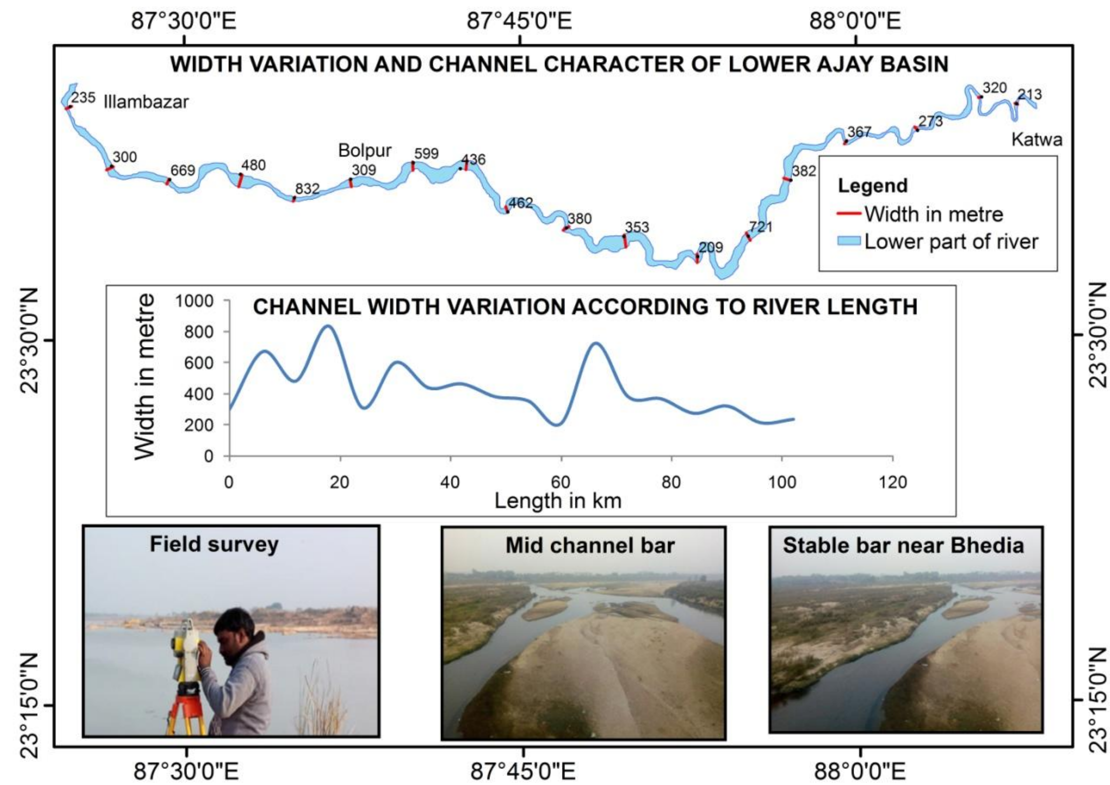


Figure 5.27 Channel width variation of the lower Ajay River

(Source-LANDSAT 8, 2018 and field survey by Total Station)

5.4.2.1 Wetted perimeter

The wetted perimeter plays a crucial role in determining river health and ecological flow by regulating the interaction between surface flow and base flow within the river channel. In the lower part of the Ajay River, there is a notable spatial variation in the active channel and wetted perimeters, as depicted in Figures 5.28-5.30. This spatial variation is primarily influenced by the control exerted by the tropical monsoon climate, leading to significant temporal fluctuations in the wetted perimeter. These fluctuations are highly relevant for understanding river health and channel behaviour. The main factors contributing to the variation in wetted perimeter include channel width and sediment trapping. Human activities such as sand quarrying and bed cultivation further exacerbate this variation and have negative impacts on the wetted perimeter of the river. During the lean season, measurements of the wetted perimeter indicate a lack of consistent trends and reveal high variability. This variability underscores the dynamic nature of river channels and the importance of considering various factors, including human interventions, in assessing wetted perimeter fluctuations.

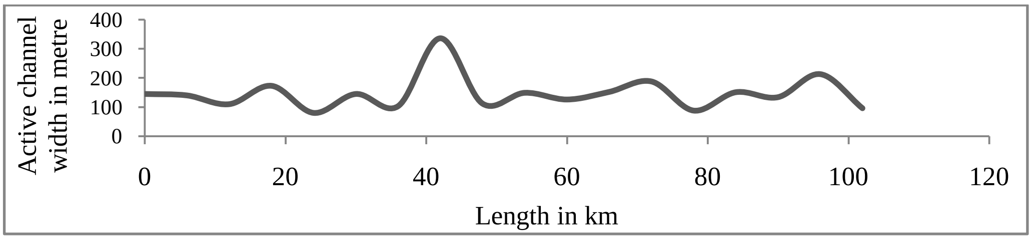


Figure 5.28 Graph showing variation of active channel widths in the lower Ajay River

(Source-Topographical sheets and field survey at various points)

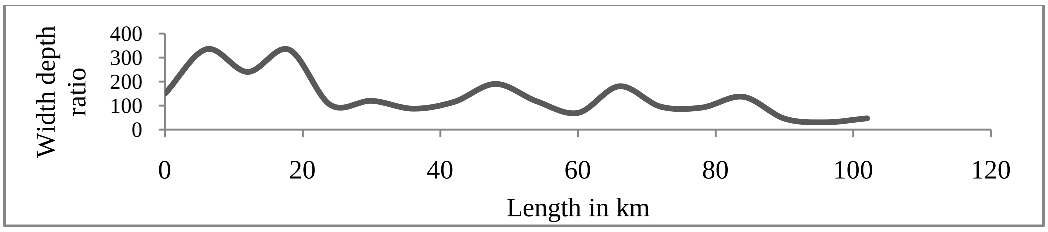


Figure 5.29 Graph showing variation of width-depth ratio in lower Ajay River

(Source-Topographical sheets and field survey at various points)

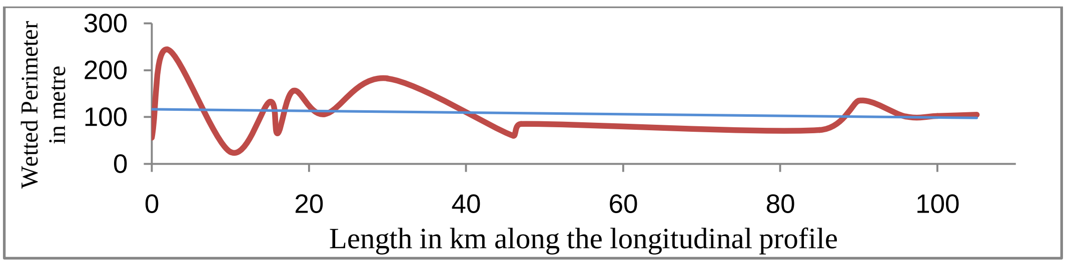


Figure 5.30 Graph showing variation of wetted perimeter in lower Ajay River

(Source-Field survey in lean season 2017-2020)

5.4.2.2 Sinuosity of the lower Ajay River

A highly sinuous river channel is evident in the lower part of the Ajay River, as indicated in Table 5.9 (Figures 5.31 & 5.32). This sinuosity is attributed to the decrease in energy and the high potential sediment load, resulting in the transformation of the channel into a sinuous form. In many instances, sinuous bends have evolved into meandering patterns. Sinuosity, quantified by the Sinuosity Index (SI) with values ranging from 1.31 to 3.90 as per Equation 4.1 (Table 5.9), further highlights this characteristic. Interestingly, while sinuosity typically increases with a decrease in the relief ratio, the lower part of the Ajay River does not follow a linear trend in channel behavior. Instead, there is significant variability in sinuosity along the river, indicating fluctuations in river energy and channel dynamics. The high sediment load and the confinement of the river within embankments have led to the common formation of sandbars in the lower part of the river channel. In some areas, this has even resulted in the development of a braided channel pattern. Various types of bars have been identified through satellite imagery and field observations, as illustrated in Figure 5.34.The sinuous channel analysis over three respective years (1991, 2001, and 2011) demonstrates the dynamic nature of sinuous channels, as depicted in Figure 5.33. There is a gradual transition towards increased meandering within these periods, often accompanied by a decrease in the radius of curvature (Table 5.10).The rise in bed load serves as a significant factor contributing to the river's meandering tendency. Although embankment construction along both sides of the riverbanks has curbed channel shifting, alterations in sinuosity in the lower part remain noteworthy. The variation in active channel width in the lower Ajay area is substantial; for instance, the active channel width near Illambazar measures 145 m, whereas near Nelegarh it is only 80 m, and near Katwa, it is 96 m (Figure 5.28). Unscientific sand quarrying from the riverbed and bed cultivation during the lean season contributes to the channel's degradation in the lower part of the Ajay River. The significant variation in width-depth ratio, exacerbated by human encroachment, is also evident (Figure 5.29). Activities like bed cultivation for Rabi crop irrigation during the lean season, along with channel restoration and diversion efforts, play a major role in channel constriction.

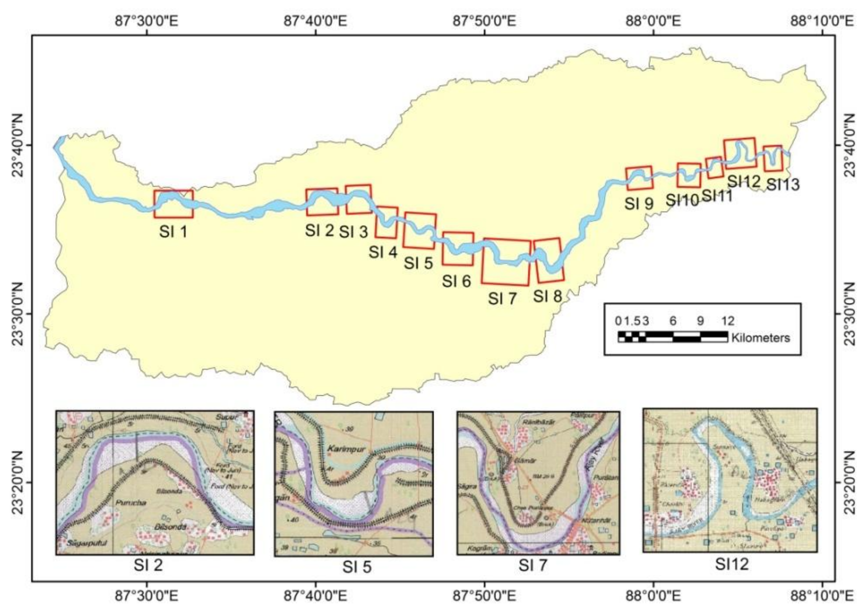


Figure 5.31 Spatial variation of sinuosity in lower part of the Ajay River

(Source-Topographical sheets 1:50000)

Table 5.9 Sinuosity measurement in lower part of Ajay River

Station name	Observed distance in km	Expected distance in km	SI
SI1	5.05	3.09	1.63
SI2	3.34	2.29	1.45
SI3	2.9	2.06	1.40
SI4	3.47	2.11	1.64
SI5	3.26	2.15	1.51
SI6	4.12	3.10	1.32
SI7	5.04	3.07	1.64
SI8	2.58	1.01	2.55
SI9	6.09	2.67	2.28
SI10	5.20	1.33	3.90
SI11	2.27	1.72	1.31
SI12	6.41	2.43	2.63
SI13	4.24	1.68	2.52

Average sinuosity of the lower channel is 1.98

(Source-calculated by researcher)

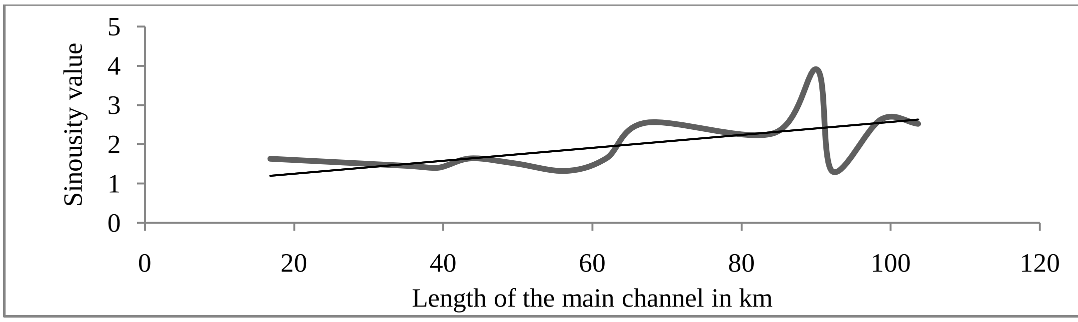
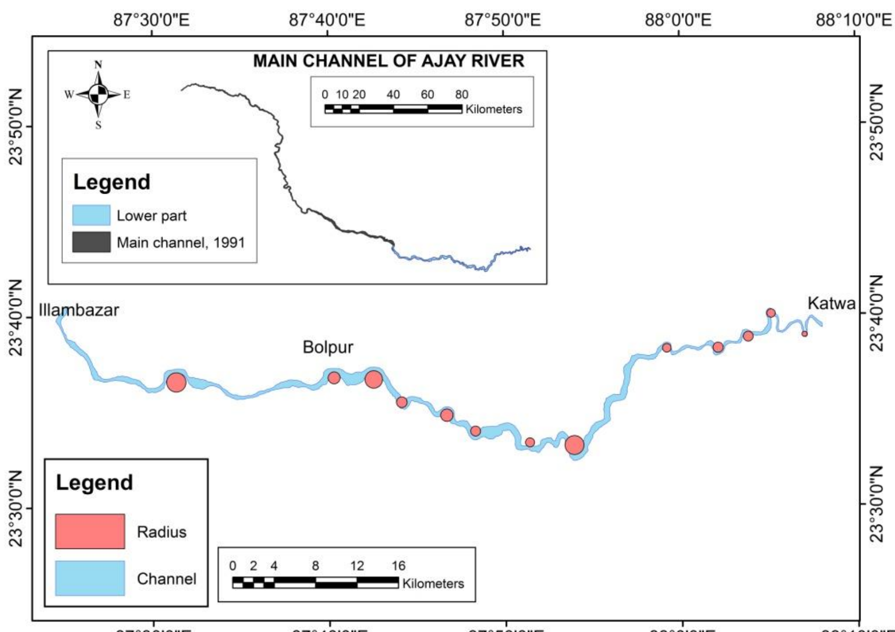
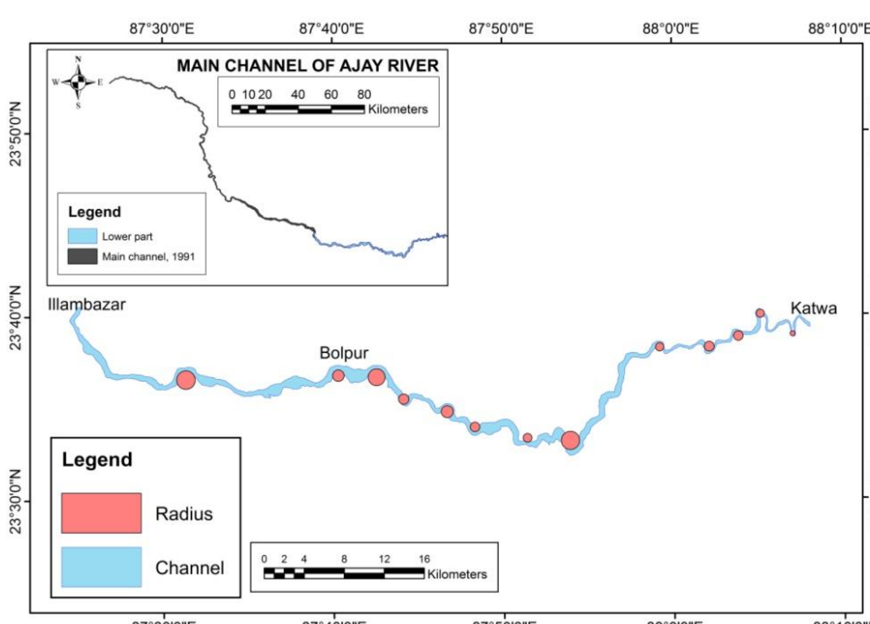


Figure 5.32 Relationship between channel length and river sinuosity

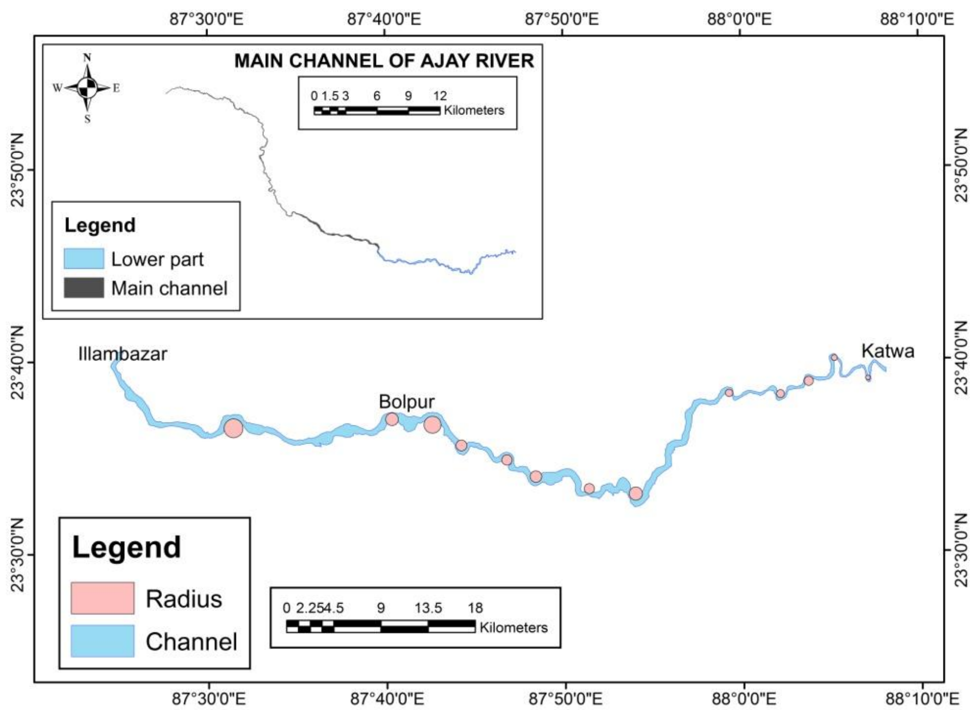
(Source-Topographical sheet 1:50000)



1991



2001



2011

Figure 5.33 Radius curvature of the lower Ajay River from 1991-2011
(Source-LANDSAT 5, 1991-2011)

Table 5.10 Variation of the sinuosity radius (m) in the lower Ajay River channel

Sl. no	1991	2001	2011
1	929.61	904	900
2	575.13	742	725
3	843.6	708	813
4	514	820	516
5	600	510	552
6	486.11	434	484
7	436.77	708	631
8	913.38	860	790
9	415.56	230	349
10	491.87	562	380
11	478.12	373	438
12	406.14	309	283
13	248	180	219

(Source-Measured from LANDSAT-5 data, 1991-2011)

5.4.2.3 Various types of bar formation

Bars are typically formed due to the accumulation of sediment within the channel (Charlton, 2008). In the lower part of the channel, various types of bars have been identified, as shown in Figure 5.34. Bar formation is a common occurrence in the Rarh Bengal River, attributed to the substantial sediment supply and a gentle slope in the plain area, facilitating sediment deposition and bar formation on the riverbed. Longitudinal bars are particularly prevalent in the Ajay River, with point bars observed in meandering channels. This gradual transformation of the river channel into a braided pattern is indicative of ongoing geomorphic processes shaping the river's morphology.

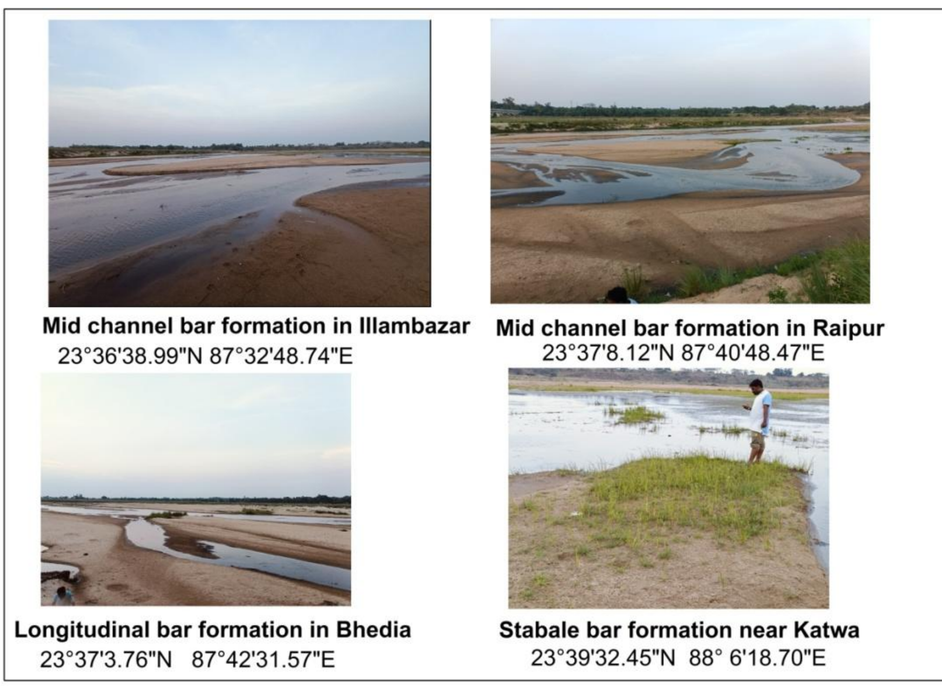


Figure 5.34 Different types of bars in the main channel of lower Ajay River (Illambazar to Katwa)

(Source-Field photograph)

5.4.2.4 Thalweg shifting

The thalweg, representing the deepest point of a channel's cross-profile, is influenced by the pool-riffle sequence, particularly in meandering river courses. Channel migration is a natural process often observed in alluvial rivers. In the context of the Ajay River, evidence of a paleo-path suggests historical channel variations. However, the lower reach of the Ajay River has long been confined by embankments, although these embankments have seen incremental increases in length and height over time. Despite efforts to stabilise channel migration through embankments, thalweg shifting remains a natural phenomenon. Thalweg shifting can be observed and studied by tracing the waterline in satellite imagery during lean seasons across different periods, further confirmed through field visits and cross-profile analyses (refer to Figure 5.35). Human activities such as sand mining and bed cultivation contribute to thalweg shifting in the lower Ajay River. Notably, thalweg shifting varies in width along different regions of the river, such as wider shifts near Bhedia and shorter shifts near the confluence (refer to Figures 5.36). These shifts impact bank stability and the overall channel curvature.

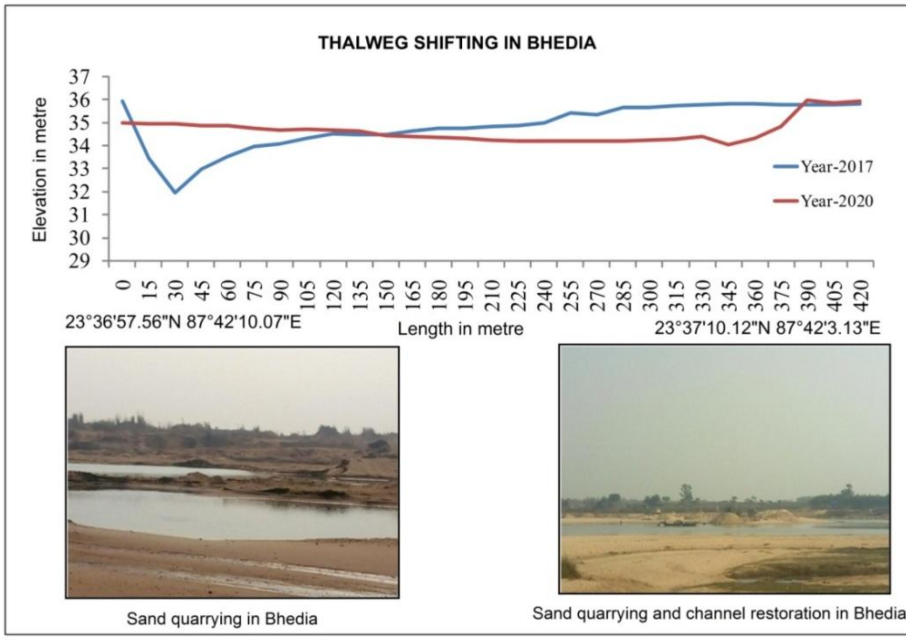


Figure 5.35 Thalweg change from 2017-2020 due to unscientific sand quarrying near Bhedia (Source-Data collected by Total Station survey, January 2017 & 2020)

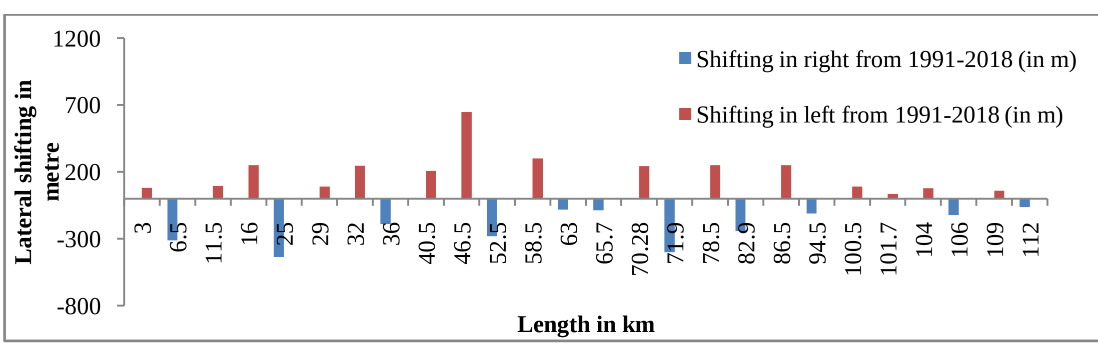
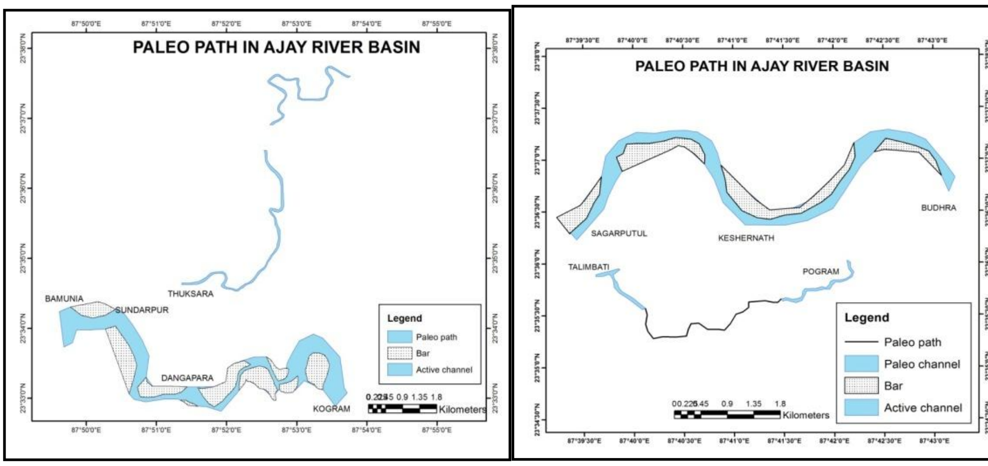


Figure 5.36 Lateral shifting of thalweg from 1991 to 2018, in lower Ajay River measured in GIS platform

(Source-LANDSAT 5, 1991, LANDSAT 8 image, 2018)

5.4.2.5 Drainage system and paleo path analysis

A highly sinuous river channel is evident in the lower part of the Ajay River, as indicated in Table 5.9. This sinuosity is attributed to the decrease in energy and the high potential sediment load, resulting in the transformation of the channel into a sinuous form. In many instances, sinuous bends have evolved into meandering patterns. Sinuosity, quantified by the Sinuosity Index (SI) with values ranging from 1.31 to 3.90 as per Equation 4.1 (Table 5.9), further highlights this characteristic. Interestingly, while sinuosity typically increases with a decrease in the relief ratio, the lower part of the Ajay River does not follow a linear trend in channel behaviour. Instead, there is significant variability in sinuosity along the river, indicating fluctuations in river energy and channel dynamics (Figure 5.32). The high sediment load and the confinement of the river within embankments have led to the common formation of sandbars in the lower part of the river channel. In some areas, this has even resulted in the development of a braided channel pattern. Various types of bars have been identified through satellite imagery and field observations, as illustrated in Figure 5.34. Bars are typically formed due to the accumulation of sediment within the channel (Charlton, 2008).



i) ii)

Figure 5.37 i) & ii) Paleo path investigation in Ajay basin

(Source- Topographical sheet 73M/10-1:500000)

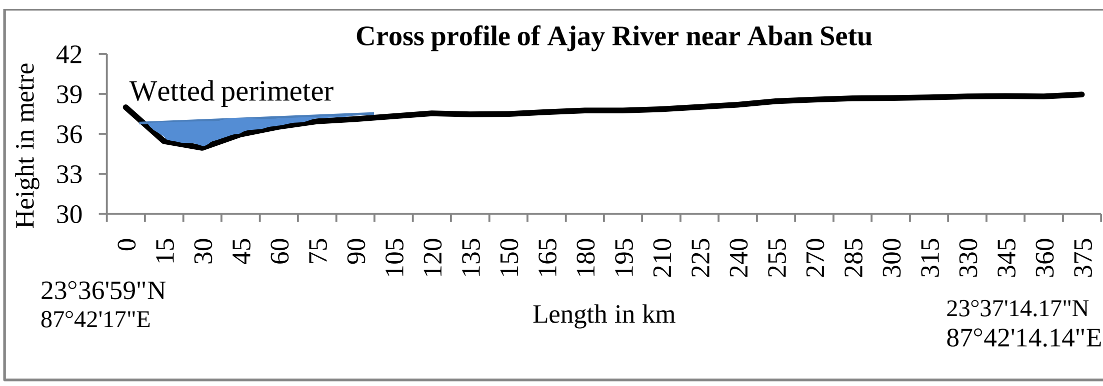
In the lower part of the channel, various types of bars have been identified, as shown in Figure 5.34. Bar formation is a common occurrence in the Rarh Bengal River, attributed to the substantial sediment supply and a gentle slope in the plain area, facilitating sediment deposition and bar formation on the riverbed. Longitudinal bars are particularly prevalent in the Ajay River, with point bars observed in meandering channels. This gradual transformation of the river channel into a braided pattern is indicative of ongoing geomorphic processes shaping the river's morphology. In the lower reaches of the region, the river's channel dynamics play a crucial role in shaping the hydrological patterns. The presence of abandoned channels and swampy lands in this area indicates the existence of paleo-channels of the Ajay River, such as Kana Ajay and Khandar, with some now functioning as tributaries to the main channel (Rudra, 2012). Many of these tributary channels are now buried, which has implications for the current flood conditions in the lower Ajay River region (Roy, 2012). Notably, Kandar Nala on the left side of the main channel has remained inactive for extended periods, only becoming active during the monsoon season when it contributes to the main channel's flow.

Human interventions, including channel restoration through embankment construction and sand quarrying from the river bed, are significantly altering the river channel's dynamics and disrupting the natural balance of water and sediment flow. Two prominent segments of the river's paleo-path have been identified from topographical sheets (73M/10 and 73M/14). The presence of the paleo-path is clearly visible in the 2018 LANDSAT 8 image, although its length appears to be decreasing over time.

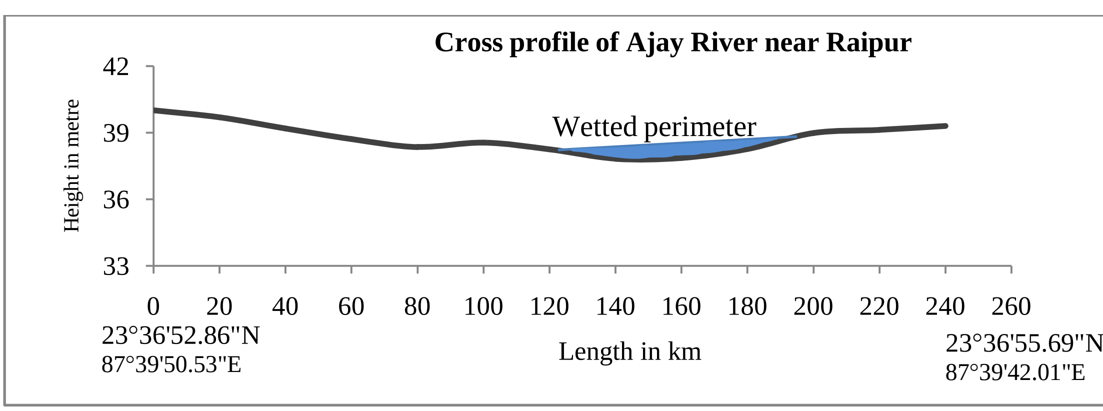
Regarding the study of the paleo-channel, the sinuosity of the main channel is around 1.5, while the sinuosity of the paleo-channel ranges from 1.59 to 1.6, indicating a similar meandering nature between the two channels (refer to Figure 5.37). This alignment further supports the existence and characteristics of the paleo-channel in this area.

5.4.2.6 Cross profile of the lower Ajay River

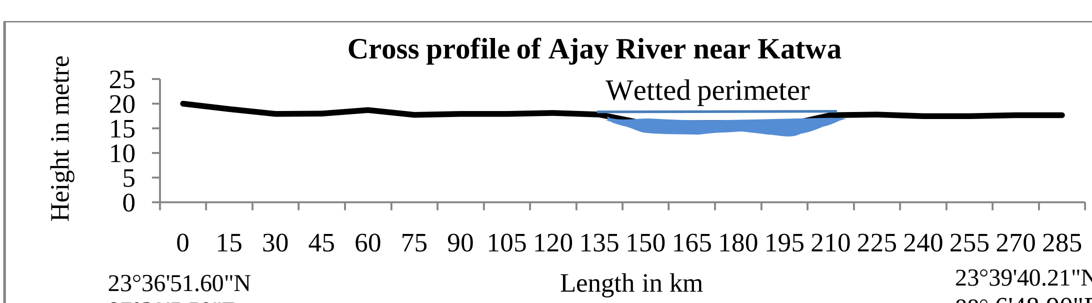
The cross profile of the lower Ajay River is typically measured through leveling surveys conducted during the lean season, as depicted in Figures 5.38 and 5.39. This cross profile serves as a vital indicator of various aspects such as the present bed condition, channel geometry, wetted perimeter, active channel ratio, and more. It reflects the overall channel condition of the river, which encompasses factors like the river's regime character influenced by climatic conditions, sediment yield, lithological conditions, and riparian characteristics. A key observation from the cross profile analysis is the high variation in channel width along the lower Ajay River, indicating varying channel carrying capacities at different locations. Additionally, the cross profile often reveals an asymmetrical thalweg character, particularly in the lower part of the river where sediment deposition leads to frequent bar formations within the channel profile. These bar formations can significantly influence the river's flood potential. Moreover, the cross profile analysis helps determine the bank stability of the river, guiding the implementation of bank protection measures tailored to the channel's varying characteristics. It also sheds light on river geometry, pool-riffle sequences, and energy distribution within the channel, offering insights into the river's geomorphic nature.



i)



ii)



iii)

Figure 5.38 i-iii Cross profiles in lower Ajay River

(Source -Measured by Total Station from the periods of 2017 to 2020 based on arbitrary benchmark)

However, human activities like sand quarrying can disrupt the natural course of the river, leading to alterations in the cross profile character and impacting the overall geomorphology of the lower Ajay River. Thus, a thorough cross profile study is crucial for understanding and managing the dynamics of the river's channel morphology and associated environmental processes.

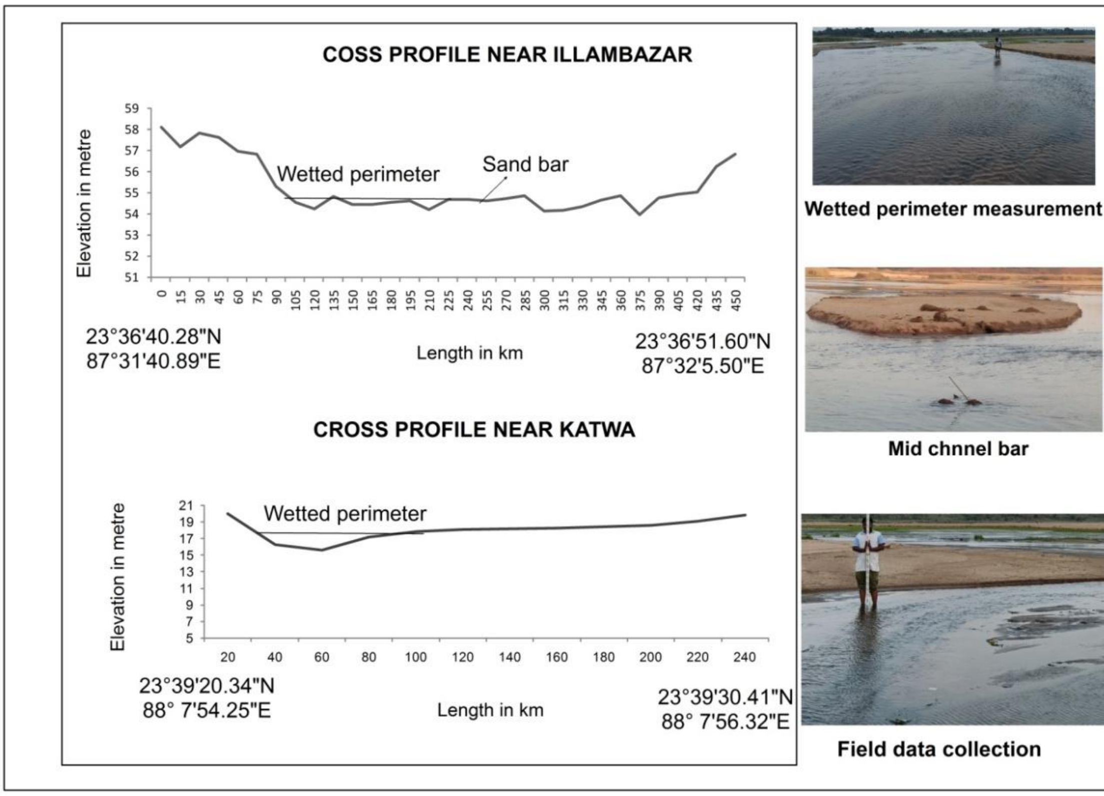


Figure 5.39 Cross profile and different features in Illambazar and Katwa

(Source - Measured by field survey based on arbitrary benchmark)

5.4.3 Impact of human encroachment on river

The historical perspective of embankment construction along the Ajay River reveals a series of developments aimed at flood protection. Initially, during the Zamindari periods, earthen embankments were constructed, albeit with limited engineering expertise. Subsequently, the British period saw efforts to strengthen these embankments. However, between 1956 and 1978, frequent flood events resulted in substantial damage and collapse of many embankment sections. Consequently, the government undertook initiatives to reconstruct and expand embankments, leading to an increase in their length and height over time (Figure 5.41). However, despite these efforts, recurring flood events and embankment failures continue to pose challenges, particularly in the lower Ajay basin.

The rate of sand quarrying by ECL, 2015 is presented in and showing the variation of the sand quarrying quantity (Table 5.11). An Environmental Impact Assessment (EIA) report by the Eastern Coalfields Limited (ECL) in 2015 notes the impact of sand quarrying activities on the river. Sand quarrying has shown some improvement in river channel intake capacity, particularly near the Pandebeswar region where sediment deposition rates are high due to reduced river energy. However, unscientific sand mining practices often carried out at numerous fixed points along the river, lead to channel diversion, bar formations, embankment failures, and changes in the river's cross profile and thalweg point. These activities also affect the base flow of the river and pose risks to the embankment's stability. Despite the ECL's report mentioning various factors related to sand mining, there is a lack of focus on river geomorphic health and its direct impact on the river's graded system. Moreover, inadequate monitoring of sand mining operations, including depth and quantity checks, contributes to the degradation of the riverbed and exacerbates flood risks, especially during peak discharge periods. Field observations corroborate these findings, highlighting the gradual transformation of the lower Ajay River bed into sand mine during lean seasons and the heightened flood threats to nearby areas during peak discharge periods. The upliftment of the river bed after the monsoon, attributed to sediment loads, further emphasises the complex interplay between human activities and river dynamics in the Ajay River basin.

Table 5.11 Quantity of sand extraction from the Ajay River bed (1990-2015)

Year	Sand quarrying/ Million m^3	Year	Sand quarrying/ Million m^3
1990-91	2.37	2003-04	1.56
1991-92	2.81	2004-05	1.70
1992-93	2.44	2005-06	2.18
1993-94	1.87	2006-07	2.15
1994-95	1.98	2007-08	1.73
1995-96	2.07	2008-09	2.04
1996-97	2.34	2009-10	1.87
1997-98	2.41	2010-11	1.55
1998-99	2.30	2011-12	1.24
1999-2000	2.13	2012-13	0.90
2000-01	2.06	2013-14	0.78
2001-02	2.34	2014-15	1.00
2002-03	1.66	2015-16	0.24

(Source- ECL report, 2015)

The Ajay River has been subject to significant human encroachment over time, which has influenced its sediment dynamics and channel morphology. The construction and expansion of embankments have exacerbated sediment deposition rates, particularly in regions with intensive embankment development such as Illambazar and Kheyarbani. Cross-sectional profiles from different time periods (2017-2022) (illustrated in Figures 5.42 and 5.43) highlight the significant increase in sediment deposition and the formation of various bar types in these areas (Figure 5.34).

In contrast, the Katwa region, which lacks substantial embankments, shows a different pattern. Here, the rate of sediment deposition is comparatively low (Figure 5.43). In the Katwa region, the thalweg experiences less shifting, but the river's sinuosity has increased, indicating a trend towards meandering (as seen in Figures 5.32 and 5.36).This suggests that embankments play a crucial role in altering river dynamics, leading to increased sediment deposition in certain areas while influencing the meandering patterns in others. The differences in sedimentation and channel morphology between the embanked and non-embanked regions of the Ajay River underscore the complex interactions between human interventions and natural river processes.

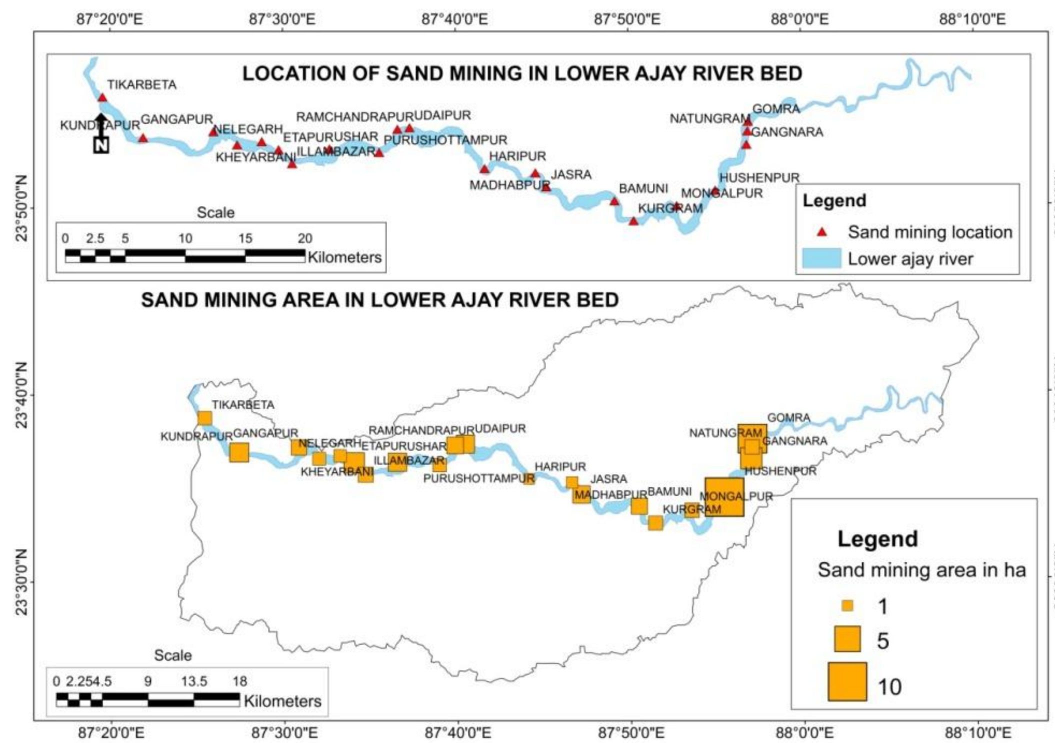


Figure 5.40 Areal coverage of Sand Mining stations in lower Ajay River bed

(Source-ECL report, 2015)

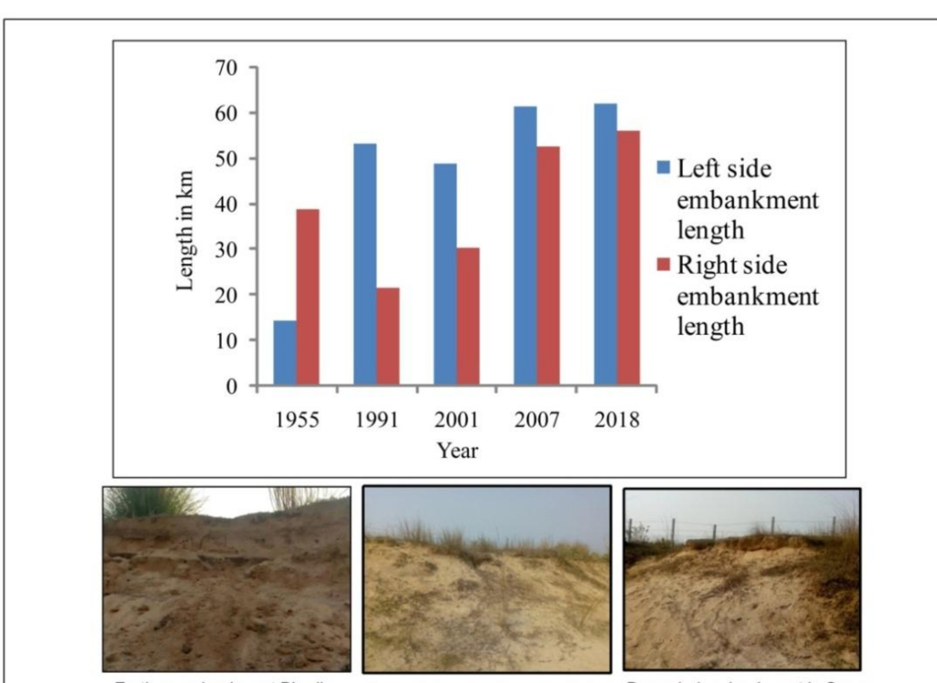


Figure 5.41 Embankment length in Ajay River from 1955 to 2018

(Source-Topographical sheet 1:250000 prepared by U.S Army-1955, LANDSAT 5-1991, 2001, 2007, LANDSAT 8-2018) (Ghosh et al., 2015)

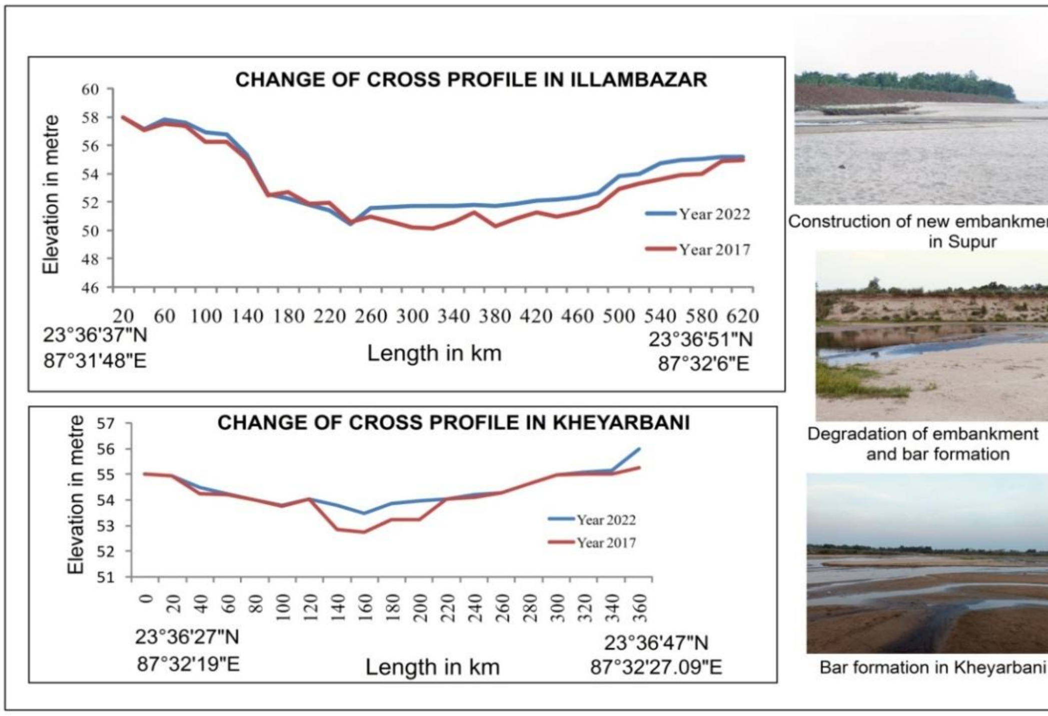


Figure 5. 42 Change of cross profile in Illambazar and Kheyarbani from 2017 to 2022

(Source-Cross profile data measured by field visit based on arbitrary benchmark)

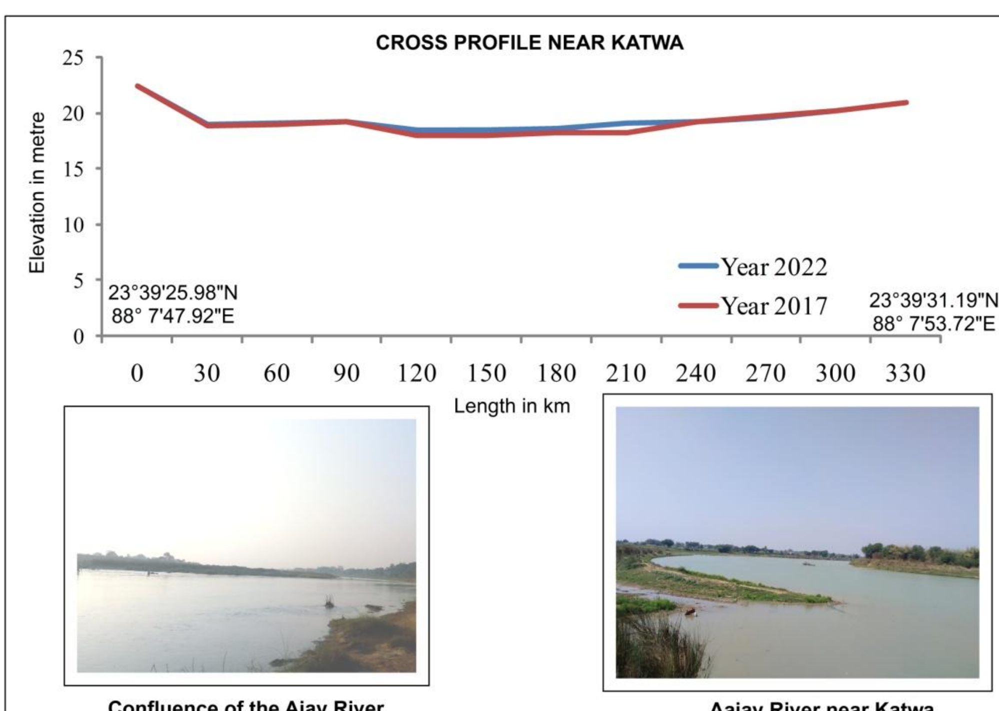


Figure 5.43 Change of cross profile in Katwa from 2017 to 2022

(Source-Cross profile data measured by field visit based on arbitrary benchmark)

5.4.4 Tectonic influence on the river channel

Generally the river channel behavior depends on load character and surface form. River channel also exposed the impact of underlined tectonic and neo-tectonic evolution of the basin.

5.4.4.1 Long profile of the river

The longitudinal profile of a river, which represents the elevation of its thalweg point along its length, provides valuable insights into the river's processes and the geological activity in its region. One significant aspect revealed by the longitudinal profile is the presence of knick points, which are breaks in slope along the channel caused by tectonic activity. These knick points are crucial markers that indicate shifts in equilibrium within each segment of the river (Niyogi, 1984).

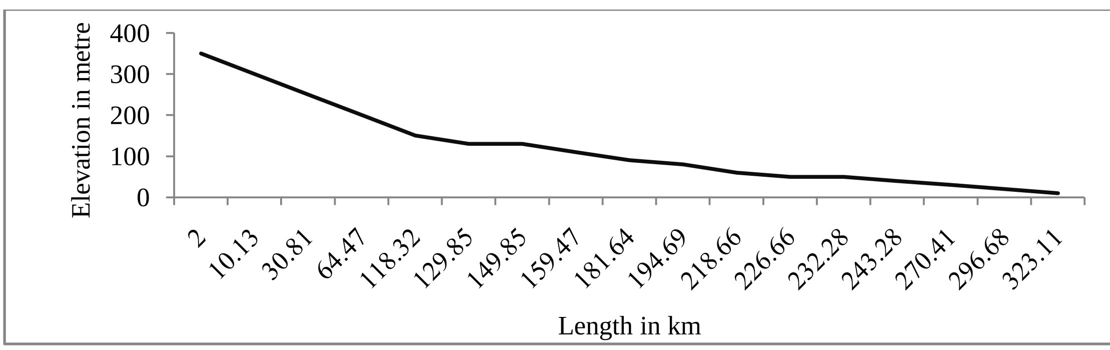


Figure 5.44 Longitudinal profile of the Ajay River

(Source - SRTM DEM, 30 m data and contour data of toposheets map-1:50000)

The Ajay River's long-profile exhibits a distinct break of slope near the Sikatia barrage and another one near Illambazar (Figure 5.44). This break of slope plays a significant role in shaping the river's characteristics. Specifically, the section near Illambazar shows a more sinuous channel pattern and displays highly aggradational features (Figure 5.34).

5.4.4.2 Asymmetry factor (AF)

The asymmetry of the channel refers to the displacement of the channel from the middle axis line of the basin (Eq. 5.5, Lavarini, 2016). This measurement indicates the tilting of the channel concerning sensitivity to tectonic or neo-tectonic activity.

$$AF = 100\ (Ar/At) \qquad \text{(Eq. 5.5)}$$

Where, Ar represents the area of the basin right-facing downstream and At represents the total area of the basin. An AF value greater than 50 indicates the channel tilting towards the left side of the basin, towards the downstream, while an AF value less than 50 indicates tilting towards the right side of the basin axis (Mohanty et al., 2017).

In the case of the Ajay basin, the asymmetry factor was analysed across three segments of the basin. The results show that the upper part of the channel tilts towards the left side (73.34), the middle part indicates a shift towards the right side (43.96), and the lower part tilts towards the left side (57.25). This analysis reveals the channel's tilting pattern, which could be attributed to various underlying structures, the presence of fault lines and lineaments (Figure 5.45), as well as other surface factors influencing channel shifting within the basin.

5.4.4.3 Transverse Topographic Symmetry Factor (T)

Cox (1994) introduced measures to detect tectonic influences on channels, as discussed by Mohanty et al. (2017). This approach assesses ground tilting and lateral shifting of channels relative to the middle line of the basin boundary. The analysis was conducted separately for three parts of the basin, as shown in Figure 5.45.

It involves measuring the ratio of Da (distance from the stream channel to the middle line of the basin) and Dd (distance of the middle line to the basin margin). A resulting value closer to 1 indicates channel tilting from the centreline. The analysis revealed that the upper part of the basin has a lower level of tectonic changes (0.34), while the middle (0.53) and lower parts (0.52) indicate a moderate to high rate of tectonic influence. The middle part of the basin encompasses unconformities between Archean Gneiss and Gondwana sedimentary rocks, whereas the lower part transitions from Gondwana sedimentary to Alluvium (Ghosh, 2015). With the presence of fault lines and lineaments in these regions (Figure 5.45), the potential for tectonic activity is high, clearly affecting river behaviour.

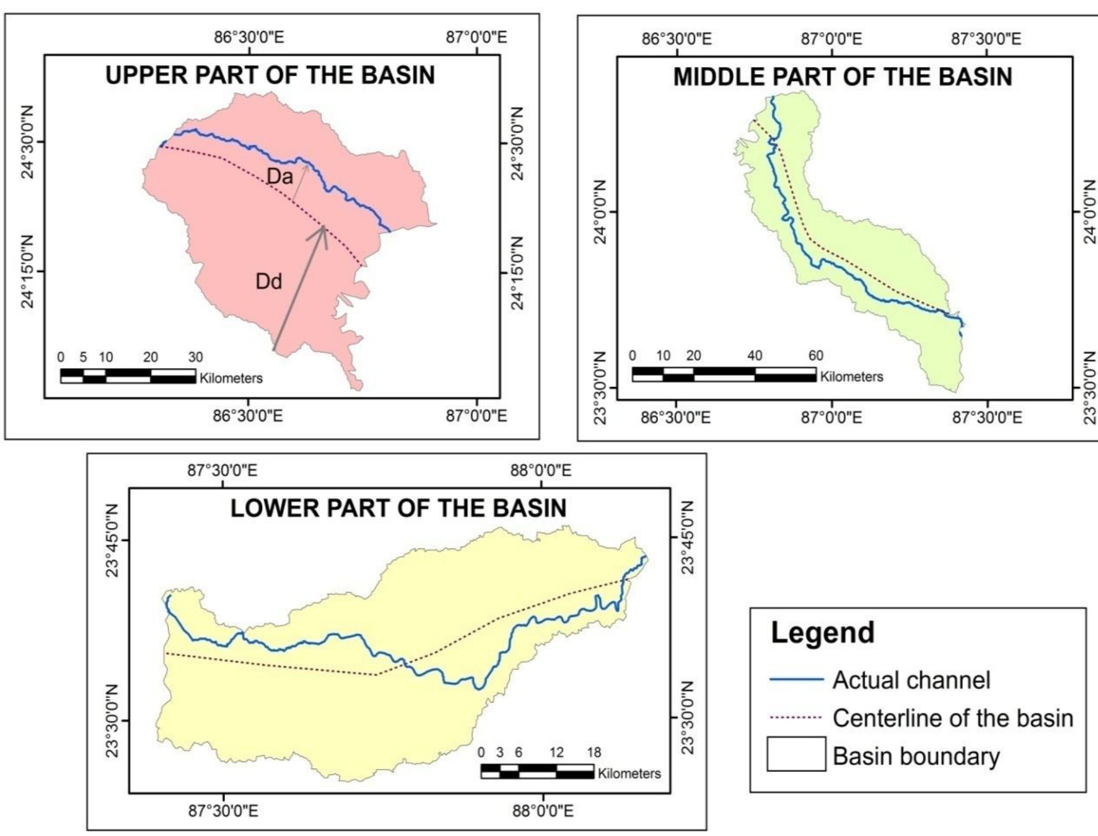


Figure 5.45 Transverse topographic asymmetry (T) of Ajay basin by divides into three parts (T = Da/Dd, where Da is the distance from stream channel to the centre of its drainage basin and Dd is the distance from the basin boundary to the centre of the basin.

(Source - River channel and basin boundary extracted from SRTM DEM, 30 m and Toposheets 1:50000)

5.5 Socio-economic characteristics of the Ajay basin

Rivers and drainage networks are products of natural processes, influenced by the physical and climatic conditions of their surroundings. However, human activity has played an increasingly significant role in shaping and developing these basins over time. Today, human interventions and activities are key factors in basin planning and management solutions. While administrative boundaries are commonly used for planning purposes, they may not always align with the natural homogeneity of a basin or watershed, leading to challenges in addressing physical aspects effectively.

The characteristics of a basin directly impact the socio-economic dynamics of the surrounding settlements. Therefore, analysing the present socio-economic conditions is crucial for making informed decisions regarding river basin management. Modern science emphasises the importance of social benefits and stakeholders involvement in decision-making processes. Understanding the vulnerability and hazards of a basin area requires a comprehensive analysis of demographic characteristics, economic status, social dynamics, and communication systems.

Communities with strong economic and educational foundations tend to have lower risk factors and better coping mechanisms, while marginalised societies often face greater challenges due to economic and cultural disparities. Block-wise census data are instrumental in understanding socio-economic conditions, especially when focusing on specific blocks like Illambazar, Kanksa, Aushgram I, Aushgram II, Mangalkote, Bolpur, Nanoor, Ketugram I, Ketugram II, Katwa I, Bhatar, Labhpur in the lower Ajay basin. By considering and analysing these key parameters; stakeholders can develop more effective strategies for sustainable basin management and resilience-building initiatives.

5.5.1 Population density

Population density is a crucial aspect of social status, reflecting the relationship between people and the land, as well as the region's carrying capacity. In the Ajay basin area, a notable variation in population density is observed. According to the Indian Census 2011, a population density above 850 people per square kilometer is considered very high in a rural context. In the study area, very high population density is observed in the lower part of the basin, specifically in regions such as Katwa I, Ketugram-I, Mangalkote, Ondal, and Pandebeswar. Conversely, the upper part of the basin, particularly the Chakai block, exhibits low population density. However a few blocks in the upper region such as, Jamatra, Fetehpur, Bengbad have moderate population density. The remaining blocks display moderate to high population density (Figure 5.46). The lower part of the basin exhibits a significantly higher population density, primarily due to favorable physical conditions such as fertile alluvium soil and the presence of the Ajay floodplain. This region attracts settlement and agricultural activities, leading to increased human encroachment along river beds, which can adversely impact river health.

However, this intensification of human activity also heightens the risk of flood hazards, particularly in densely populated areas. Managing population density alongside sustainable land use practices is crucial for ensuring the resilience of communities and the health of river ecosystems in the Ajay basin area.

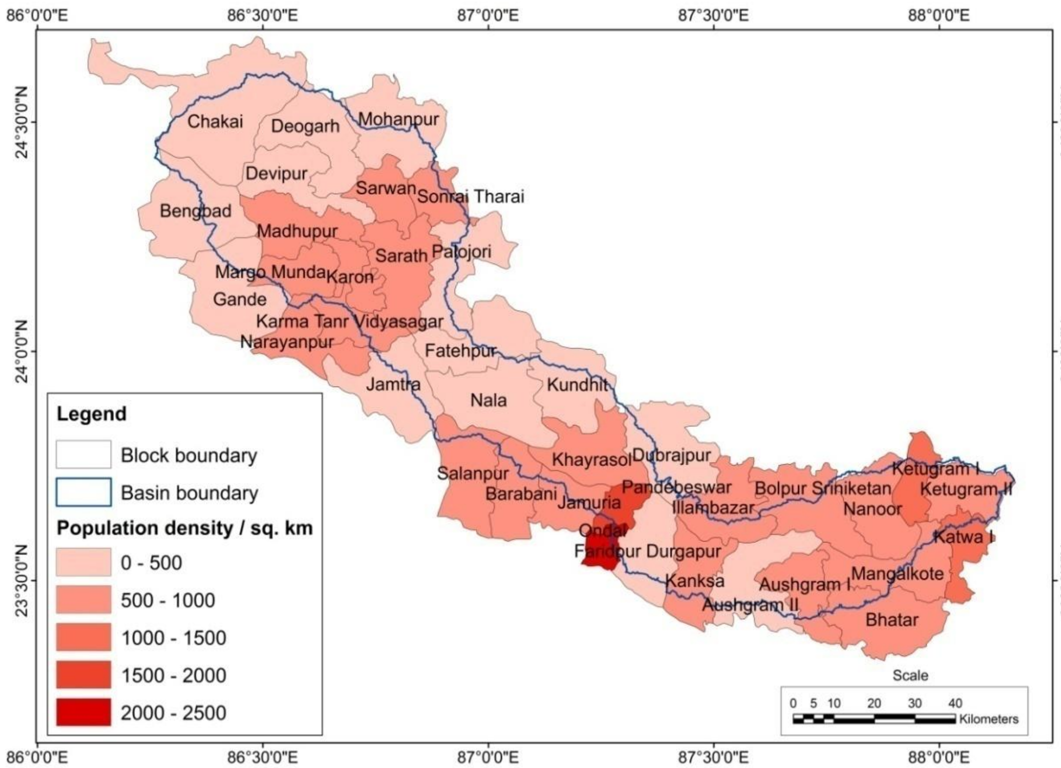


Figure 5.46 Population density of Ajay basin

(Source-Census data, 2011)

5.5.2 Rural-urban population distribution

The distribution of rural and urban populations within the basin area reflects the region's social and economic dynamics. Predominantly rural, the basin has few urban blocks, typically arising from commercial growth or administrative significance (Figure 5.47). Notably, Bolpur-Sriniketan has developed into an urban center due to its educational heritage. Except for a few blocks like Illambazar, Pandebeswar, Ondal, Barbani, Jamuria, Salanpur, Katwa I, and Nanoor, the rest of the blocks in the basin are rural. Rural areas are characterised by mud houses, agricultural fields, and unpaved roads (kacha rasta). These communities heavily rely on agriculture, making them more vulnerable to natural hazards like floods or droughts due to limited infrastructure and dependency on the land.

Understanding the distribution of rural and urban populations is essential for effective planning and development initiatives within the basin. Providing adequate infrastructure, improving agricultural practices, and enhancing resilience to natural hazards are key considerations for promoting sustainable development and improving the socio-economic conditions of both rural and urban populations in the Ajay basin area.

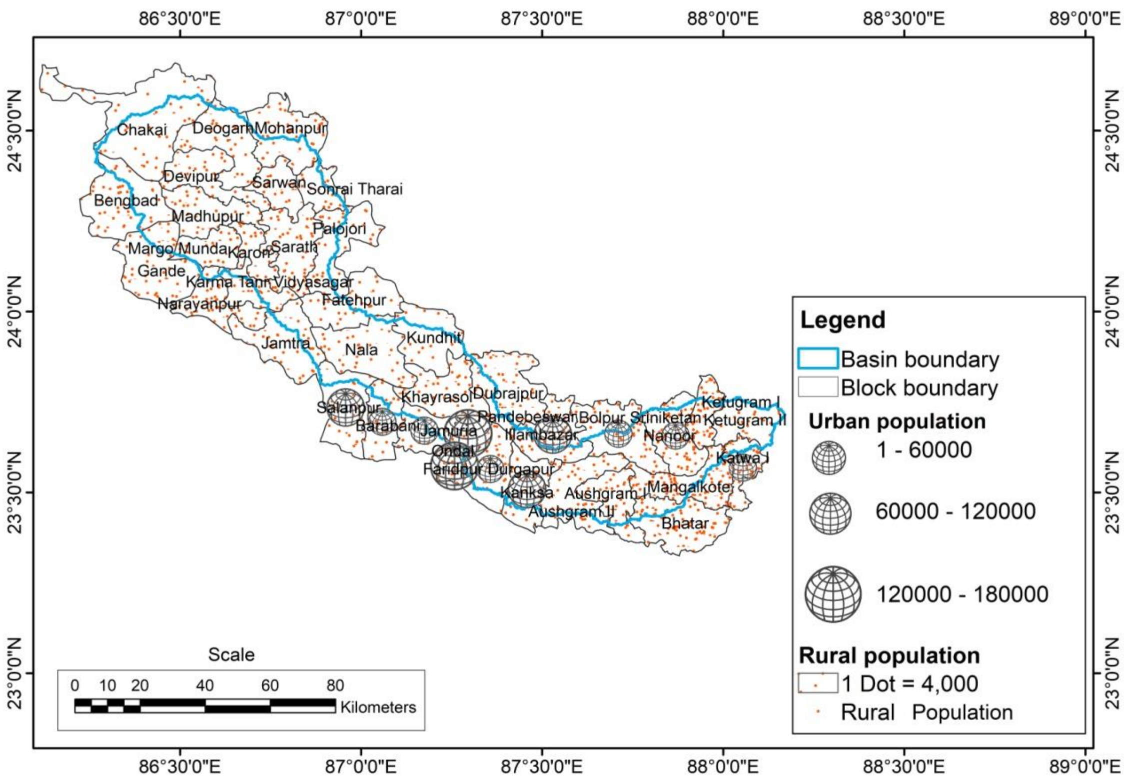


Figure 5.47 Rural-urban population distributions in Ajay basin

(Source - Census data, 2011)

5.5.3 Demographic structure

The lower part of the Ajay basin boasts a high total population, particularly in blocks like Mangalkote, Nanoor, Bhatar, Bolpur-Sriniketan, Katwa, Ketugram I & II, each with over 2 lakhs residents (Figure 5.48). Examining the sex ratio is crucial for the assessment of development. Indian Census, 2011 data indicates that in blocks like Pandebeswar, Jamuria, Ondal, Faridpur-Durgapur, Katwa I, Ketugram II, the male-female ratio is below both the country average (<943) and the average of West Bengal (<950) (Figure 5.49). A high sex ratio, leaning towards males, impacts social dynamics, workforce composition, family structures, and socio-economic activities. Analysing such demographic trends is vital for policymakers in the Ajay basin to tackle gender-related challenges and promote inclusive development and societal progress through gender equality initiatives.

5.5.4 Educational status

The literacy rate is a vital indicator of educational status. Unfortunately, no blocks in the in the Ajay basin area meet the country's average literacy rate (74.04%). Only Kanksa and Salanpur have rates above 70%, while the rest are below this mark. Female literacy rates are notably low across the basin, with Salanpur showing the highest (63.61%) and the remaining blocks below 60% (Figure 5.50). This educational disparity reflects economic challenges and overall backwardness. Low education levels co-relate with increased vulnerability to various risks, including limited socio-economic opportunities, health awareness, and adaptive capacity to environmental changes. Improving educational infrastructure, promoting literacy campaigns, and addressing gender disparities can uplift communities in the Ajay basin, fostering sustainable development and resilience against challenges.

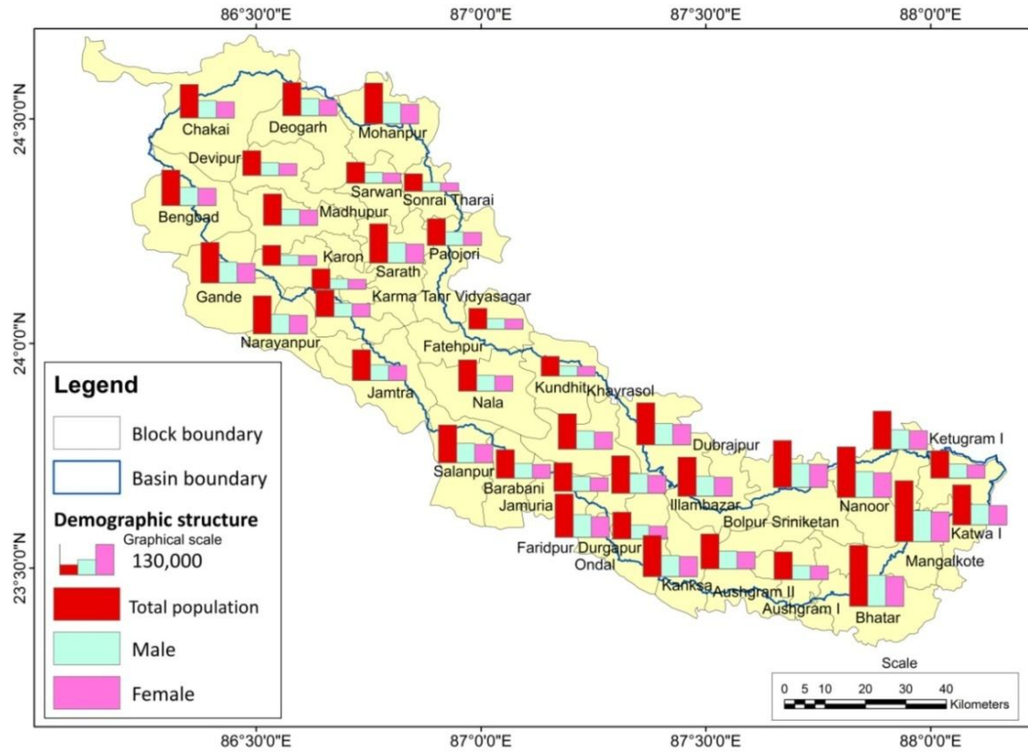


Figure 5.48 Demographic structure of the Ajay basin

(Source - Census data, 2011)

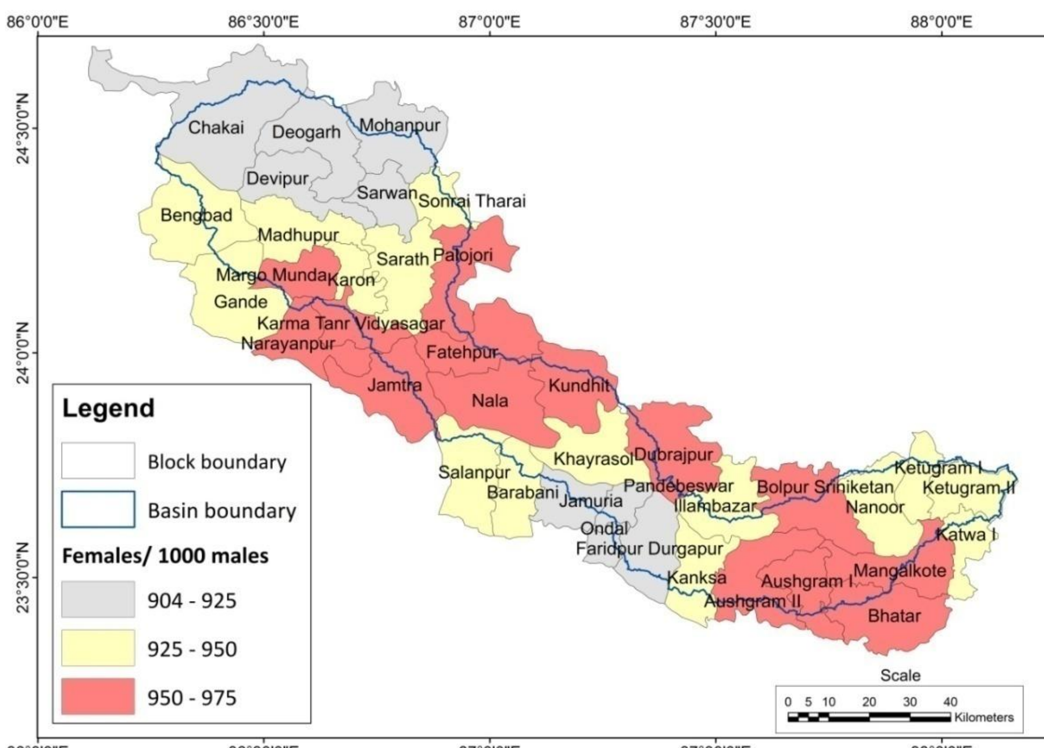


Figure 5.49 Sex ratio in the Ajay basin

(Source - Census data, 2011)

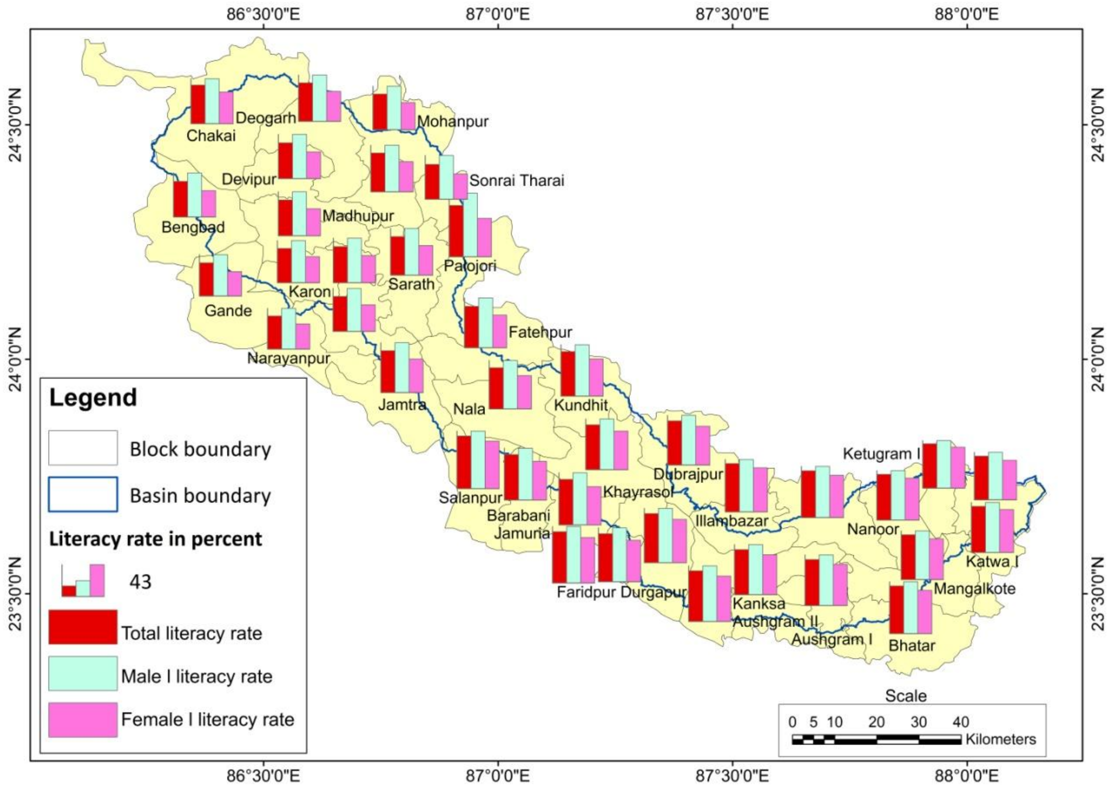


Figure 5.50 Literacy rate in the Ajay basin

(Source - Census data, 2011)

5.5.5 Socio-economic status in lower Ajay basin

In West Bengal, the average child population ratio is 12.58% based on Census data from 2011. In the study area, the child population ratio is highest in Bolpur-Sriniketan blocks at 18.26%, followed by Illambazar at 13.02% and Ketugram I at 12.70%. Other blocks in the area also have significant child populations, ranging from approximately 10% to 12%.

In terms of socio-economic conditions, the lower part of the basin area primarily follows an agro-based economy, with limited industrial development. Many individuals are engaged in agricultural labour, and there are a high number of marginal farmers, highlighting the low-income status prevalent in the region (Figures 5.51 & 5.52). The average marginal population rate in West Bengal is 26.1%. However, in the lower part of the Ajay basin area, excluding four blocks - Katwa I, Ketugram II, Mangalkote, and Nanoor - the percentage of marginal population exceeds 27%. In some blocks, such as Aushgram I and II, the marginal population is even above 40%. The presence of significant number of marginal working population also suggests a high rate of unemployment and under utilisation of human resources. The reliance on agriculture-based livelihoods underscores the importance of water availability and basin resources. However, the region's dependency on rivers and floodplains, coupled with human encroachment, poses challenges for river geomorphology and environmental sustainability. While river water availability is crucial for irrigation and soil fertility, it also exposes livelihoods to flood hazards, leading to substantial damages.

The concentration of a predominantly rural population in the lower part of the basin area underscores the reliance on agro-based societies, further emphasising the importance of rivers and floodplains. Balancing development needs with environmental conservation and disaster resilience is crucial for ensuring the long-term well-being and prosperity of communities in the Ajay basin area.

The availability of road facilities is illustrated by a road density map (Figures 5.53 & 5.54) in the lower part of the region. In comparison to 11 blocks maximum road density (1.2-1.8 km/km^2) is observed in Aushgram I, Aushgram II, and Kanksa, medium in Mangalkote, Bhatar, and Katwa I and low (<0.6 km/km^2) in Illambazar, Bolpur, Nanoor, Ketugram I, Ketugram II. In the case of road categories, the longest roads are *morrum* or brick types, but other types of roads are almost equally distributed (Figure 5.55). The categories of roads play a very significant role in the case of flood hazards planning. Maximum unmetalled roads in rural areas are disconnected from the main road during the high flood intensity. So people become more vulnerable. Poor connectivity of roads and transport also enhances the risk of any hazards and it also symbolises the spatial development of socio-economic conditions. Health facilities concern mainly three types of health centres: block primary health centres, sub-centres, and primary health centres, which are available in all the blocks. Health facilities are discussed by the ratio of the total population in the block and the number of health centres that are available. From these indices, high ratio indicates poor facilities or overburdening of population and a low value indicates good health facilities. In terms of health centre availability, Bolpur and Aushgram I are in a good position, while Bhatar, Mangalkote, and Katwa I are in a poor position. Good health facilities indicate high socio-economic development and also reduce the risk. Besides, roof categories of the house reflect highly the economic status (Figure 5.56).

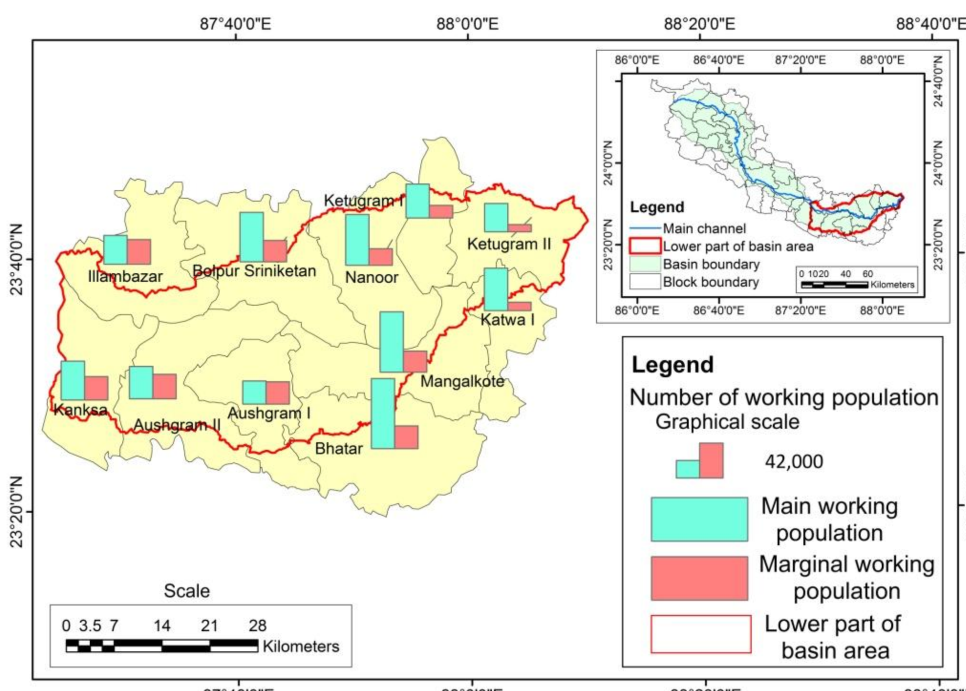


Figure 5.51 Working categories in lower Ajay basin

(Source-Census data, 2011)

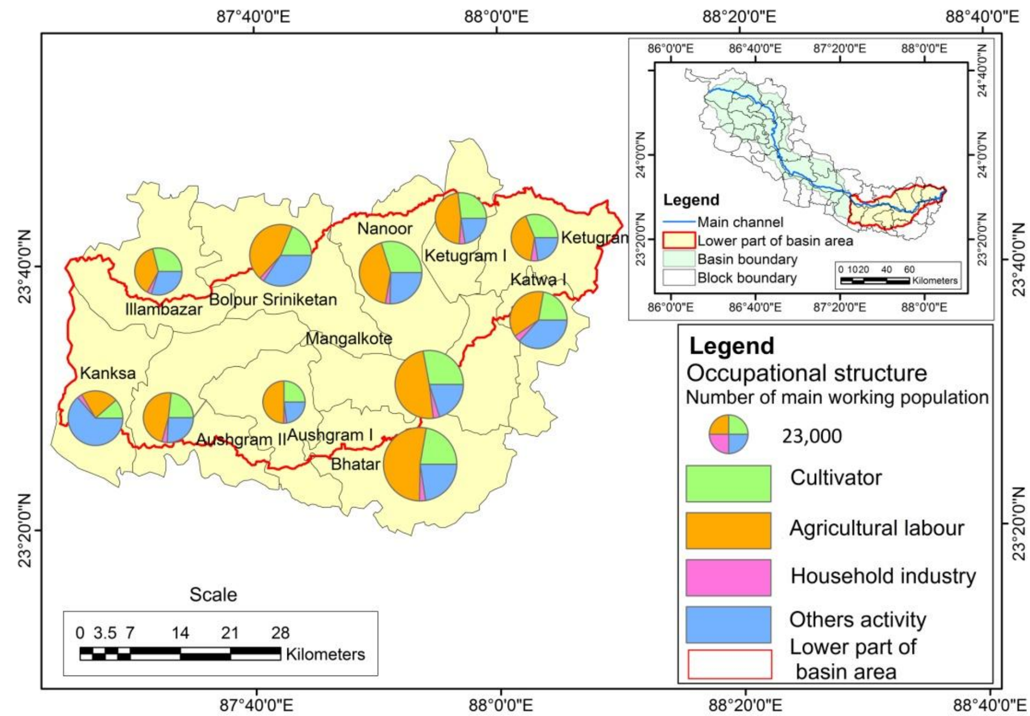


Figure 5.52 Occupation structure in lower Ajay basin

(Source-Census data, 2011)

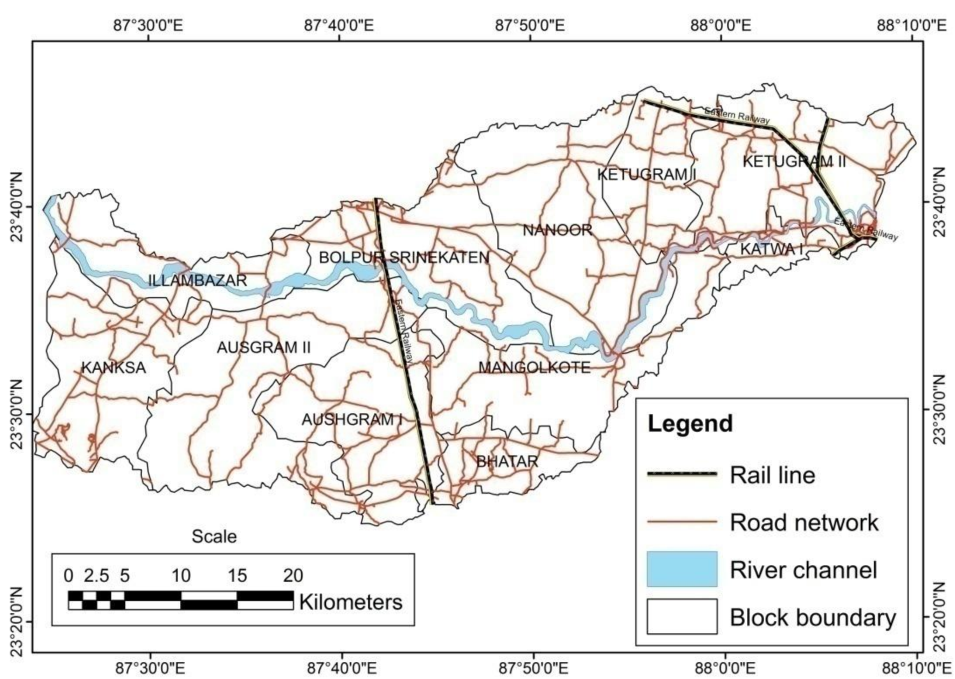


Figure 5.53 Road connectivity in lower Ajay basin

(Source-Toposheets and LANDSAT 8 data)

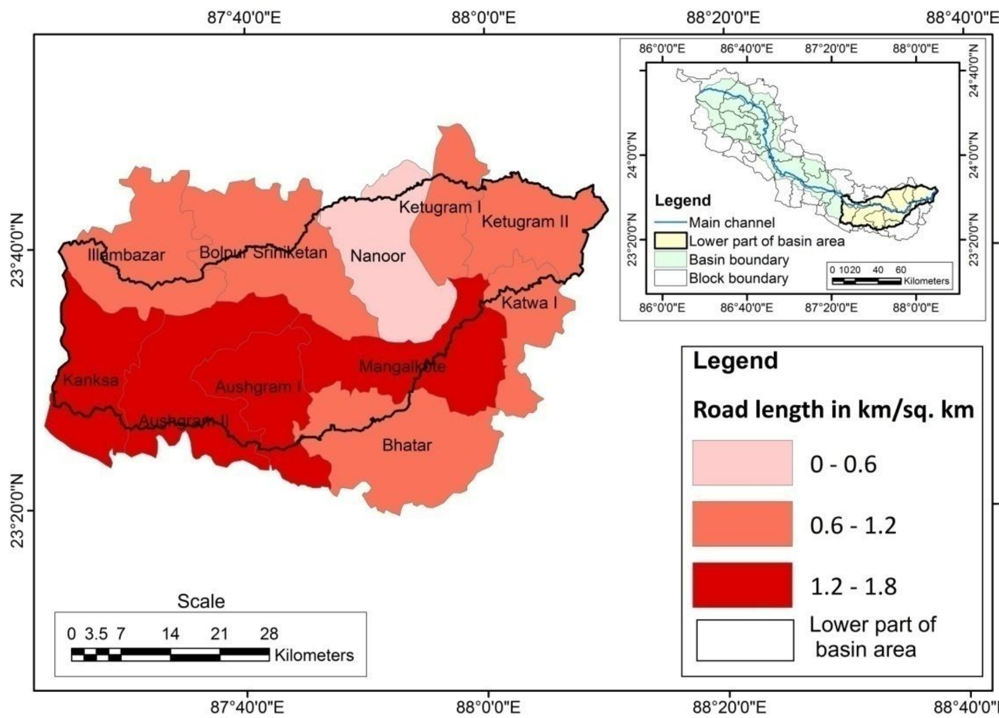


Figure 5.54 Road density in lower Ajay basin

(Source-ISGP, Programme II, Panchayet and Rural Development Department, Govt. of West Bengal)

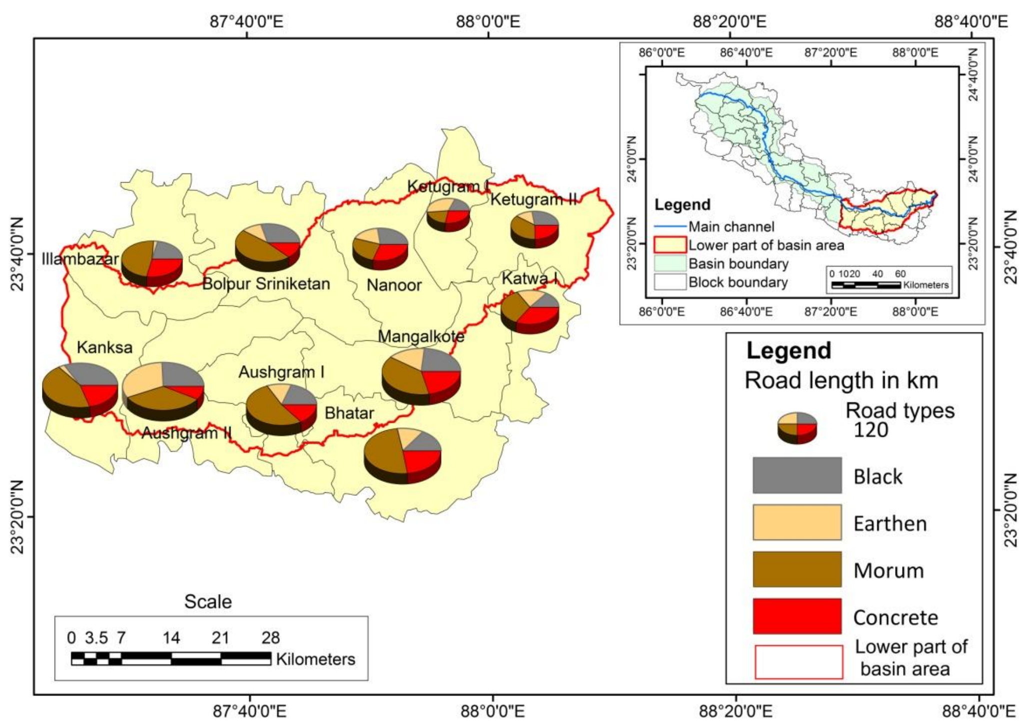


Figure 5.55 Road categories in lower Ajay basin

(Source-ISGP, Programme II, Panchayet and Rural Development Department, Govt. of West Bengal)

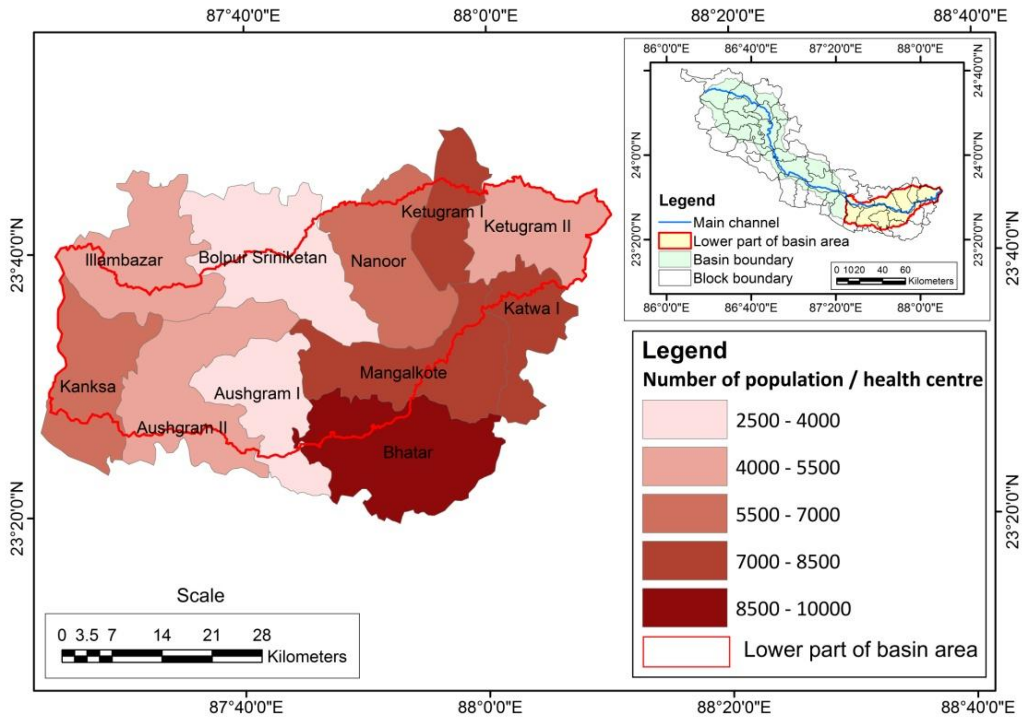


Figure 5.56 Health facilities in lower Ajay basin

(Source - ISGP, Programme II, Panchayet and Rural Development Department, Govt. of West Bengal)

In terms of housing categories, the majority of households in the Ajay basin area belong to the poor classes. Many houses are constructed with bamboo roofs and asbestos, with only a small percentage having concrete roofs (Figure 5.57). This composition poses a significant threat during hazards, as a large portion of the population is vulnerable due to their socio-economic status. Regarding drinking water sources, most households rely on nearby facilities, with a typical distance of 100 meters in urban areas and 200 meters in rural areas (Table 5.12). However, there are cases where a considerable number of people still depend on water sources located beyond these distances, especially in rural areas (Figure 5.58). Longer distances between households and drinking water sources can lead to significant problems during inundation periods and result in a serious water crisis. In most cases, groundwater sources are submerged, posing a serious threat to public health conditions. Absolutely, ensuring that drinking water supplies are located close to households is crucial. Installing water sources at a height above flood levels can help maintain their safety and accessibility during inundation periods.

These socio-economic factors underscore the importance of addressing infrastructure and resource accessibility issues to enhance the resilience and well-being of communities, particularly during hazards or crises. Efforts to improve housing conditions ensure access to safe drinking water within reasonable distances, and address gender disparities are critical for enhancing the overall quality of life and reducing vulnerabilities in the Ajay basin area.

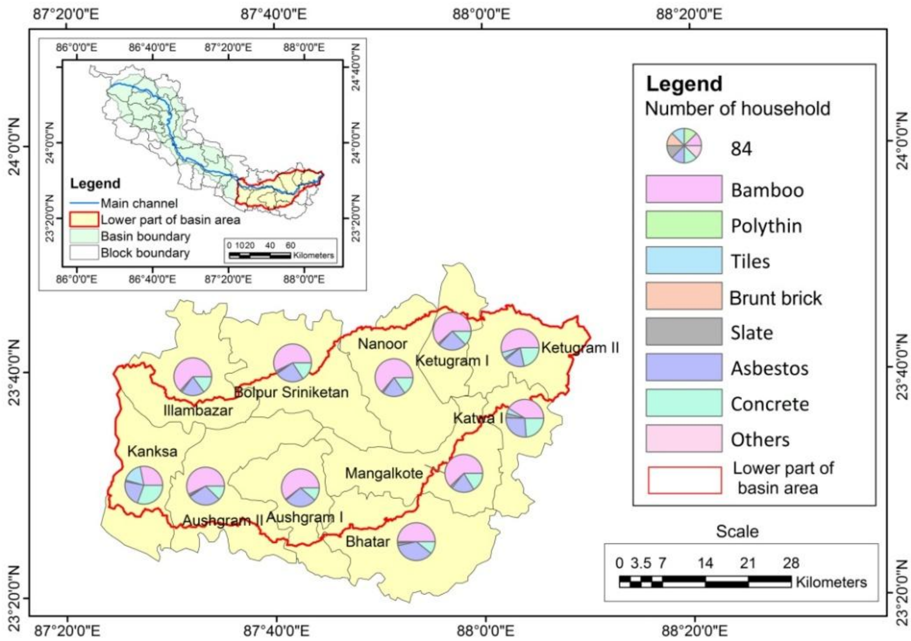


Figure 5.57 Roof quality of house building in lower Ajay basin area

(Source - House Listing & Housing Census, 2011)

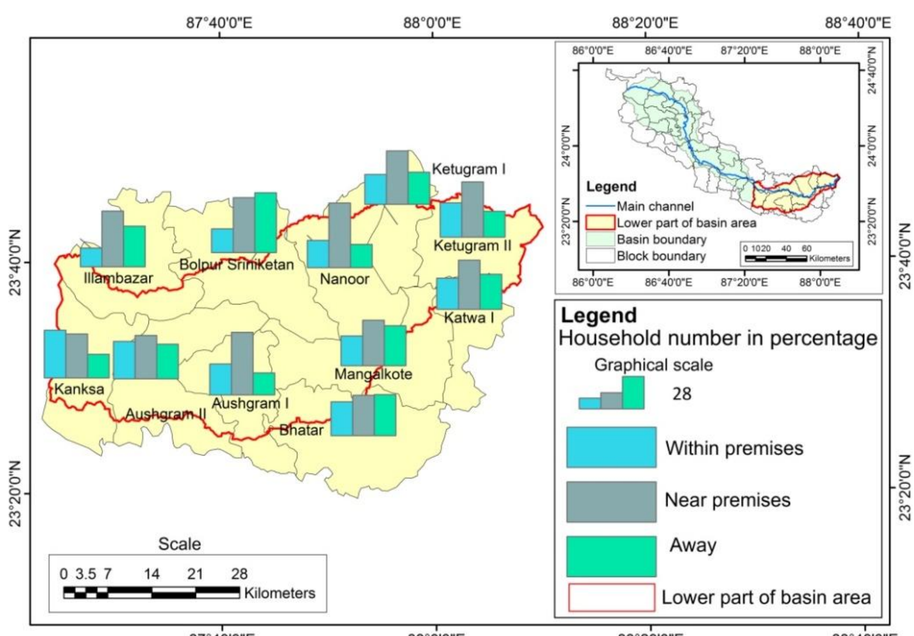


Figure 5.58 Availability of the drinking water sources

(Source - House Listing & Housing Census, 2011)

Table 5.12 Types of drinking water supply

Category	Distance
Within premises	In household
Near premises	100 m in urban areas and within 200 m in rural areas
Away	Above 100 m in urban areas and 200 m in rural areas

(Source - House listing & Housing Census, 2011)

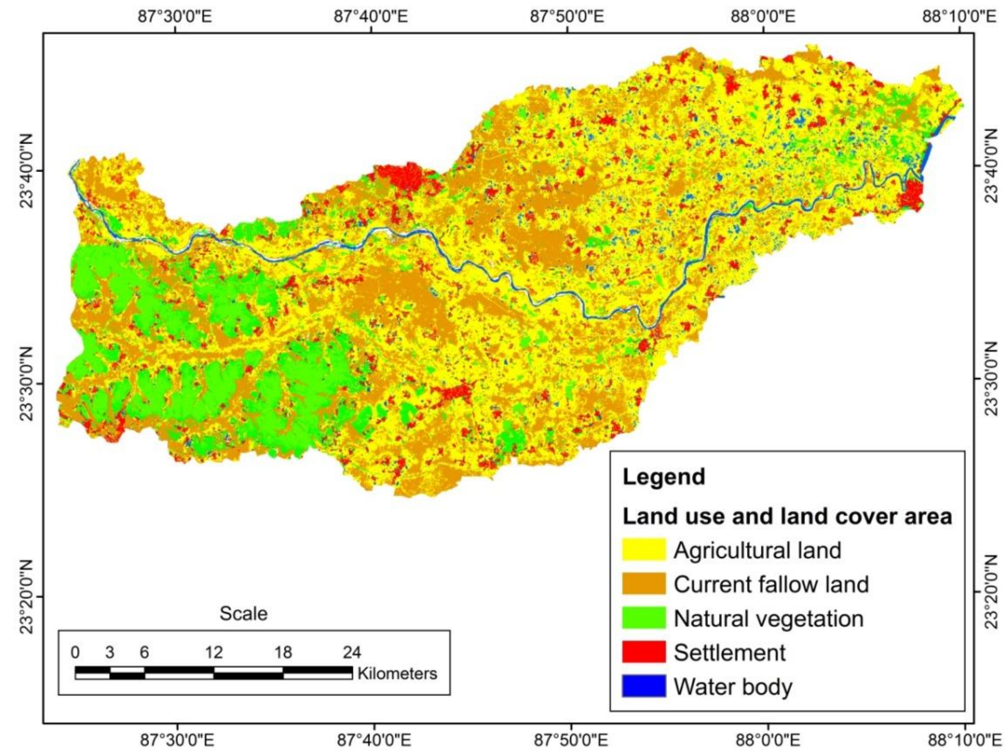


Figure 5.59 Land use land cover map of lower Ajay basin, 2000

(Source - LANDSAT-5 data, 2000)

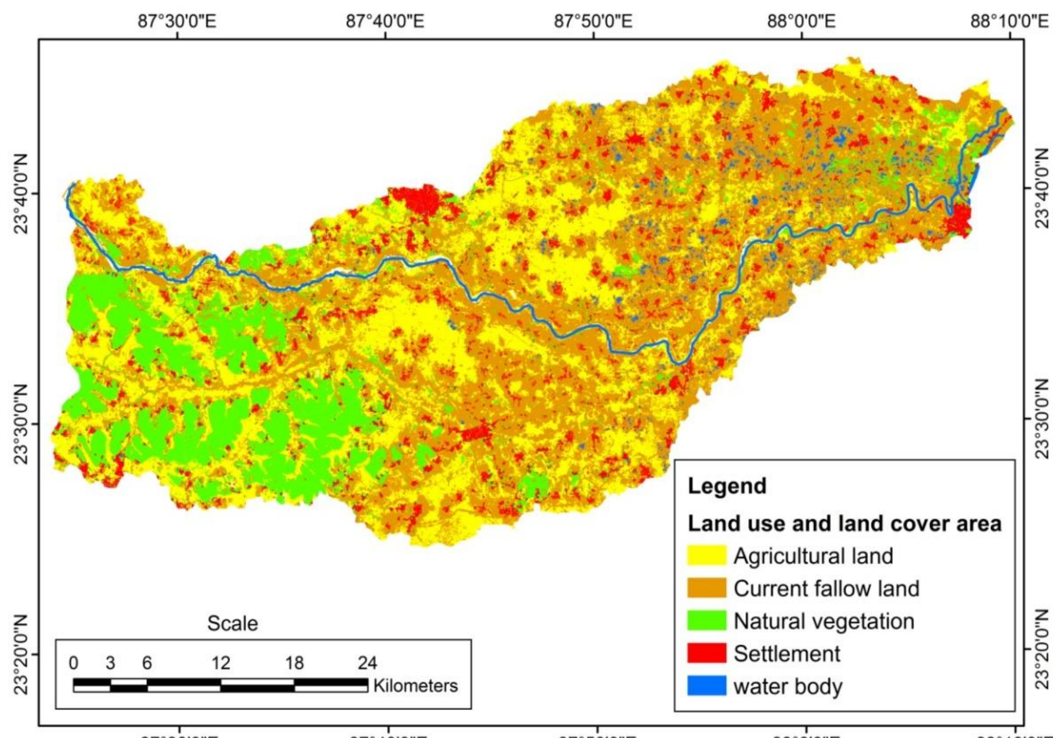


Figure 5.60 Land use land cover map of lower Ajay basin, 2018

(Source - LANDSAT-8 data, 2018)

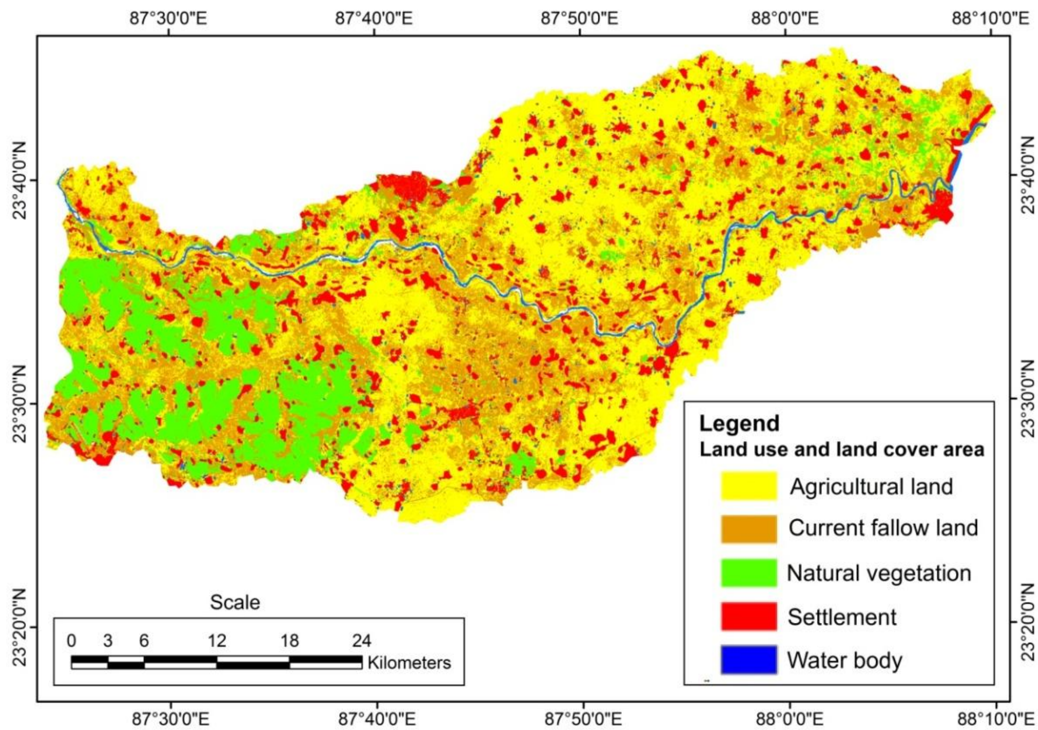


Figure 5.61 Land use land cover map of lower Ajay basin, 2022

(Source – LANDSAT - 8 data, 2022)

5.5.6 Land use land cover in the lower Ajay basin area

From 2000 to 2018, agricultural land has consistently been the dominant land use cover in the Ajay basin area, covering approximately 75% of the total land area (Table 5.13). However, there has been a notable increase in settlement coverage, rising from 13% to 17% over this period. This shift indicates changes in land use patterns, with implications for the environment and human settlements. The decrease in the area of natural vegetation is another significant trend observed during this period. This change in land cover composition, particularly the dominance of agricultural activities, has implications for flood risk in the lower Ajay basin area (Figures 5.59-5.61). During the monsoon season, extensive paddy fields cover the agricultural landscape, making it highly vulnerable to flood losses. The reliance on agriculture as the backbone of the economy exacerbates the impact of flood events, leading to significant economic losses.

Furthermore, the impact extends to settlements, especially those with kancha houses and poor-quality roofing materials. These structures are more susceptible to damage during floods, posing risks to human lives and livelihoods. Addressing these vulnerabilities requires a comprehensive approach that considers land use planning, infrastructure resilience, and disaster preparedness measures to mitigate the adverse effects of floods on both agricultural and settlement areas in the Ajay basin region.

Table 5.13 Land use land cover area in lower Ajay basin area

Lulc category	Area sq. km, 2000	Percentage of area, 2000	Area sq. km, 2018	Percentage of area, 2018	Area sq. km, 2022	Percentage of area, 2022
Water body	53.01	3.053	50.17	2.88	44.991	2.591
Agriculture Land	659.96	38.012	645.25	37.16	693.88	39.966
Current fallow land	676.83	38.980	660.25	38.02	619.43	35.678
Natural Vegetation	119.85	6.903	98.28	5.66	79.31	4.568
Settlement	226.53	13.060	282.23	16.25	298.56	17.196

(Source - Calculated by researcher in GIS field)

Chapter - 6

Assessment of Flood Intensity and Prediction of Flood Potential Area

6.1 Flood intensity and characterisation in the Ajay and its surrounding basins

The Ajay basin's location between the Mayurakshi and Damodar basins, coupled with its dense drainage network and tropical climate, indeed makes it prone to frequent flooding. The seasonal rainfall, especially during the monsoon, exacerbates this situation. The backflow of water near the Bhagirathi-Hugli River confluence adds complexity to the flood scenario, impacting a wider region beyond the Ajay basin. Human interventions such as settlement development on riverbeds, intensive agricultural practices, unscientific sand mining, and embankment heightening sheds light on how human activities contribute significantly to flood risks. These activities alter the natural flow patterns of rivers and exacerbate flood intensities, making the flood nature quasi-natural rather than purely natural. Embankment failures further compound these issues, leading to heightened flood impacts on agriculture and livelihoods. It is evident that a comprehensive approach blending natural and human-induced factors is crucial for effective flood management in the Ajay basin and surrounding areas. Such an approach should include sustainable land use practices, better water resource management, and strategic flood mitigation measures to reduce the adverse impacts of floods on communities and ecosystems.

6.1.1 Chronological study of flood disaster scenario in Burdwan and Birbhum district (districts covering study area)

Understanding the flood scenario in the Ajay basin and its impact on the adjoining districts of Burdwan and Birbhum in West Bengal is crucial for effective flood management and disaster preparedness. The collaborative efforts and reports published by various departments provide valuable insights into the chronological flood occurrences and their impacts on the region.

The Ajay basin's interconnectedness with neighbouring basins like Mayurakshi, Damodar, and Bhagirathi underscores the complexity of flood dynamics. During flood events, these basins become interlinked, amplifying the flood impact across multiple districts.

The reports from the Department of Geology at Precedency University, along with collaborative work from the Department of Disaster Management and Disaster Management Action & Plan, offer detailed analyses of flood scenarios in Burdwan and Birbhum districts for specific years. These reports likely provide information on flood intensity, duration, affected areas, infrastructure damage, and community impacts, helping stakeholders formulate effective flood mitigation and response strategies.

Including flooded year information from 'Secehpatra' published by the Irrigation and Waterways Department, Government of West Bengal, further enriches the understanding of flood patterns and trends over time. This comprehensive approach to studying floods integrates scientific data, governmental reports, and local observations to provide a holistic view of flood occurrences and their consequences.

Such information is invaluable for authorities, disaster management agencies, and communities to enhance flood preparedness, infrastructure resilience, early warning systems, and community outreach programs aimed at reducing the adverse impacts of floods in the Ajay basin and its surrounding areas.

1968

The Ajay and the Damodar Rivers were overflowed. As a result, more than thousands of hectares of agricultural fields were completely inundated under water. Remarkably vast areas of Bolpur and Nanur of Birbhum district were overflowed. Dams are found broken the area of Fatehpur, Geetgram, Jahanabaj, Ranibazar and Gheedah. Villages like Thupsar, Noyanagar, Tikuri, Mangalpur, Ramkrishnapur, and Sariska are completely flooded. Thousands of bighas of land was submerged under water. Ajay, Damodar, Matla, Churni, Bidyadhari, Dwaraka, Mundeshwari and Bhagirathi were flowing above danger level. Tents and funds were being sent by boat.

1978

3735 sq. km area of the Bardwan district, 24.35 lakhs people, and 1788 villages were affected and 792 people died. 80044 cattle died. 128634 houses were damaged costing Rs. 188238000/-. Burdwan Sadar, Raina 1 & 2, Jamalpur, Khandaghosh, Ausgram 1 & 2, Galsi 1&2, Bhatar, Memari 1 & 2, Kalna 1 & 2, Manteswar, Purbathali 1 & 2, Katwa 1&2, Maongalkot, Ketugram-1 & 2, Faridpur-Durgapur and Kanksa blocks were affected.

In Birbhum 3760 sq. km area, 17.5 lakhs people, 1778 villages were affected and 159 people died. 74500 cattle died. 124000 houses, were damaged amounting Rs.60800000/. Md.Bazar, Sainthia, Bolpur-Sriniketan, Dubrajpur, Ilambazaar, Rajnagar, Siuri 1 & 2, Nalhati 1&2, Murario 1 & 2, Mayureswar 1 & 2, Lavpur, Nanoor, Khoirasole, Rampurhat 1 & 2 blocks were affected heavily.

1980

In Burdwan, 405.13 sq. km area, 169,981 people and 62616 acres of farmland were affected. 60100 houses were fully collapsed.

In Birbhum, 167.50 sq.km area, 1761 houses, 84,846 people and 36522 acres of farmland were affected.

1984

In Birbhum, 895 sq. km area with a population of 353,000 was affected. 14523 houses were damaged and 5556 houses were collapsed. 3457 hectares area of farmland was affected. Losses of public utilities were estimated 473.33 lakh rupees.

In Burdwan, 610 sq. km areas with a population of 240,000 were affected. 4,314 houses were damaged and 4,721 houses were collapsed. 28,249 hectares of farmland affected with a loss of public utilities of Rs.980.97 lakh.

1986

In Burdwan, 872 sq. km areas of 23 blocks were affected. Almost 757 villages with a population of 5 lakh, Crops of 23,100 hectares of land were damaged worth Rs. 820.64 lakh. 4 persons died. 7000 houses were damaged.

In Birbhum, 19 blocks including 412 sq. km area, 395 villages with a population of 2.80 lakh, Crops of 12,000 hectares of land were damaged estimating Rs. 427 lakhs.

1988

In Birbhum, 3 blocks with 49 villages were destroyed. Almost 49 lakhs population, about 1000 houses and 4360 hectares of farmland were damaged.

1989

In Burdwan, 8 lakh people were affected in 14 blocks and 4 municipalities. Almost 1430 houses were damaged.

In Birbhum, 2.04 lakh people were affected in 19 blocks and 5 municipalities spreading over 4000 sq. km area. 2 persons died and 2900 houses were damaged.

1990

In Birbhum 0.187 million populations, 0.000320 million hector land was affected. 1 person died and 7473 houses were damaged. Total area affected was 0.097 million hector and 0.25 crores rupee lost of public utility.

In Burdwan 0.212 million populations, 0.0005 million hector farmlands were affected. 6 people died and 15,497 houses were damaged. Total area of 0.054 million hector was affected 0.35 crore rupees of public utility was lost.

1993

In Burdwan, a population of 1078 was affected and 634 houses were damaged.

In Birbhum, population of 2,29,192 was affected directly. Crops of 12,774 hectares, 1875 houses were damaged. Estimated 12,662 houses worthing Rs. 52, 46, 000 were damaged significant numbers of cattle were died.

1994

In Birbhum, 6 blocks were affected with 1 Municipality area. Almost 794 houses, 500-hectare farmland were affected and 8,164 people and 351 villages are affected.

1995

In Burdwan, 0.15 hectares area with a population of 0.51 million were affected. Crops of 0.03 million hectares, worth Rs. 30 cr., were damaged. 30,000 houses were destroyed. 3 people died. The loss of public utility amounted to Rs.21.86 cr. with a total loss of 89.91 cr. rupees.

In Birbhum, 0.2 hectares area with a population of 0.6 million were affected. Crops of 0.02 million hectares worth Rs. 32.5 cr. damaged. 4018 houses were collapsed. 6 people died. The loss of public utility costs 97.322 crores rupees in total.

1996

Birbhum – 0.14305 million population and 0.005166 million hector farmlands were affected directly. 1470 houses were damaged. Total area affected was 2.998 sq. km 3.77 crores rupee was the loss amount of public utility.

Burdwan – 0.148 million population, 0.000757 million hector farmland were affected. Total area affected was 656.15 sq. km with 0.17 crores rupee loss of public utility.

1997

In Birbhum 402 sq. km area with a population of 27750 which cover 65 villages in 4 blocks and 1 municipality, were affected. Crops of 1720.07 acres damaged. 1468 houses in consideration with the value of 277.05 lakhs were destroyed.

In Burdwan, 87.55 sq. km area with a population of 21594 is affected spread in 214 villages of 9 blocks and 1 municipality. Crops of 2025 acres were damaged. 652 houses which valued at Rs. 48.46 lakh were destroyed. 7 people died.

1998

In Birbhum, 632400 people are affected in 752 villages in 2207 sq. km area in 19 blocks and 5 municipalities. 33117 houses were collapsed. 2 people died. Loss of public property amounts to Rs. 3875 lakhs.

In Burdwan, 957231 people are affected in 1479 villages in 2374.73 sq. km area in 18 blocks and 8 municipalities. 20 thousand houses were collapsed. 12 people died. Loss of public property amounts to Rs. 50 lakhs.

2000

In Birbhum 19 blocks, 5 Municipalities are affected. 457947 houses are damaged. 240300 hec farmland and about 33 lacks people are affected. 228 persons died and 10 persons are untraced. Total affected area is 282500 hectares. In Burdwan 25 blocks and 9 Municipalities are affected. 215695 houses are damaged. 300400 hectares farmland and about 33.25 lacks people are affected. 70 persons died. Total affected area is 359796 hectares.

In Birbhum 197 hector farmland and about 220 people were affected. 18 persons died. Total area, affected, was 556 hectares.

2004

In Birbhum, 32,520 people are affected in 320 villages in 6 blocks. 7 people, 16 cattle died. Crops of 41 hectares of Rs. 24,60,000 worth are damaged. 2441 houses collapsed fully and 2693 partly.

In Burdwan, 56,700 people are affected in 55 villages in 14 blocks. 32 people, 108 cattle died. Crops of 4269.42 hectares of Rs. 1,12,61,870 are damaged. 645 houses collapsed fully and 2954 partly.

2005

In Burdwan, 1,24,095 people are affected in 1300 villages. 34 people died. Crops of 2827.25 hectares of Rs. 2478.307 lakh are damaged. 2178 houses collapsed fully and 5410 partly. In the 2nd week of August, the road connecting Katwa and Bethuadahari submerged under water of Ganga. Almost 150 feet of road and 300-acre area with 30 houses are totally submerged under water.

In Birbhum, 1,54,043 people are affected in 110 villages in 14 blocks. 25 people, 23 cattle died. Crops of 62,213 hectares of Rs. 1178.13 lakh worth are damaged. 2708 houses collapsed fully and 6208 partly.

2006

In Burdwan, 612879 people are affected in 4406 villages in 133 blocks. 96 people, 25 cattles were died. Crops of 136770 hectares worth of Rs. 30290.89 lakh are damaged. 21783 houses collapsed fully and 22172 partly.

In Birbhum, 883117 people are affected in 800 villages in 23 blocks. 41 people, 59 cattles are died. Crops of 83705 hectares worth of Rs. 1146.68 lakh worth are damaged. 30661 houses collapsed fully and 51001 partly.

2007

In Burdwan, 2,95,707 people are affected in 2911 villages in 4 blocks. 116 people, 37 cattle died. Crops of 1,05,092 hectares worth of Rs. 15 lakh worth are damaged. 19,060 houses were collapsed fully and 56,915 partly.

In Birbhum, 60,545 people are affected in 1665 villages in 12 blocks. 40 people died. Crops of 3,19,429 hectares worth with the valuation of Rs. 3,70,545 lakhs are damaged. 33,549 houses collapsed fully and 52,452 partly.

2008

In Burdwan, 57682 people were affected in 304 villages in 6 blocks. 106 people died. Crops of 1200 hectares, 920 houses fully and 2625 partly were damaged.

In Birbhum, 30,001 people were affected in 291 villages in 12 blocks. 24 people, 69 cattle died. 397 houses were collapsed fully and 4600 partly.

2011

In Burdwan, 95,584 people were affected in 551 villages of 21 blocks and 7 municipalities. 3713 houses were fully damaged.

In Birbhum, 1,50,000 people were affected in 1810 villages of 19 blocks. 3686 houses were fully damaged.

2015

In Burdwan Aushgram I, II was heavily affected.

6.1.2 Disaster scenario in Ajay and surrounding basin area

The interconnectedness of rivers originating from the Rarh Bengal region and their convergence into the Bhagirathi-Hugli River highlights the complexity of flood dynamics in South Bengal. During peak seasons, high discharge flow often leads to flooding in the lower basin areas, impacting not just the Ajay basin but also the Bhagirathi-Hugli River and its left bank tributaries.

Historical flood events, such as the 1978 flood, had severe impacts on various regions. For example, the Tilpara barrage was affected, and Ketugram, Aushgram, and Katwa regions in the Ajay River basin experienced significant flooding. Spillover from Damodar basin affected areas in Howrah and Hugli districts, illustrating the interconnectedness of flood impacts across different basins and districts.

Similarly, in 2000, torrential rainfall in the Pagla-Banshloi-Mayrakshi-Ajay basin region led to widespread flooding. The cumulative water discharge affected areas along the Bhagirathi-Hugli River's left bank and regions in Medinipur district, emphasising the far-reaching consequences of flood events in the region. Understanding flood routing in the lower Ajay basin is crucial for effective flood management. Tropical regions, dominated by monsoons, experience seasonal and intense rainfall patterns that influence river gauge levels and flooding. The lower basin's susceptibility to floods, coupled with embankment failures, exacerbates flood events. Studying flood history helps in gauging the frequency, intensity, and impacts of floods, aiding in flood management and preparedness efforts.

6.1.3 Flood routing in the lower Ajay basin

Flooding is the most common natural disaster globally, with tropical regions often experiencing flood monsoons. The seasonal nature and intensity of rainfall significantly influence river gauge levels and subsequent flooding events. The Ajay River, particularly in the lower part of its basin, is notably prone to flooding. This susceptibility is primarily due to specific rainfall patterns and the river's limited carrying capacity, leading to frequent flood incidents.

One of the major factors contributing to floods in the Ajay River is the failure of embankments. These structures are crucial for containing river water, and their failure can result in significant flooding. Moreover, heavy rainfall within a short period exacerbates the situation, causing extensive areas to become submerged. The river's decreasing slope and sinuous channel characteristics also play a role, as they reduce the river's carrying capacity over time.

Effective flood management and preparation necessitate a thorough understanding of the river's flood history. Analysing past flood events provides valuable insights into the frequency, intensity, and damage caused by these incidents. This historical data is crucial for developing strategies to mitigate the impacts of future floods and for planning more resilient infrastructure and emergency response measures. The Budra gauge station is selected for the case study to analyse flood patterns in the Ajay basin area.

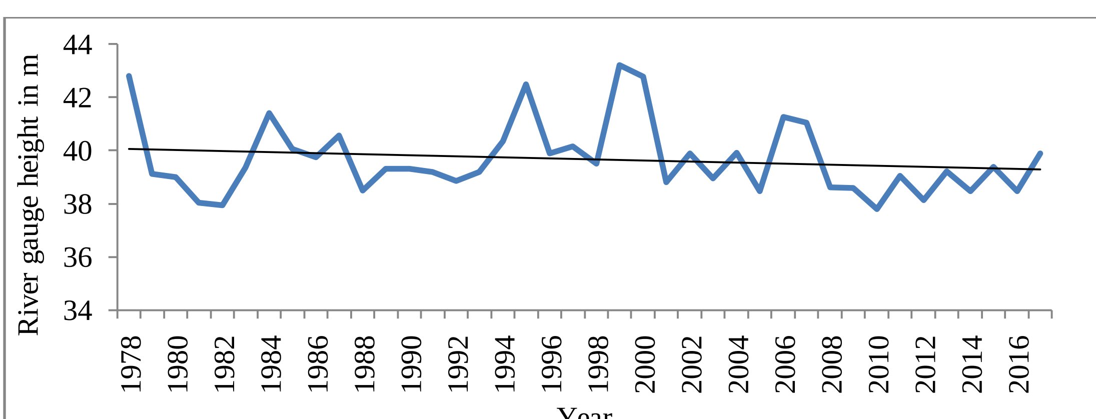


Figure 6.1 Peak gauge height in Budra gauging station from 1978 to 2017

(Source - Gauge height data collected from Budra gauge station)

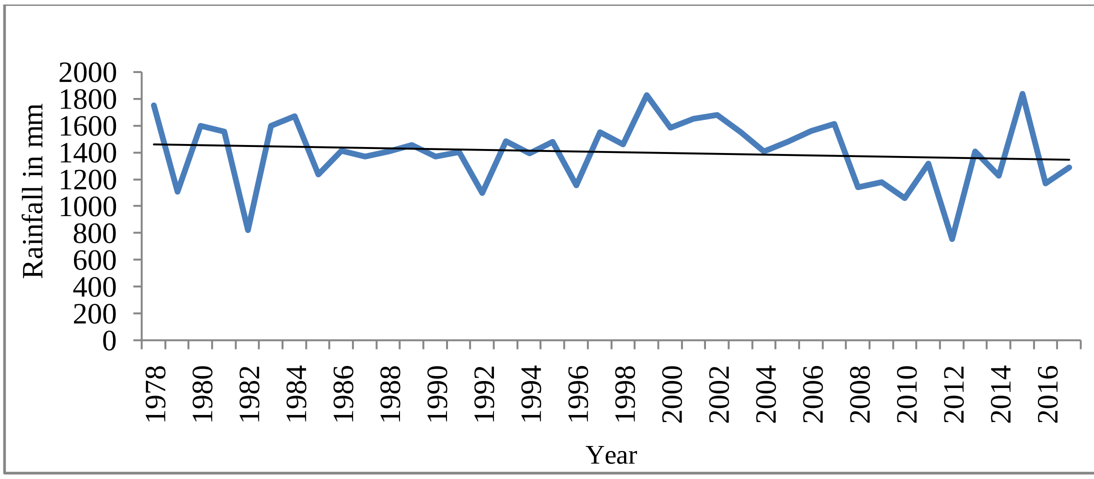


Figure 6.2 Rainfall trend in the lower Ajay River near Budra station from 1978 to 2017

(Source - Rainfall grid data IMD, Budra)

The observed trends in the peak flow, annual rainfall, and flood frequency over the last 40 years reveal some interesting patterns. While the peak gauge height has gradually decreased, indicating potentially lower water levels during peak flow periods, there is a simultaneous decreasing trend in annual rainfall (Figures 6.1 & 6.2). Despite these declines, the frequency of floods is on the rise, especially in terms of moderate and low peak flood events (Figures 6.3 & 6.4).

One plausible explanation for this paradoxical situation could be the increase in population and encroachment on river plain areas. Human activities such as urbanisation, infrastructure development, and agricultural expansion can alter natural drainage patterns, reduce water retention capacity, and increase surface runoff, leading to more frequent flooding events.

The economic and agricultural impacts of these floods are becoming more pronounced over time. Damage to infrastructure, loss of crops, disruption of livelihoods, and increased costs of flood management and recovery efforts are some of the consequences observed due to the increasing flood frequency despite declining peak flows and annual rainfall.

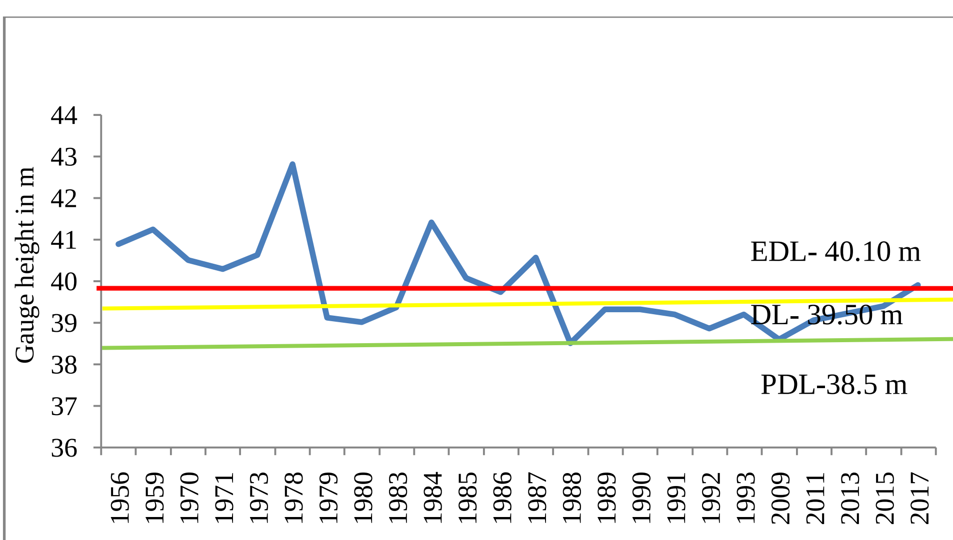


Figure 6.3 Flood trend analysis in the lower Ajay River (Budra)

(Source - Gauge height data collected from Budra gauge station)

The relationship between peak rainfall and peak gauge height, as well as the total amount of rainfall, plays a crucial role in determining flood conditions in the Ajay basin. While huge rainfalls can lead to increased peak gauge height and significant floods. The correlation between peak rainfall and peak gauge height shows a moderate relationship (0.618) (Figure 6.5). This suggests that single-day maximum rainfall events are not the sole factor responsible for floods; rather, it's the cumulative rainfall over the monsoon period that contributes to flooding.

The total amount of rainfall during flood years tends to be higher, with occasional exceptional rainfall events (Figure 6.6). These high rainfall intensities during the monsoon season contribute significantly to flooding, especially when coupled with high rainfall intensity. The monsoon season, defined by the IMD from June to September, is crucial for flood analysis (Figure 6.7), but its unpredictable nature leads to variability in flood occurrences. The timing of the monsoon's arrival and retreat greatly influences flood characteristics.

The Ajay basin has experienced floods even beyond the typical monsoon season, with late monsoon floods observed in years like 1994, 2013, and 2017 (Figure 6.8). The pulsatory nature of the monsoon contributes to these variations in flood timings, emphasising the need for comprehensive flood management strategies that account for the variability and unpredictability of monsoon patterns.

Table 6.1 Flood scenario in lower Ajay basin area

Moderate flood intensity	High flood intensity
1996, 2002, 2004	1956, 1959, 1970, 1971, 1973, 1978, 1984, 1985, 1987, 1994, 1995, , 1997, 1999, 2000, 2006, 2007, 2017

(Source - Gauge height data collected from Budra, Satkahonia and Nutanhut gauge station)

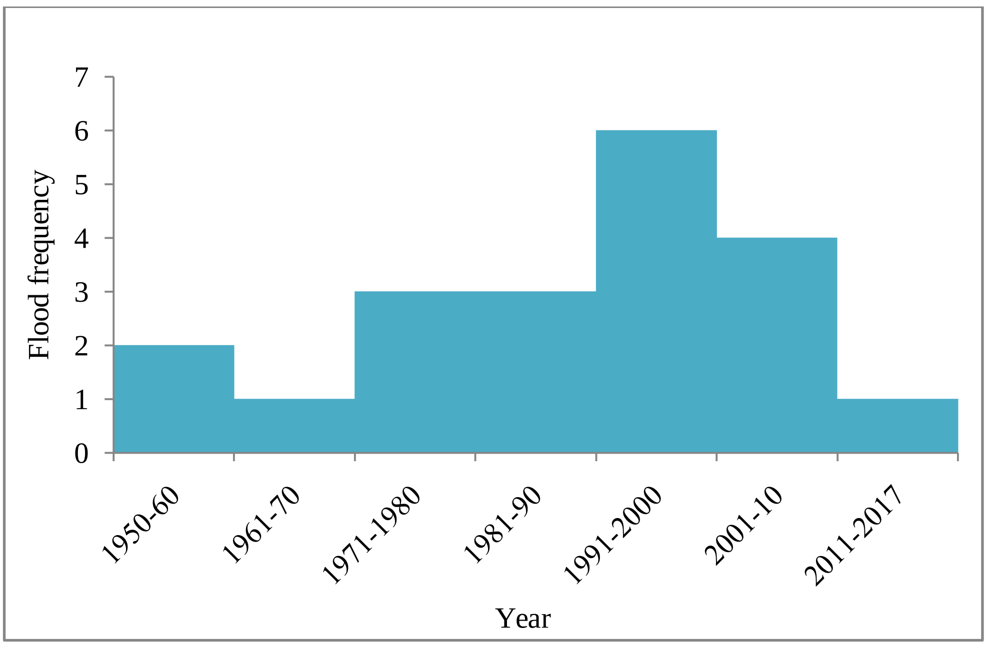


Figure 6.4 Flood frequency

(Source - Gauge height data collected from Budra, Satkahonia and Nutanhut gauge station)

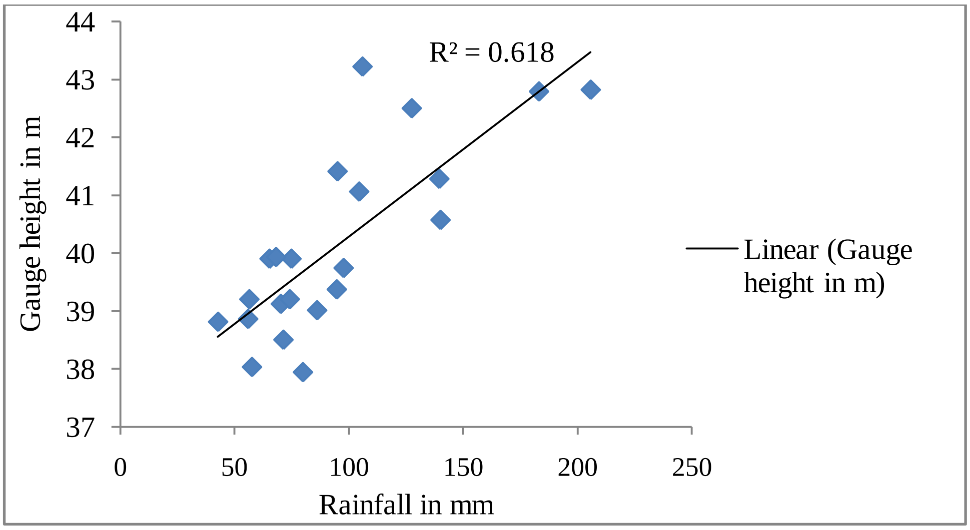


Figure 6.5 Relationship between rainfall and peak flood in Budra gauge station

(Source - Gauge height data collected from Budra gauge station and IMD grid data in Budra used for rainfall)

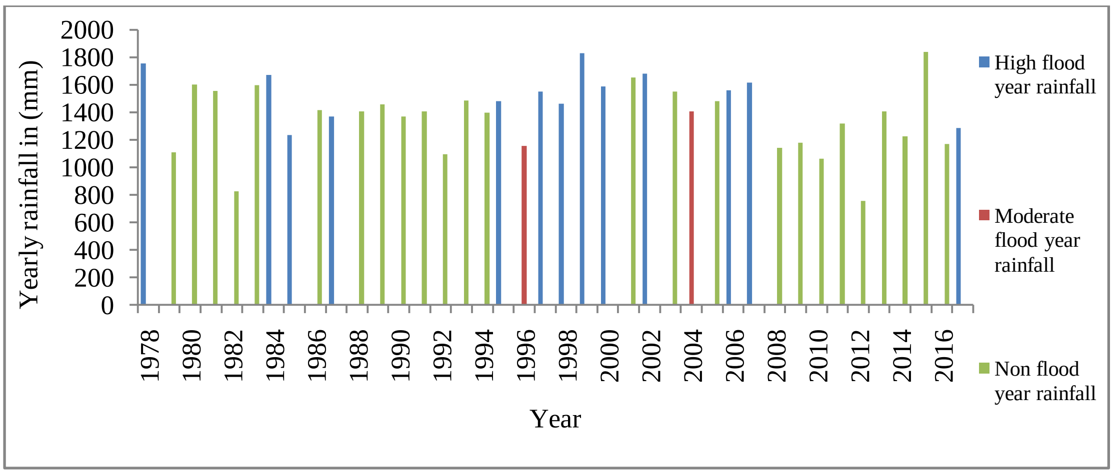


Figure 6.6 Annual rainfall trends in Budra gauge station

(Source - Grid wise rainfall data, IMD, Budra)

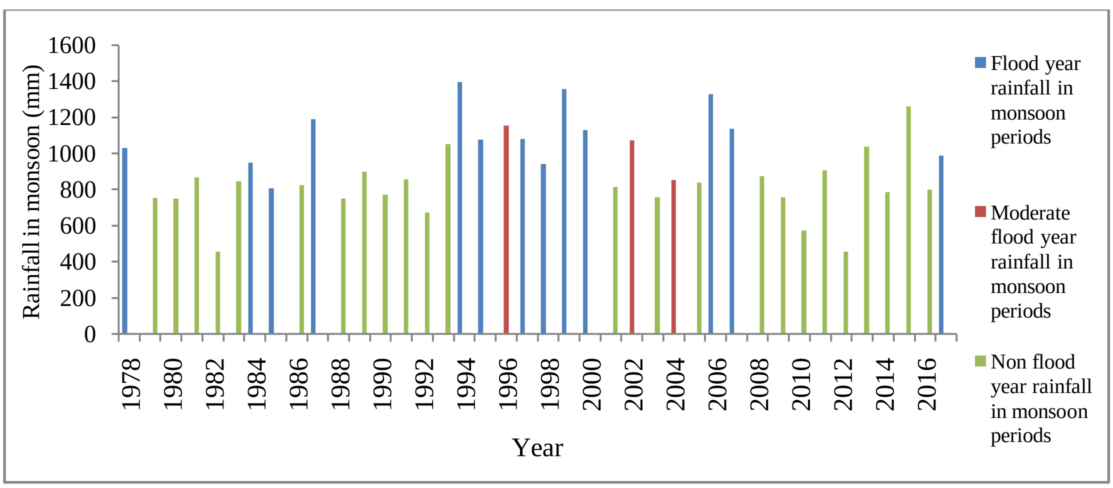


Figure 6.7 Rainfall in monsoon season in Budra gauge station

(Source - Grid wise rainfall data, IMD, Budra)

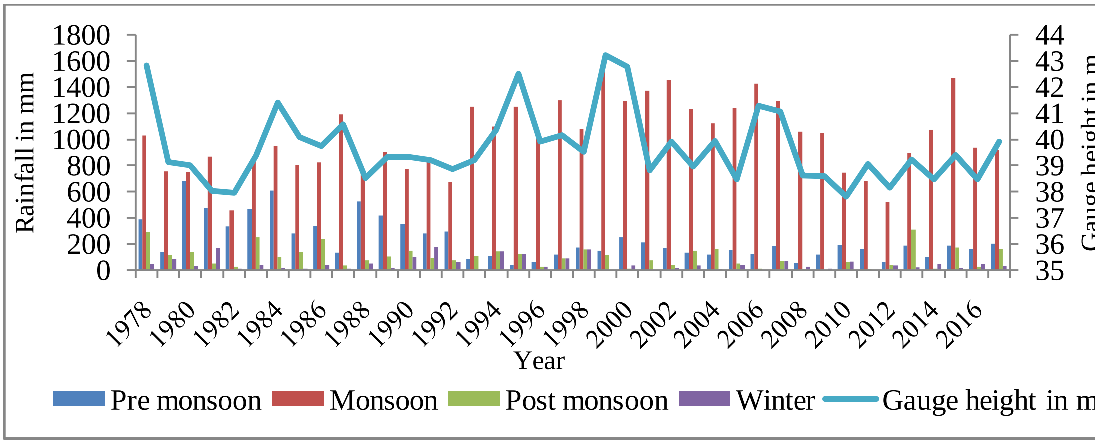


Figure 6.8 Season wise rainfall and flood level in Budra gauge station (considering the IMD seasonal classification)

(Source - Grid wise rainfall data, Budra and gauge height data in Budra)

6.1.4 Flood frequency analysis

Flood events are indeed complex and influenced by various factors, including rainfall patterns, topography, and antecedent conditions. Statistical methods for flood frequency analysis are crucial in predicting flood intensity and developing effective flood management plans. By utilising past flood data and peak gauge height measurements, flood magnitudes corresponding to different return periods can be calculated using Gumble's distribution.

In the case of the Ajay basin, which is particularly prone to floods in its lower regions, flood frequency analysis is focused on specific gauge stations such as Satkahonia, Budra, and Nutanhut. Data spanning a 40-year period from 1978 to 2017 from these stations are used to calculate return periods for flood events occurring at 5, 10, and 25-year intervals (Table 6.2-6.7) (Figure 6.9). This analysis helps in understanding the historical flood experiences and provides a basis for preparing flood management strategies.

While statistical approaches offer valuable insights, it's important to note that flood prediction based on such methods can be uncertain due to the multitude of factors influencing flood events. Nonetheless, long-term data analysis serves as a valuable tool for benchmarking flood management preparations and understanding the potential magnitude and frequency of floods in a region.

Table 6.2 Calculation for flood return period in Satkahonia gauge station

Year	Order	T	Gauge height in m (Satkahonia)	Year	Order	T	Gauge height in m (Satkahonia)
1978	1	40	55.44	1993	21	1.904	51.99
2000	2	20	54.9	1992	22	1.818	51.79
1999	3	13.333	54.68	1979	23	1.739	51.74
1995	4	10	54.42	2004	24	1.666	51.7
1984	5	8	54.02	1980	25	1.6	51.62
2006	6	6.666	53.45	1998	26	1.538	51.62
2007	7	5.714	53.23	2015	27	1.481	51.57
1987	8	5	53.22	2013	28	1.428	51.56
1994	9	4.444	53.15	1988	29	1.379	51.29
1997	10	4	52.94	2011	30	1.333	51.22

Year	Order	T	Gauge height in m (Satkahonia)	Year	Order	T	Gauge height in m (Satkahonia)
1996	11	3.636	52.69	2001	31	1.290	50.92
1985	12	3.333	52.57	2008	32	1.25	50.79
1986	13	3.076	52.39	2009	33	1.212	50.76
1989	14	2.857	52.25	1981	34	1.176	50.64
2003	15	2.666	52.13	2005	35	1.142	50.64
1990	16	2.5	52.11	2014	36	1.111	50.64
2002	17	2.352	52.07	2016	37	1.081	50.64
2017	18	2.222	52.07	1982	38	1.052	50.55
1983	19	2.105	52	2012	39	1.025	50.31
1991	20	2	51.99	2010	40	1	49.97

(Source - Calculated by researcher)

Table 6.3 Calculation for flood intensity in various return periods in Satkahonia

T years (Return period)	X_T (obtained gauge height in m)
5	52.98
10	54.06
25	55.13

(Source - Calculated by researcher)

Table 6.4 Calculation for flood return period in Budra gauge station

Year	Order	T	Gauge height in m (Budra)	Year	Order	T	Gauge height in m (Budra)
1999	1	40	43.22	1990	21	1.904	39.32
1978	2	20	42.82	2013	22	1.818	39.23
2000	3	13.333	42.79	1991	23	1.739	39.2
1995	4	10	42.5	1993	24	1.666	39.2
1984	5	8	41.41	1979	25	1.6	39.12
2006	6	6.666	41.28	2011	26	1.538	39.05
2007	7	5.714	41.06	1980	27	1.481	39.01
1987	8	5	40.57	2003	28	1.428	38.96
1994	9	4.444	40.36	1992	29	1.379	38.86
1997	10	4	40.15	2001	30	1.333	38.81
1985	11	3.636	40.07	2008	31	1.290	38.62
2004	12	3.333	39.93	2009	32	1.25	38.59
1996	13	3.076	39.9	1988	33	1.212	38.5
2002	14	2.857	39.9	2005	34	1.176	38.47
2017	15	2.666	39.9	2014	35	1.142	38.47
1986	16	2.5	39.74	2016	36	1.111	38.47
1998	17	2.352	39.51	2012	37	1.081	38.14
2015	18	2.222	39.4	1981	38	1.052	38.03
1983	19	2.105	39.37	1982	39	1.025	37.94
1989	20	2	39.32	2010	40	1	37.8

(Source - Calculated by researcher)

Table 6.5 Calculation for flood intensity in various return periods in Budra

T years (Return period)	X_T (obtained gauge height in m)
5	40.59
10	41.71
25	42.83

(Source-Calculated by researcher)

Table 6.6 Calculation for flood return period in Nutanhut gauge station

Year	Order	T	Gauge height in m (Nutanhut)	Year	Order	T	Gauge height in m (Nutanhut)
1995	1	40	23.21	2012	21	1.904	19.17
1996	2	20	22.89	1984	22	1.818	19.15
2017	3	13.333	22.42	2006	23	1.739	19.14
2000	4	10	22.3	2004	24	1.666	19.12
2011	5	8	21.4	2002	25	1.6	19.1
1987	6	6.666	21.34	1986	26	1.538	19.09
1989	7	5.714	21.25	1982	27	1.481	19.03
1988	8	5	21.02	1992	28	1.428	19.01
2001	9	4.444	20.29	2015	29	1.379	18.91
1980	10	4	20.21	1994	30	1.333	18.8
2008	11	3.636	20.17	2003	31	1.290	18.76
2010	12	3.333	20.06	2016	32	1.25	18.72
1998	13	3.076	20.05	2007	33	1.212	18.49
1991	14	2.857	19.92	1981	34	1.176	18.45
1999	15	2.666	19.9	1979	35	1.142	18.44
1978	16	2.5	19.89	1990	36	1.111	18.42
2009	17	2.352	19.74	2014	37	1.081	18.03
1993	18	2.222	19.6	2013	38	1.052	18.01
1997	19	2.105	19.5	1985	39	1.025	17.9
2005	20	2	19.17	1983	40	1	17.64

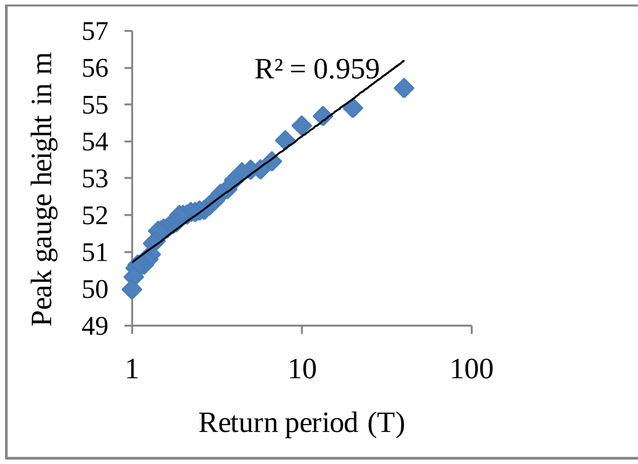
(Source-Calculated by researcher)

Table 6.7 Calculation for flood intensity in various return periods in Nutanhut

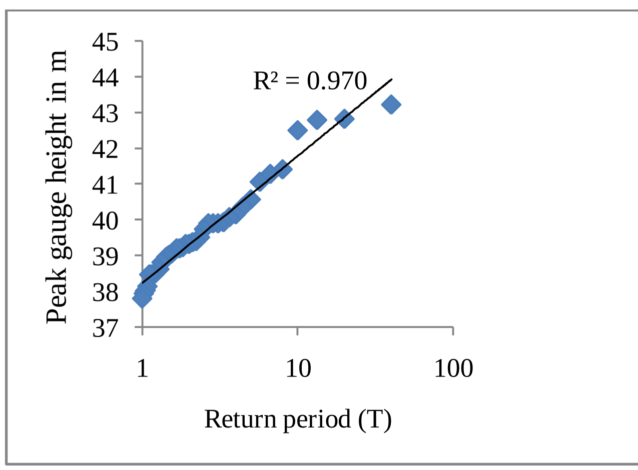
T years (Return period)	X_T (obtained gauge height in m)
5	20.61
10	21.73
25	22.85

(Source-Calculated by researcher)

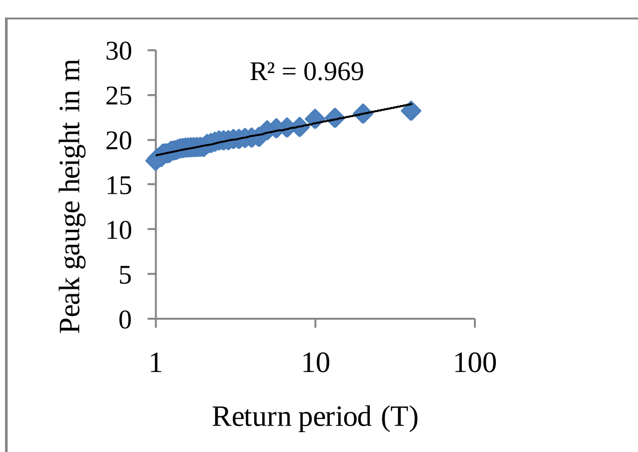
The relationship between the return period and gauge height, measured using the Gumbel distribution, provides critical insights into flood risk and frequency in the Ajay basin. A return period of 5, 10, or 25 years indicates the average interval between floods of a certain magnitude. When the gauge height data from stations such as Satkahonia, Budra, and Nutanhut is analysed through the Gumbel distribution, a strong correlation with a value above 0.9 indicates a very reliable predictive relationship (Figure 6.9). This high correlation suggests that the gauge height predictions for different return periods at these stations are highly accurate, allowing for more precise flood forecasting and better-informed flood management strategies. This significant relationship is crucial for measuring the flood mitigate and impact of future flood events.



i) Satkahonia gauging station



ii) Budra gauging station



iii) Nutanhut gauging station

Figure 6.9 Return period of peak gauge height at different gauging stations

(Source - Gauge height data collected from Budra, Satkahonia and Nutanhut gauge station)

6.2 Prediction of flood potential area

6.2.1 General overview

The estimation of flood vulnerability and risk prediction is crucial for effective flood management, and modern approaches priorities non-structural measures over structural ones. Potential flood area prediction is a fundamental step in this process, but it's challenging due to the dynamic and variable nature of flood areas over time and space. To address this challenge, various flood models are analysed and validated using historical flood records, leading to a comprehensive flood vulnerability analysis.

The Niti Ayog's report, 2021 underscores the importance of spatial flood plain zonation and advocates for leveraging recent spatial technologies like remote sensing and GIS (Geographic Information System) in flood management. These technologies enable more accurate mapping and monitoring of flood-prone areas. Additionally, the report emphasises the need for developing hydrological models specifically designed for flood area prediction.

In this study, different approaches are employed for analysing the spatial area of floods. One approach involves a factor-based flood model, developed to overcome data limitations. Another approach utilises simulation-based hydrological models to simulate flood scenarios. By integrating the results of both models, a comprehensive vulnerability index can be calculated, providing a more nuanced understanding of flood vulnerability and aiding in risk prediction and management strategies.

6.2.2 Flood potential area identification by AHP model in geospatial platform

Flood prediction and management have indeed evolved significantly with the integration of non-structural measures and advanced technologies like Geographic Information Systems (GIS) and Analytic Hierarchy Process (AHP). Flood zonation, which involves categorising flood-prone areas based on their risk levels, has become a crucial step in effective flood control and management strategies.

The combination of AHP with GIS has made flood prediction more accessible, cost-effective, and accurate. While traditional hydrological stations are not always available, especially in areas like the Ajay River basin, using multivariate factors and decision-making tools like AHP allows for reliable flood prediction. GIS, on the other hand, aids in spatial prediction by mapping and analysing various parameters that contribute to flood risk.

By leveraging the results obtained from AHP and GIS-based flood prediction, it becomes possible to estimate flood risks more accurately. This information is invaluable for resource allocation, emergency preparedness, and implementing measures to mitigate the impact of floods on communities and infrastructure. Overall, these modern approaches significantly enhance flood management strategies and help minimise the damage caused by floods.

6.2.2.1 Factors analysis for estimating flood hazards

The Analytic Hierarchy Process (AHP) is employed to assign weighted values to various factors influencing flood vulnerability. By comparing these factors and incorporating expert opinions and stakeholder inputs, the significance of factors such as rainfall, discharge, slope, altitude, groundwater table height, drainage characteristics, and channel carrying capacity is determined.

The use of thematic layers in ArcGIS 10.1, based on the extracted weights from AHP, allows for a spatial analysis of flood factors. This approach helps identify critical areas prone to flooding based on a combination of hydrological and geomorphological factors. Factors like sediment deposition, flat surfaces leading to bar formation in the riverbed, sinuosity of the channel, and embankment failure in the lower part of the basin are thoroughly evaluated.

The presence of various types of bars, such as longitudinal bars, scroll bars, and mid-channel bars, indicates the complex dynamics of sedimentation and channel morphology in the lower basin (Figure 5.34). The sinuosity index and relief ratio play a crucial role in understanding sediment trapping and channel behaviour, leading to the formation of braiding characteristics in the river channel.

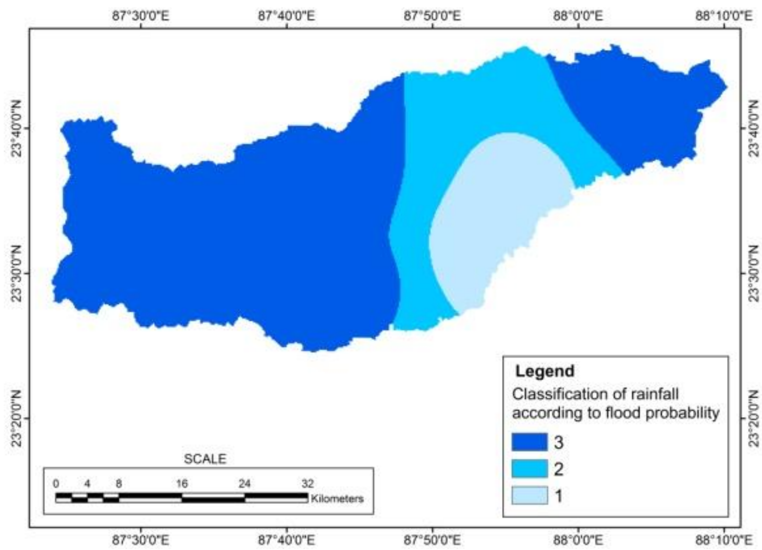
Moreover, the analysis underscores the interplay between hydrological and geomorphological factors in flood occurrences. While rainfall and discharge are primary drivers of floods, the geomorphological characteristics of the basin, including drainage networks, channel carrying capacities, slopes, and altitudes, significantly influence the severity and extent of fluvial floods. Understanding these factors is essential for flood management strategies, including embankment maintenance and mitigating the impact of embankment failures during flood events.

6.2.2.2 Zonation of estimated flood area

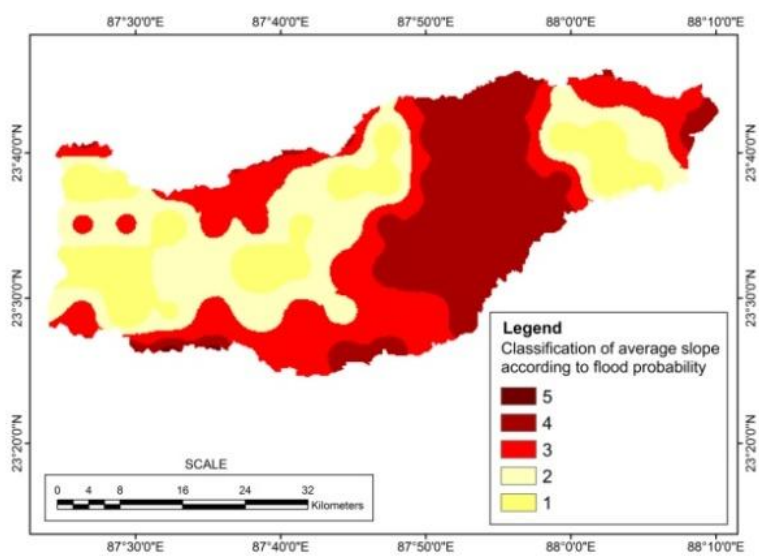
The classification of flood hazards into high, moderate, and low zones in the Ajay River basin reveals critical areas prone to flooding. High flood hazards are concentrated near confluences like Kunur tributary junctions and main channel confluences like Ketugram I, Ketugram II, Katwa, Nanoor, Bhatar, etc. These areas experience high rainfall during monsoons, combined with the contributions of Kunur tributaries and backflow from the Bhagirathi-Hugli River near Katwa, leading to flooding.

Factors such as increased groundwater table height due to heavy rainfall and poor drainage conditions in saturated alluvial soil contribute significantly to flood occurrences. The peak discharge of the Ajay River, especially during back flow through Kunur, exacerbates flooding in the Kunur watershed area. However, it's established that geomorphological features play a crucial role in flood dynamics within the basin.

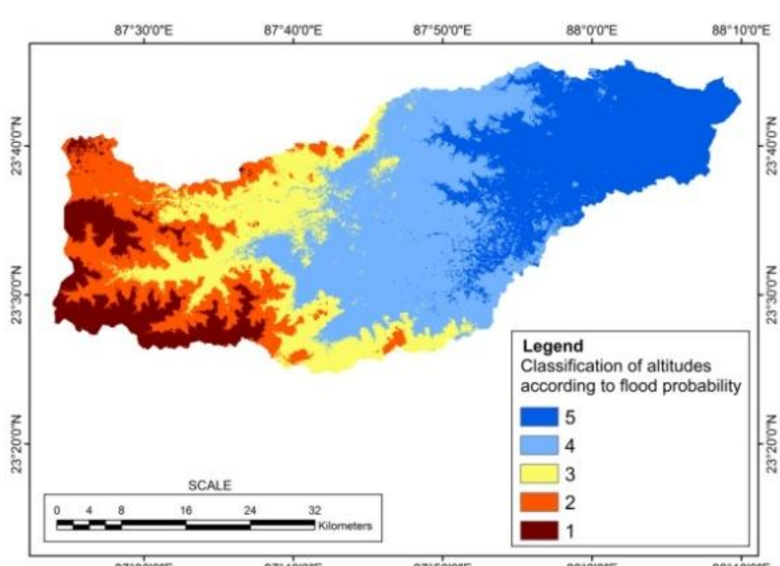
Parts of Illambazar and Kanksa blocks are categorised as safe zones due to terrain height, although historical flood data indicates occasional inundation in these areas. Efforts to protect livelihoods through embankment construction are ongoing, but the risk of embankment failure remains a concern, potentially increasing vulnerability. In the year, 2000 embankment failure incident resulted in extensive flooding in Ketugram and Katwa, with overflow affecting Nabadweep, Santipur, and Kalna. Rapid human activity growth in the basin, coupled with high sediment deposition in riverbeds, contributes to an increasing flood probability. The estimated flood area designates major portions of five blocks as very high flood hazard zones, with parts of four blocks falling into the moderate flood hazard zone, emphasising the need for comprehensive flood management strategies in the Ajay River basin.



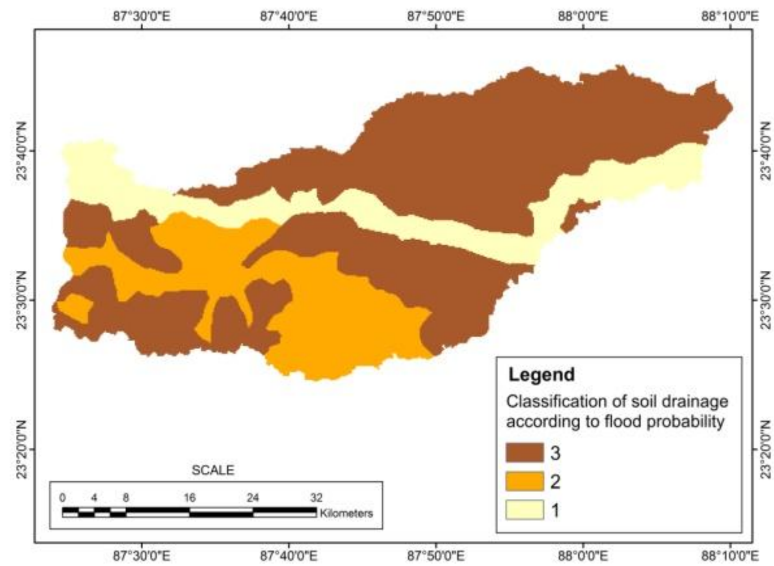
1 Rainfall



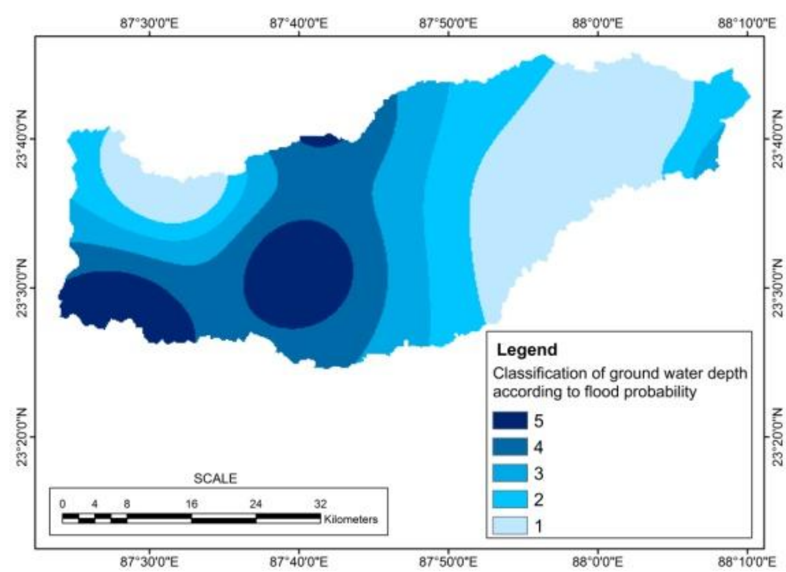
2 Slope



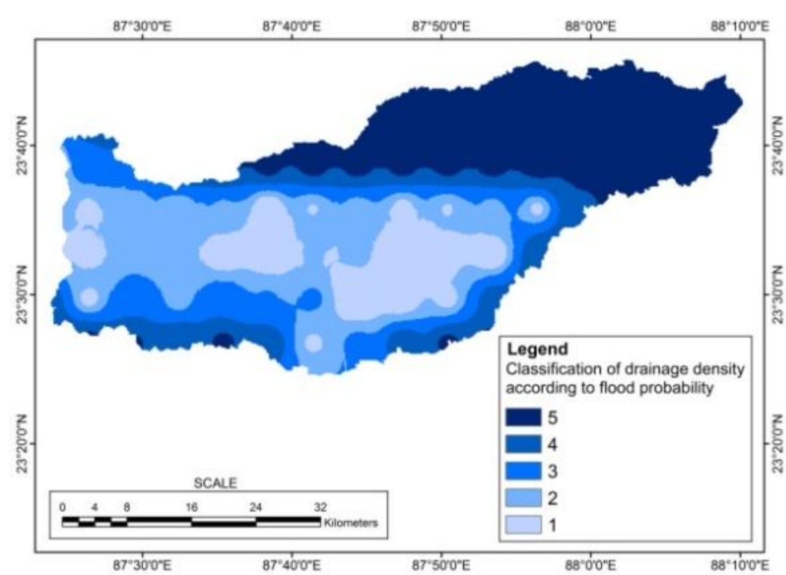
3 Altitude



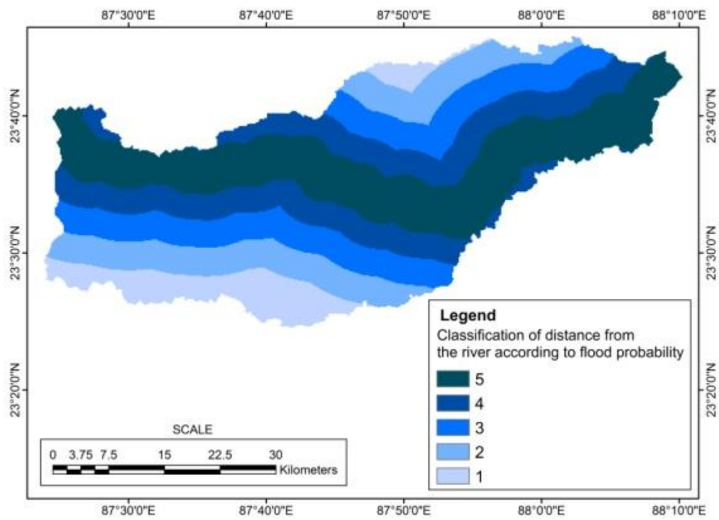
4 Soil



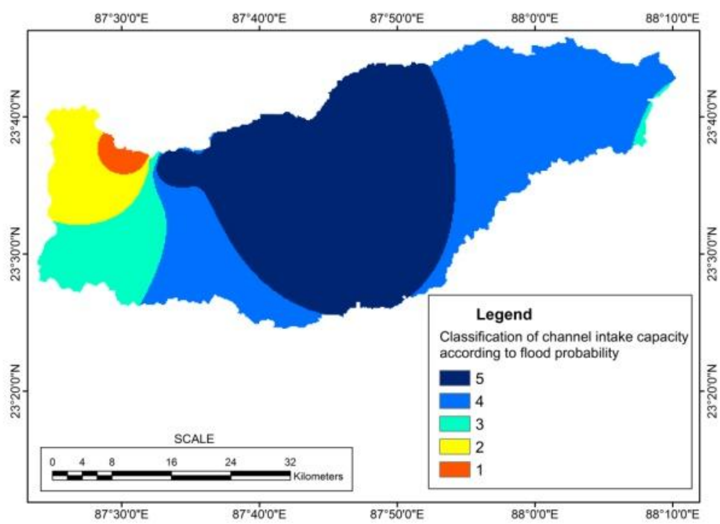
5 Ground water table height



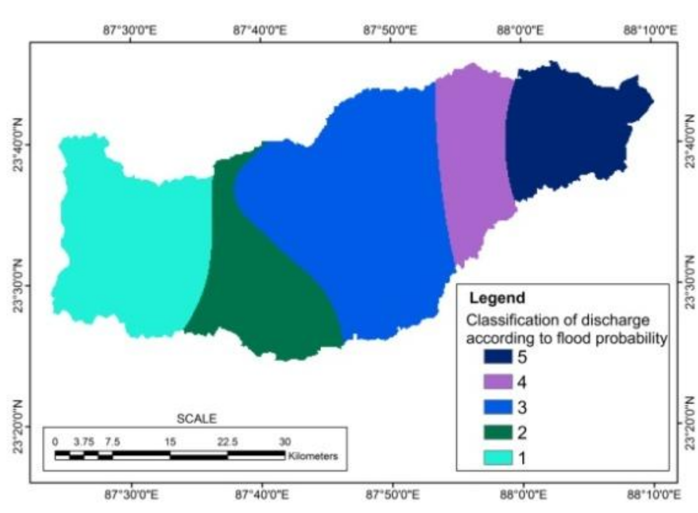
6 Drainage density



7 Distance from river



8 Channel intake capacity



9 Discharge

Figure 6. 10 Multiple factors responsible for flood (Rank based on priority, 5 indicates high priority and 1 indicates low priority)

(Source-Data classified and ranked based on priority by the researcher in GIS platform)

Table 6.8 Rank score of parameters (following equal class method)

Factors	Class	Assigned rank
(1) Rainfall in mm	1160-1190	1
	1190-1220	2
	1220-1250	3
(2) Slope (In degree)	0-0.10	5
	0.10-0.20	4
	0.20-0.30	3
	0.30-0.40	2
	0.40-0.50	1
(3) Altitude in metre	0-20	5
	20-40	4
	40-60	3
	60-80	2
	>80	1
(4) Soil (drainage quality)	Highly drained	1
	Moderately drained	2
	Poor drained	3
(5) Ground water table height in (m)	0-4	5
	4-8	4
	8-12	3
	12-16	2
	16-20	1
(6) Distance from river(m)	0-3500	5
	3500-7000	4
	7000-10500	3
	10500-14000	2
	14000-17500	1
(7) Drainage density km/km^2	0-0.015	5
	0.15-0.30	4
	0.30-0.45	3
	0.45-0.60	2
	0.60-0.75	1
(8) Channel intake capacity (Sq. km)	206-392	5
	392-578	4
	578-764	3
	764-950	2
	950-1136	1
(9) Discharge m^3/s (Avg-june-Oct)	770-790	1
	790-810	2
	810-830	3
	830-850	4
	850-870	5

(Source-calculated by researcher)

Table 6.9 Comparison matrix on the basis of expert opinion

Factors	Rainfall (1)	Slope (2)	Altitude (3)	Soil (4)	Ground Water table height (5)	Distance from river (6)	Drainage system (7)	Channel intake capacity (8)	Discharge (9)
1	1	3	4	4	4	3	3	3	2
2	0.33	1	2	3	3	2	1	1	0.5
3	0.25	0.5	1	2	3	0.5	1	1	0.5
4	0.25	0.33	0.5	1	2	0.5	0.5	0.5	0.33
5	0.25	0.33	0.33	0.5	1	0.5	0.5	0.5	0.33
6	0.33	0.5	2	2	2	1	1	0.5	0.5
7	0.33	1	1	2	2	1	1	0.5	0.5
8	0.33	1	1	2	2	2	2	1	0.5
9	0.5	2	2	3	3	2	2	2	1
Σ=	3.57	9.66	12.83	19.5	22	12.50	12	10	6.16

(Source-Calculated by researcher)

Table 6.10 Calculation of weightage as per priority

Factors	1	2	3	4	5	6	7	8	9	Weighatge
1	0.28	0.31	0.31	0.20	0.18	0.24	0.25	0.3	0.32	0.266
2	0.09	0.10	0.15	0.15	0.13	0.16	0.08	0.1	0.08	0.118
3	0.07	0.05	0.07	0.10	0.13	0.04	0.08	0.1	0.08	0.081
4	0.07	0.03	0.03	0.05	0.09	0.04	0.04	0.05	0.04	0.051
5	0.07	0.03	0.02	0.02	0.045	0.04	0.04	0.05	0.04	0.042
6	0.09	0.05	0.15	0.10	0.09	0.08	0.08	0.05	0.08	0.086
7	0.09	0.10	0.07	0.10	0.09	0.08	0.08	0.05	0.08	0.084
8	0.09	0.10	0.07	0.10	0.09	0.16	0.16	0.1	0.08	0.108
9	0.14	0.20	0.15	0.15	0.13	0.16	0.16	0.2	0.16	0.164
Σ=	0.99	0.97	1.04	0.98	1.08	1	0.97	1	0.96	1.00

(Source-Calculated by researcher)

Consistency checking

CI= (9-8.99)/(9-1) =0.00125

CR= CI/RI when variable is 9 then RI= 1.45

0.00125/1.45

= 0.0008

Table 6.11 Comparison matrix on the basis of stakeholders opinion

Factors	Rainfall (1)	Slope (2)	Altitudes (3)	Soil (4)	Ground Water table height (5)	Distance from river (6)	Drainage system (7)	Channel intake capacity(8)	Discharge (9)
1	1	3	3	4	4	2	3	2	2
2	0.33	1	2	3	4	3	2	3	0.5
3	0.33	0.5	1	3	3	3	0.5	3	0.33
4	0.25	0.33	0.33	1	2	0.5	0.5	0.5	0.25
5	0.25	0.25	0.33	0.5	1	0.5	0.5	0.5	0.2
6	0.5	0.33	0.33	2	2	1	1	0.5	0.25
7	0.33	0.5	2	2	2	1	1	0.5	0.33
8	0.5	0.33	0.33	2	2	2	2	1	0.33
9	0.5	2	3	4	5	4	3	3	1
Σ=	3.99	8.24	12.32	21.5	25	17	13.5	14	5.19

(Source-Calculated by researcher)

Table 6.12 Calculation of weightage as per priority

Factors	1	2	3	4	5	6	7	8	9	
1	0.25	0.36	0.243	0.186047	0.16	0.117647	0.222222	0.142857	0.385356	0.22968
2	0.0827	0.12	0.162	0.139535	0.16	0.176471	0.148148	0.214286	0.096339	0.14438
3	0.0827	0.06	0.081	0.139535	0.12	0.176471	0.037037	0.214286	0.063584	0.10829
4	0.0626	0.04	0.026	0.046512	0.08	0.029412	0.037037	0.035714	0.04817	0.045
5	0.0626	0.03	0.026	0.023256	0.04	0.029412	0.037037	0.035714	0.038536	0.0358
6	0.1253	0.04	0.026	0.093023	0.08	0.058824	0.074074	0.035714	0.04817	0.06456
7	0.0827	0.06	0.162	0.093023	0.08	0.058824	0.074074	0.035714	0.063584	0.0788
8	0.1253	0.04	0.026	0.093023	0.08	0.117647	0.148148	0.071429	0.063584	0.085
9	0.1253	0.24	0.243	0.186047	0.2	0.235294	0.222222	0.214286	0.192678	0.20653
Σ=	0.99	0.99	0.99	1	1	1	1	1	1	8.97

(Source-Calculated by researcher)

Consistency checking

CI= (9-8.97)/(9-1) =0.00375

CR= CI/RI when variable is 9 then RI= 1.45

0.00375/1.45=0.0026

Table 6.13 Average weightage calculation applying AHP methods by stakeholders opinion and expert opinions

Factors	Weightage from stakeholder	Weightage from expert	Average of weightage
1) Rainfall	0.229	0.266	0.25
2) Slope	0.144	0.118	0.13
3) Altitudes	0.108	0.081	0.09
4) Soil	0.045	0.051	0.05
5) Ground Water table height	0.035	0.042	0.04
6) Distance from river	0.064	0.086	0.08
7) Drainage system	0.078	0.084	0.08
8) Channel intake capacity	0.085	0.108	0.09
9) Discharge	0.206	0.164	0.19

(Source-Calculated by researcher)

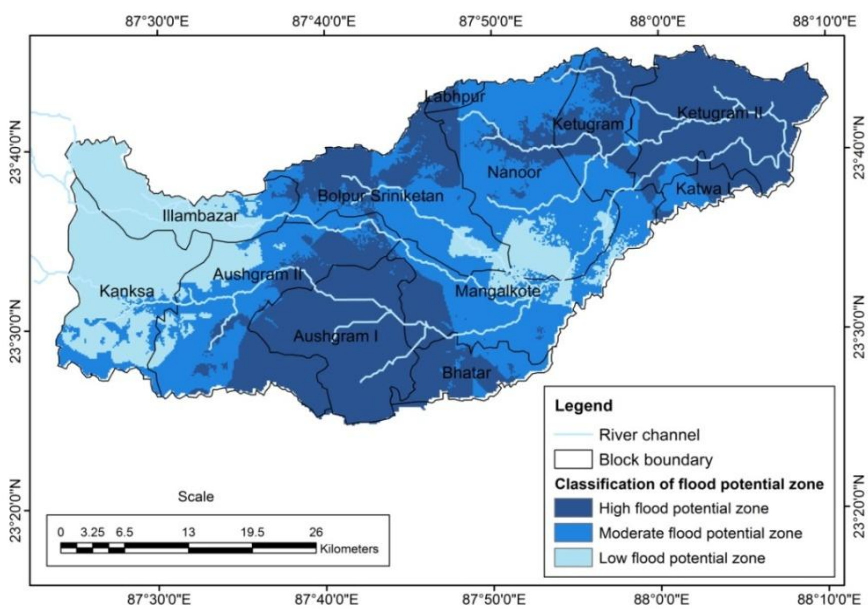


Figure 6.11 Potential flood area prediction by applying AHP method

(Source-Prepared by researcher)

Table 6.14 Estimation of flood potential area by AHP method

Blocks	High	Medium	Low
Illambazar	1.28	25.85	91.05
Kanksa	0	15.38	158.16
Ausgram II	50.62	177.4	23.37
Ausgram I	158.75	15.16	0
Mangalkote	32.44	122.43	21.46
Bolpur	85.96	84.96	14.02
Nanoor	35.8	177.67	31.82
Ketugram I	67.73	30.9	0
Ketugram II	198.46	4.34	0
Katwa I	21	12.08	0
Bhatar	46.98	18.86	0
Labhpur	5.9	5.75	0

(Source- Calculated by researcher)

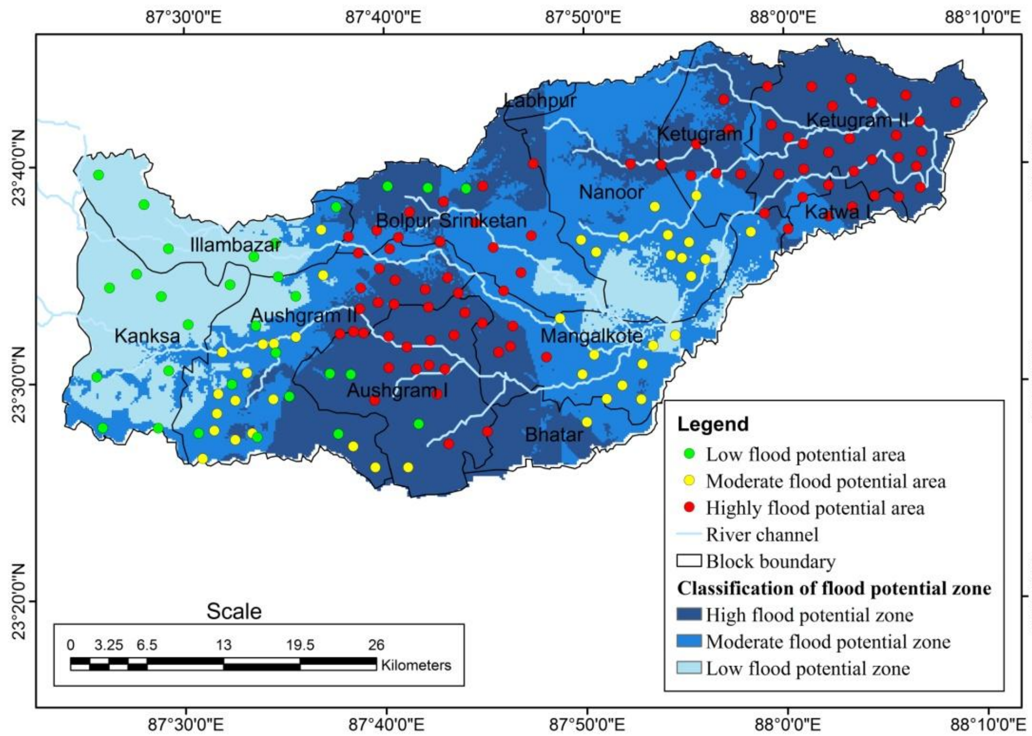


Figure 6.11 A Calibration map for validation of AHP model

(Source-Prepared by researcher)

Table 6.15 Validation for AHP

Type	High	Moderate	Low	Total
High	71	14	0	85
Moderate	03	37	0	40
Low	0	5	25	30
Total	74	56	25	155

(Source-Calculated by researcher)

Over all accuracy (Eq. 4.5)= 133/155=85.80%

Kappa (Eq. 4.6) = (20615-9280)/(24025-9280)

11335/14745 =76.87%

6.2.2.3 Validation of the result

An overall accuracy rate of 85.80% and a Kappa statistic testing result of 76.87% are both well above the 75% threshold, indicating the model's reliability and suitability. These metrics suggest that the model is effective in predicting flood hazards within the Ajay River basin and can be considered acceptable for further use in flood management and risk assessment.

6.2.3 FUZZY-AHP method for flood potential area prediction

The FUZZY-AHP (Fuzzy Analytical Hierarchy Process) method for spatial flood prediction combines fuzzy logic and AHP to handle uncertainty and subjectivity in the evaluation process. This method involves structuring complex decision problems into a hierarchy, assessing various criteria related to flood risk (such as rainfall, topography, land use, soil type etc.), and incorporating expert judgment. By applying fuzzy logic, the FUZZY-AHP method accounts for imprecise data and provides a more accurate and robust spatial flood risk prediction.

6.2.3.1 Fuzzification for potential flood area prediction

Spatial flood hazard area prediction is an essential step for risk assessment and formulating a management plan. In this study, the spatial flood extension is predicted using a combined method of fuzzy logic and the Analytical Hierarchy Process (AHP). Fuzzy-AHP is an effective mathematical tool for addressing uncertainty in multi-criteria factors, which can help reduce human ambiguity and biasness (Yodying et al., 2019). The use of fuzzy set theory is particularly powerful in the absence of precise data. Combining fuzzy-AHP within a GIS platform is an emerging application for decision-making, especially in spatial science (Nguyen, 2019). This study focuses on predicting the spatial extent of floods based on factors with imprecise and uncertain data.

6.2.3.2 Triangular Fuzzzification

Floods represent one of the most unpredictable and uncertain natural disasters. Accurate prediction of the spatial extent of flooding is vital for effective flood management. Hydrological data plays a crucial role in this prediction, yet in the Ajay basin, the absence of gauge stations recording daily discharge poses a challenge. This issue is common for numerous rivers in India and West Bengal that lack gauge stations.

In such cases, a factor-based multicriteria decision-making approach proves valuable for flood prediction. This study employs globally recognised multicriterion-based models like AHP and Fuzzy-AHP for flood area prediction. These models consider various factors influencing floods and their spatial distribution patterns. By integrating GIS tools with mathematical weightage calculations, flood prediction becomes more accessible and impactful.

The weightage derived from qualitative opinions and spatial patterns of flood-affecting factors facilitates accurate predictions of flood extents. GIS tools further analyze these spatial patterns to assess risks and vulnerabilities associated with floods. Triangular fuzzyfication is utilised for fuzzy-AHP weightage calculations (refer to Tables 6.16 and 20), based on comparison-based matrices crafted from expert and stakeholder opinions (refer to Tables 6.9 and 11). Following the AHP-FUZZY rules, the defuzzified weightage values (refer to Tables 6.17 to 19 and 6.21 to 23) are averaged to extract the spatial flood zonation (refer to Table 6.24).

Table 6.16 Triangular Fuzzyfication based on expert opinion

Factors	Rainfall (1)	Slope (2)	Altitudes (3)	Soil (4)	Ground Water table height (5)	Distance from river (6)	Drainage system (7)	Channel intake capacity (8)	Discharge (9)
1	1, 1,1	2,3,4	3, 4, 5	3, 4, 5	3, 4, 5	2, 3, 4	2, 3, 4	2, 3, 4	1, 2, 3
2	¼, 1/3, 1/2	1,1,1	1, 2, 3	2,3,4	2,3,4	1, 2, 3	1,1,1	1,1,1	1/3,1/2,1
3	1/5,1/4,1/3	1/3,1/2,1	1,1,1	1, 2, 3	2, 3, 4	1/3,1/2, 1	1,1,1	1,1,1	1/3,1/2,1
4	1/5,1/4,1/3	¼,1/3,1/2	1/3, ½, 1	1,1,1	1, 2, 3	1/3, ½, 1	1/3, ½, 1	1/3,1/2,1	¼,1/3, 1/2
5	1/5, ¼, 1/3	¼, 1/3, 1/2	¼, 1/3, ½	1/3, ½, 1	1, 1, 1	1/3, ½, 1	1/3, ½, 1	1/3, ½,1	¼, 1/3, 1/2
6	¼, 1/3, 1/2	1/3,1/2,1	1, 2,3	1, 2,3	1,2,3	1,1,1	1,1,1	1/3,1/2,1	1/3, ½, 1
7	¼,1/3, 1/2	1, 1, 1	1,1,1	1, 2,3	1,2,3	1,1,1	1,1,1	1/3,1/2,1	1/3,1/2,1
8	¼,1/3,1/2	1, 1, 1	1, 1,1	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 1,1	1/3, ½,1
9	1/3, ½, 1	1,2, 3	1, 2, 3	2, 3, 4	2, 3, 4	1, 2, 3	1, 2, 3	1, 2, 3	1, 1, 1

(Source-Calculated by researcher)

Geometric mean of lower, upper and middle-1*2*3*3*3*2*2*2*1 =432 $\sqrt[9]{432}$=1.96 $\sqrt[9]{10368}$ = 2.79

Table 6.17 Calculation for de-fuzzification of weighatge

Sl. no	Lower (L)	Middle (M)	Upper (U)
1	1.96 *1/14.32	2.79 * 1/10.43	3.57 *1/7.26
2	0.88	1.21	1.53
3	0.62	0.83	1.16
4	0.37	0.53	0.85
5	0.32	0.47	0.70
6	0.59	0.88	1.33
7	0.67	0.88	1.18
8	0.75	1.11	1.50
9	1.10	1.73	2.50
Σ=	7.26	10.43	14.32

(Source-Calculated by researcher)

Table 6.18 Calculation of de-fuzzified Weightage

Sl. no	L	M	U	Total
1	0.137	0.26	0.491	0.296
2	0.06	0.11	0.21	0.126
3	0.04	0.07	0.159	0.089
4	0.02	0.05	0.117	0.0623
5	0.02	0.04	0.096	0.052
6	0.04	0.08	0.183	0.101
7	0.046	0.084	0.162	0.097
8	0.05	0.07	0.206	0.108
9	0.07	0.16	0.344	0.191
				Σ=1.222

(Source-Calculated by researcher)

Table 6.19 Calculation of weighatge by minimising error

Weightage	Correction of weightage	Final Weightage After correction
0.296	0.296/1.122	0.263815
0.126	0.126/1.122	0.112299
0.089	0.089/1.122	0.079323
0.0623	0.0623/1.122	0.055526
0.052	0.052/1.122	0.046346
0.101	0.101/1.122	0.090018
0.097	0.097/1.122	0.086453
0.108	0.108/1.122	0.096257
0.191	0.191/1.122	0.170232
Σ=1.122		Σ=1

(Source-Calculated by researcher)

Table 6.20 Triangular Fuzzyfication as per stakeholder opinion

Factors	Rainfall (1)	Slope (2)	Altitudes (3)	Soil (4)	Ground Water table height (5)	Distance from river (6)	Drainage system (7)	Channel intake capacity (8)	Discharge (9)
1	1, 1,1	2,3,4	2, 3, 4	3, 4, 5	3, 4, 5	1, 2, 3	2, 3, 4	1, 2, 3	1, 2, 3
2	¼, 1/3, 1/2	1,1,1	1, 2, 3	2,3,4	3,4,5	2, 3, 4	1,2,3	2,3,4	1/3,1/2,1
3	1/4,1/3,1/2	1/3,1/2,1	1,1,1	2, 3,4	2, 3, 4	2,3,4	1/3,1/2,1	2,3,4	1/4,1/3,1/2
4	1/5,1/4,1/3	¼,1/3,1/2	1/4, 1/3, 1/2	1,1,1	1, 1, 1	1/3, ½, 1	1/3, ½, 1	1/3,1/2,1	1/5,1/4, 1/3
5	1/5,1/4,1/3	1/5, 1/4, 1/3	1/4, 1/3, 1/2	1/3, ½, 1	1, 1, 1	1/3, ½, 1	1/3, ½, 1	1/3, ½,1	1/6, 1/5, 1/4
6	1/3, ½,1	1/4,1/3,1/2	¼,1/3, 1/2	1, 2,3	1,2,3	1,1,1	1,1,1	1/3,1/2,1	1/5, 1/4, 1/3
7	¼,1/3, 1/2	1/3, ½,1	1,2,3	1, 2,3	1,2,3	1,1,1	1,1,1	1/3,1/2,1	1/4,1/3,1/2
8	1/3,1/2,1	1/4,1/3,1/2	1/4,1/3,1/2	1, 2, 3	1, 2, 3	3,4,5	2, 3,4	2,3,4	1,1,1
9	1/3, 1/2, 1	1,2, 3	2, 3,4	3, 4, 5	4,5,6	3,4,5	2, 3,4	2, 3, 4	1, 1, 1

(Source-Calculated by researcher)

Geometric mean of lower, upper and middle value- $\sqrt[9]{72}$=1.60 (1*2*2*3*3*1*2*1*1) =72

Table 6.21 Calculation for de-fuzzification of weighatge

Factors	L	M	U
1	1.60*1/14.81	2.47*1/11.11	3.27*1/7.685
2	1.07	1.60	2.24
3	0.78	1.09	1.36
4	0.355	0.455	0.67
5	0.30	0.399	0.62
6	0.48	0.670	0.96
7	0.60	0.844	1.23
8	0.85	1.25	1.78
9	1.65	2.34	2.68
Σ=	7.685	11.11	14.81

(Source-Calculated by researcher)

Table 6.22 Calculation of de-fuzzified weightage

Factors	L	M	U	Avg.
1	0.108	0.22	0.42	0.249
2	0.07	0.144	0.291	0.168
3	0.05	0.09	0.176	0.105
4	0.02	0.04	0.087	0.049
5	0.02	0.03	0.08	0.043
6	0.03	0.06	0.124	0.07
7	0.04	0.07	0.160	0.09
8	0.05	0.11	0.23	0.13
9	0.11	0.21	0.34	0.22
				Σ=1.124

(Source-Calculated by researcher)

Table 6.23 Calculation of weighatge by minimising error

Factors	Weightage	Correction of weighatge	Final weighatge
1	0.249	0.249/1.124	0.221
2	0.168	0.168/1.124	0.149
3	0.105	0.105/1.124	0.0934
4	0.049	0.049/1.124	0.0435
5	0.043	0.043/1.124	0.0382
6	0.07	0.07/1.124	0.062
7	0.09	0.09/1.124	0.080
8	0.13	0.13/1.124	0.115
9	0.22	0.22/1.124	0.1957
	Σ= 1.124		Σ=1.0

(Source-Calculated by researcher)

Table 6.24 Calculation of average weightage

Factors	Wightage by stakeholder	Weightage by expert	Avg. weightage
(1) Rainfall	0.221	0.264	0.242
(2) Slope	0.149	0.112	0.131
(3) Altitudes	0.0934	0.079	0.086
(4) Soil	0.0435	0.056	0.050
(5) Ground Water table height	0.0382	0.046	0.042
(6) Distance from river	0.062	0.090	0.076
(7) Drainage system	0.08	0.086	0.083
(8) Channel intake capacity	0.115	0.096	0.106
(9) Discharge	0.1957	0.170	0.183

(Source-Calculated by researcher)

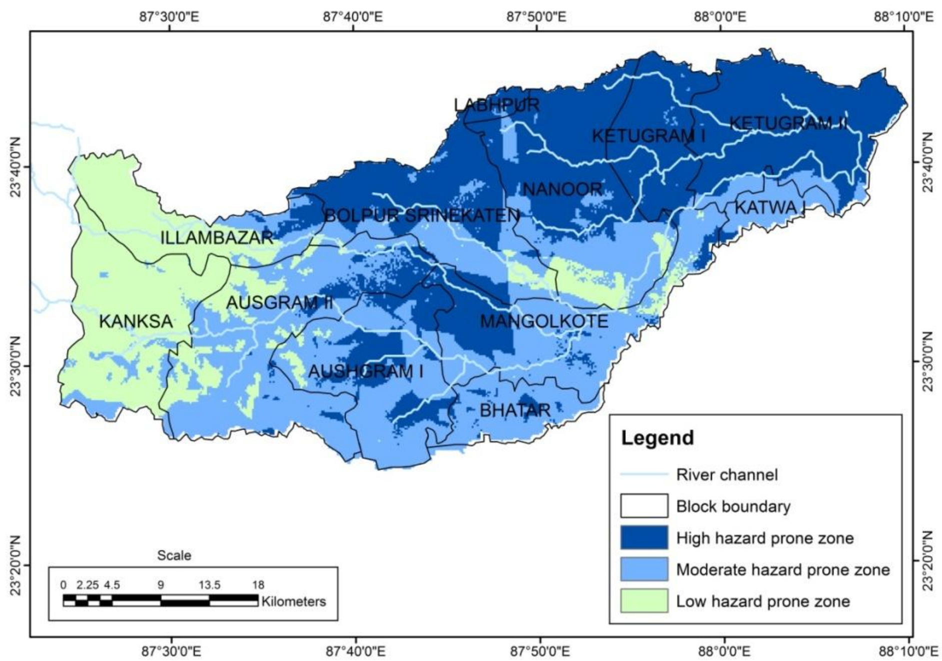


Figure 6.12 Potential flood area prediction by applying Fuzzy-AHP method

(Source-Prepared by researcher)

Table 6.25 Flood potential area estimation by FUZZY-AHP model

Blocks	High	Medium	Low
Illambazar	5.78	28.25	84.118
Kanksa	0	36.1	137.341
Ausgram II	53.24	170.39	27.76
Ausgram I	100.83	93.08	0
Mangalkote	37.23	139.1	0
Bolpur	105.23	79.717	0
Nanoor	41.28	189.73	14.28
Ketugram I	65.18	33.45	0
Ketugram II	191.73	11.09	0
Katwa I	5.01	28.07	0
Bhatar	5.84	60	0
Labhpur	8.16	3.5	0

(Source-Calculated by researcher)

6.2.3.3 Potential flood area analysis based on the Fuzzy AHP model

The Fuzzy AHP model shows that rainfall carries the maximum weightage, followed by other factors like slope and altitude. Both expert opinion and stakeholder opinion align in giving rainfall the highest weightage. In the final model implementation, rainfall holds a weightage value of 0.242, closely followed by discharge at 0.183, and then slope, among others. The

AHP weightage calculation also places rainfall at 0.25, which is very close to the Fuzzy AHP result of 0.242. Utilising the weightage results from both models, areas like Ketugram II, Aushgram I, and Bolpur are predicted to experience the maximum flood extent, while areas like Mangalkote, Aushgram II, and Nanoor are expected to be moderately affected. Conversely, regions like Kanksa and Illambazar are projected to have the minimum flood area (refer to Table 6.25). The fuzzy AHP model results indicate that the confluence region of the Ketugram area experiences the maximum flood area (refer to Figure 6.12). This is due to the high water flow from the main channel and the backflow from the Bhagirathi Hugli River, resulting in extensive flooding in these blocks. Aushgram I is also vulnerable to inundation, particularly during peak flows when Kunur tributaries act as distributaries and spill over a vast area. Comparing AHP with Fuzzy AHP, Ketugram consistently appears as the area with the maximum flood coverage. On the other hand, the topography and slope characteristics of Kanksa and Illambazar blocks suggest they are comparatively safer regions during flood events.

Table 6.26 Validation for FUZZY-AHP result

Type	High	Moderate	Low	Total
High	74	11	0	85
Moderate	04	34	2	40
Low	0	2	28	30
Total	78	47	30	155

(Source-Calculated by researcher)

Over all accuracy (Eq. 4.5) = 136/155 =87.74%

Kappa (Eq. 4.6) = (21080-9410)/(24025-9410)

=11670/14615

= 79.84%

6.2.3.4 Validation of the model

In the spatial validation-based method, both over-all accuracy and KAPPA statistics are applied (Appendix F) (Table 6.26). The validation result of the overall accuracy is 87.74%, and the Kappa statistic value of 79.84% proves the model's suitability. The validation result by using the AHP model is 85.70% in the case of overall accuracy and 76.87% in the case of Kappa statistics, which is less than the value of the Fuzzy AHP value.

6.2.4 Prediction of the flood potential area based on topographic variation

6.2.4.1 General overview

The estimation of spatial flood areas based on gauge height and topographic relations is a crucial aspect of this study. Leveraging historical river gauge height data alongside topographic conditions allows for the extraction of flood potential areas, which is a pivotal step in flood management. For fluvial floods, the identification of flood areas relies on past gauge height data and the current topographic features. Additionally, flood area identification at micro scale aids in crafting new management plans tailored to specific regional characteristics.

6.2.4.2 Flood frequency analysis and spatial area prediction in the lower Ajay River

The analysis of floods is intricate due to various influencing factors. Among these factors, rainfall and topographic characteristics hold significant importance. Peak flood gauge height data are utilised to determine flood frequency and magnitude, often through Gumbel's distribution. Over a span of 40 years from 1978 to 2017, data from three gauge stations—Satkahonia, Budra, and Nutanhut—were used to calculate the return period. This analysis aids in understanding past flood experiences and helps to formulate flood management strategies. This long-term historical data helps reduce uncertainty in flood frequency analysis and supports decision-making processes.

The computation of Gumbel distribution involves several statistical parameters such as return period, plotting position, and plotting probability, which are detailed in Tables 6.2-7. Notably, the mean peak gauge heights differ among the three gauge stations: 52.09 m in Satkahonia, 39.67 m in Budra, and 19.69 m in Nutanhut. The micro flood analysis in the lower Ajay basin is crucial, especially considering tributaries like Kunur that contribute significantly during peak seasons. The inclusion and separate analysis of all relevant data using statistical methods are vital for accurately understanding flood characteristics in this basin.

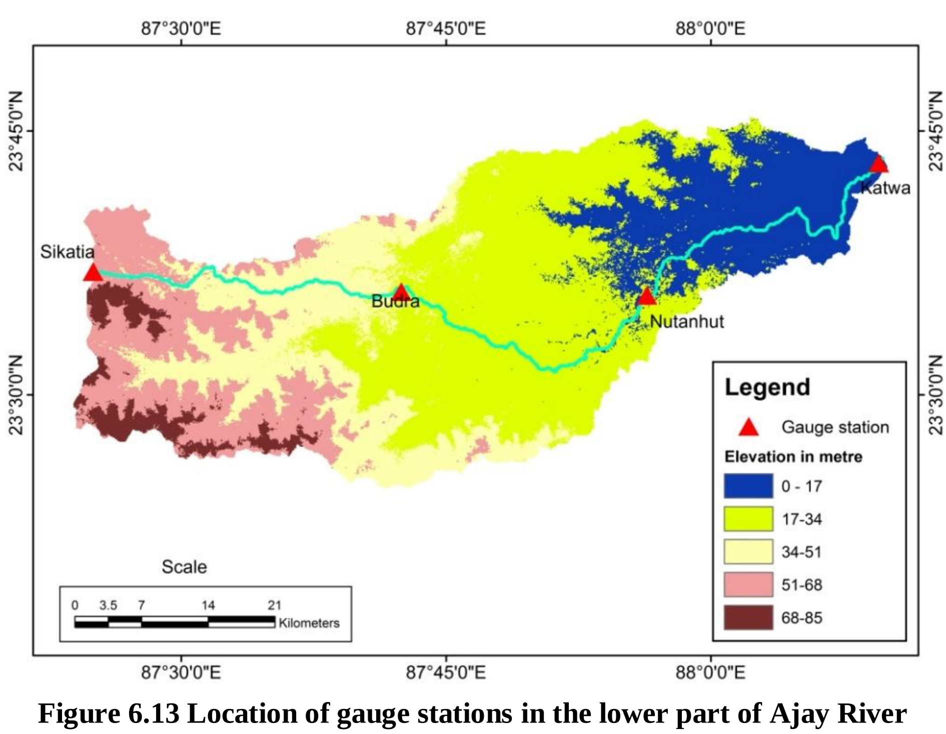


Figure 6.13 Location of gauge stations in the lower part of Ajay River
(Source - SRTM DEM data 30 m and gauge station collected from Irrigation and Waterways, Govt. West Bengal)

To validate the applicability of the Gumbel probability distribution, the mean annual flood (T=2.33) is graphically verified, showing a good correspondence between theoretical and graphical results. The strong correlation ($R^2 > 0.95$) between peak gauge height and return period across all gauge stations further confirms the reliability of the Gumbel distribution in this area. Figure 6.13 depicts the locations of the three gauge stations in the lower Ajay River.

Table 6.27 Calculation of flood magnitudes in various return periods

T years (Return period)	X_T (obtained gauge height in m) Satkahonia	X_T (obtained gauge height in m) Budra	X_T (obtained gauge height in m) Nutanhut
2.33	52.13	39.71	19.73
5	52.98	40.59	20.61
10	54.06	41.71	21.73
25	55.13	42.83	22.85

(Source-Calculated by researcher)

Table 6.28 Estimation of flood potential area in different return periods

Return period (years)	Flooded Area in percent		
	Satkahonia to Budra	Budra to Nutanhut	Nutanhut to Katwa
5	18.06	40	23.31
10	27.12	45.49	31.60
25	33.14	51.23	47.48

(Source-Calculated by researcher)

6.2.4.3 Flood inundation area mapping

The two-dimensional extent of flood inundation area is derived from past flood records and topographical characteristics, as illustrated in Figure 6.14. The spatial extension of the flood area, correlated with respective return periods, is depicted in Figures 6.15 to 17, showcasing a proportional increase in the flooded area across the three gauge station areas (refer to Table 6.28). Notably, the flood-extended area from Satkahonia to Budra is relatively low, indicating minimal inundation due to the higher elevation of this region. Approximately 42% of the area is prone to flooding within a 25-year return period (Figure 6.18).

Certain pockets in the lower Ajay basin exhibit flood potential area, particularly in areas where tributaries converge, resulting in low-lying regions frequently affected by floods. The topographic patterns reveal that these low-lying areas experience frequent submergence, with significant flood depths. Analysing the relationship between flood extension and topography aids not only in understanding flood hazards but also in flood management decisions. For instance, flood shelter locations and relief distribution centers can be identified based on this analysis.

Although the government constructs embankments to protect flood-prone areas, embankment breaches are common, especially during high flood magnitudes. The flood potential area analysis considers various return periods, highlighting that low-lying areas are consistently flooded, albeit with varying intensities each year. However, during high flood conditions like 25-year return periods or more, the most severely affected areas are those located in vulnerable topographical locations.

This model not only identifies hazard-prone areas but also helps pinpoint safe locations during different flood return periods, aiding in flood management strategies. Risk calculations estimate the number of affected populations, with approximately 99,639 individuals at risk in Ketugram II and 85,339 populations at risk in Aushgram I. This identification of hazards and vulnerable groups provides insights into the volume of risk associated with flooding.

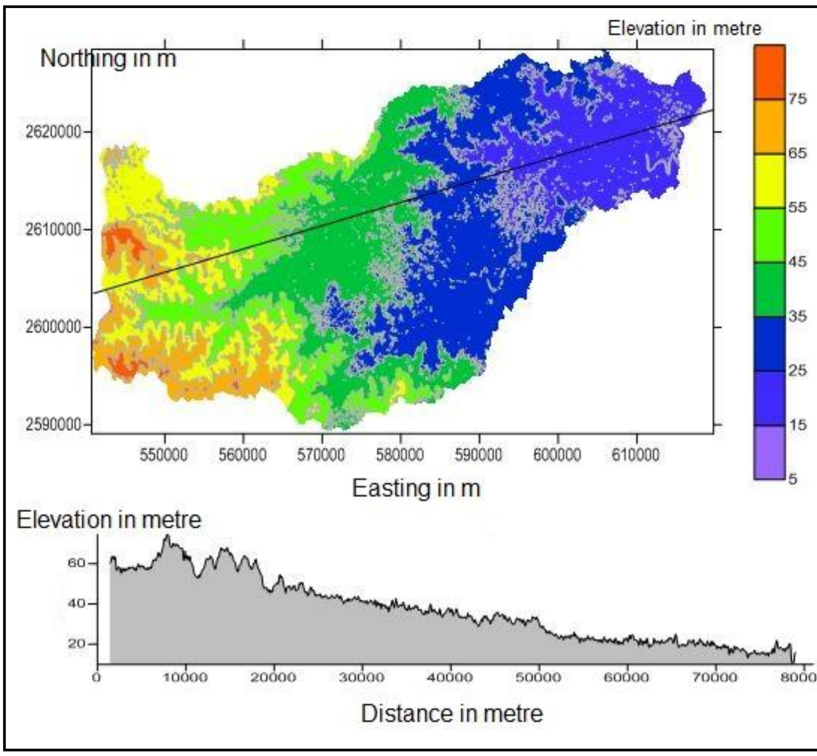


Figure 6. 14 Topographic characters from Satkahonia to Katwa

(Source –Prepared by researcher)

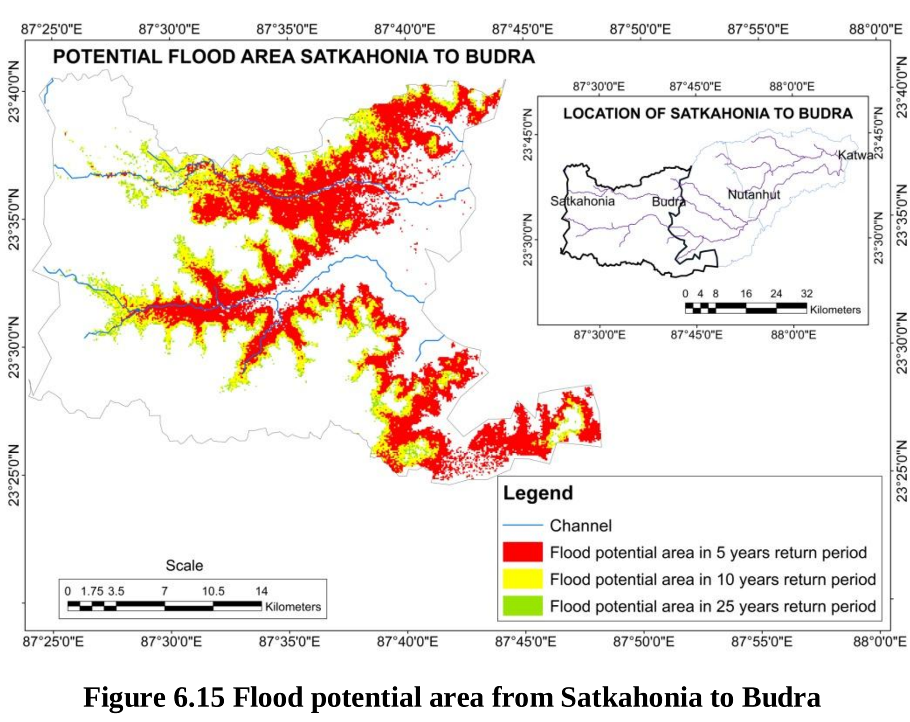


Figure 6.15 Flood potential area from Satkahonia to Budra

(Source –Prepared by researcher)

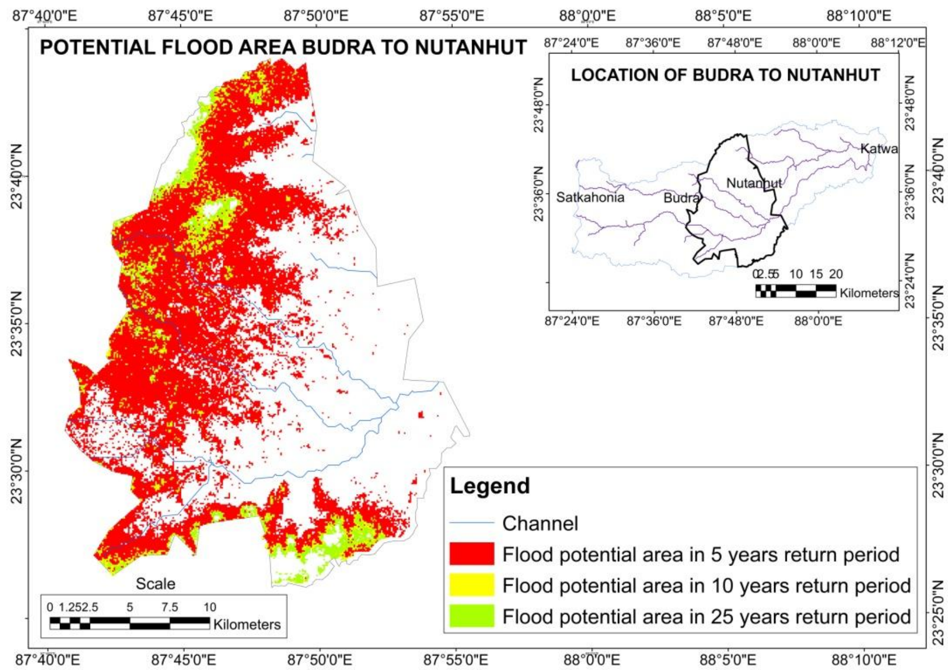


Figure 6.16 Flood potential area from Budra to Nuntahut

(Source –Prepared by researcher)

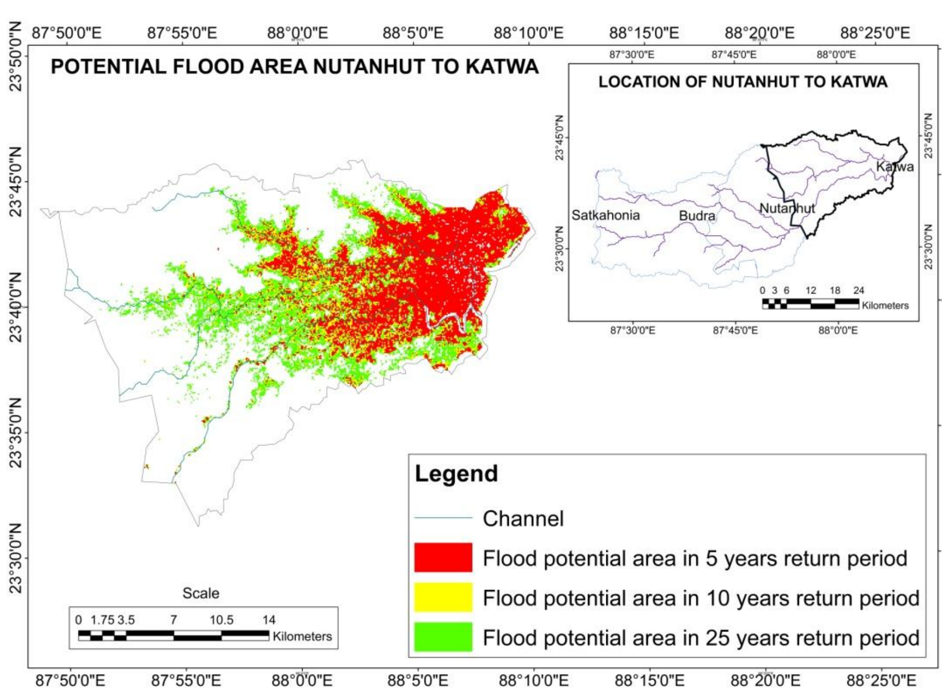


Figure 6.17 Flood potential area from Nutahut to Katwa

(Source –Prepared by researcher)

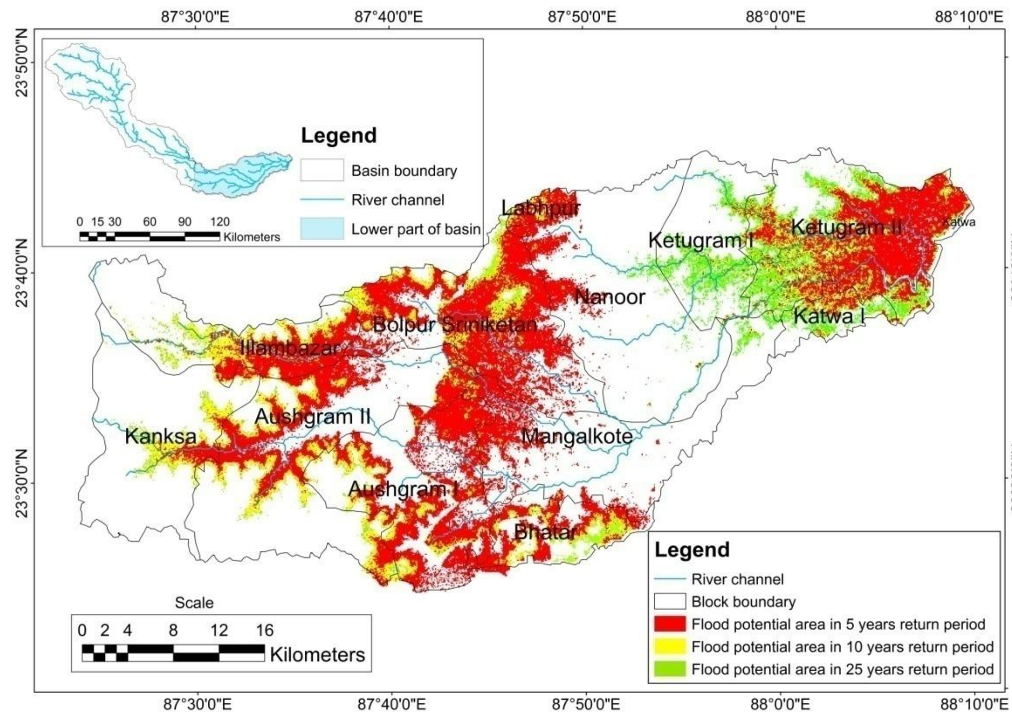


Figure 6.18 Block wise flood potential area estimation in the lower Ajay basin

(Source –Prepared by researcher)

Table 6.29 Block wise estimation of flood potential areas considering the 25 year return period

Blocks	Estimated flood area in sq. km (25 year)
Illambazar	25.32
Kanksa	5.02
Aushgram II	53.52
Aushgram I	133.28
Mangalkote	44.034
Bolpur	80.86
Nanoor	60.25
Ketugram I	51.1
Ketugram II	146.2
Katwa I	19.03
Bhatar	18.25
Labhpur	11.25

(Source-Calculated by researcher)

6.2.4.4 Block wise and GP wise flood potential area estimation

The flood coverage analysis reveals that Ketugram II block and Aushgram I block exhibit significant flood areas, as outlined in Table 6.29. Specifically, Berenda GP in Aushgram I block and Nabagram GP in Ketugram II block are identified as experiencing maximum flood coverage (refer to Table 6.30 and figure 6.19). Notably, areas like Aushgram I & II blocks are significantly flooded due to the confluence of the major tributary Kunur, while Ketugram block is predominantly affected by its low-lying topography, leading to higher gauge heights (Figure 6.18).

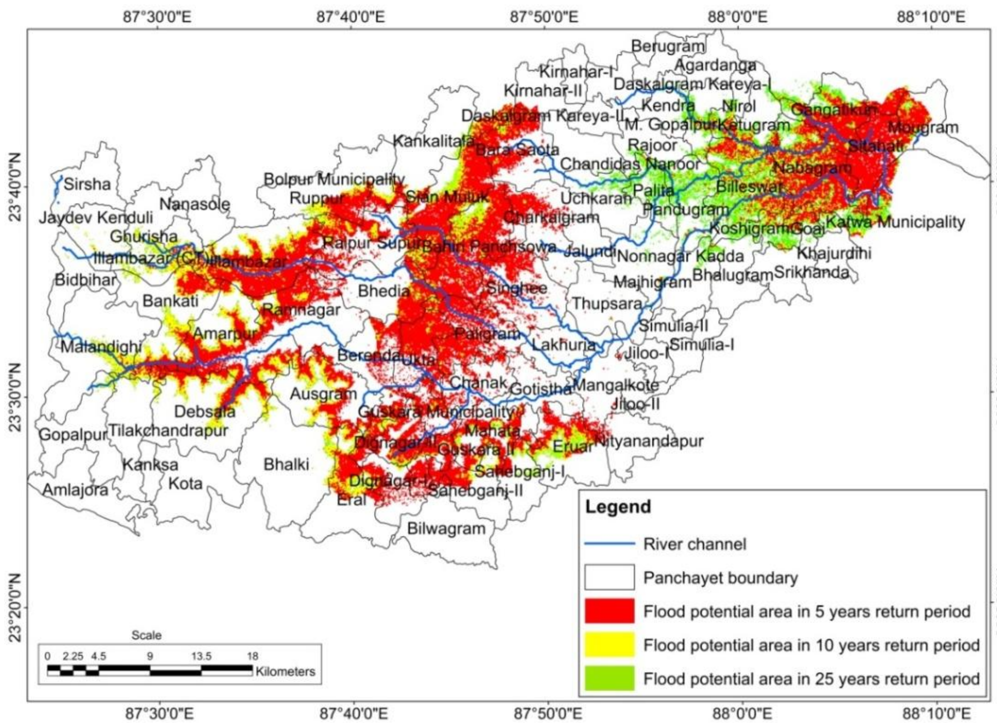


Figure 6.19 Gram Panchayet wise flood potential area estimation

(Source –Prepared by researcher)

The combined effect of discharge in the confluence region contributes to an increase in river gauge height, resulting in spillage across the entire region. Additionally, the impact of additional water from the Bhagirathi-Hugli River can exacerbate the gauge height effect, further affecting the flood-prone areas.

Table 6.30 Gram Panchayet wise flood potential area estimation

Block	GP	Flood affected area (sq. km) gauge	Block	GP	Flood affected area (sq. km) gauge
Bolpur	Sian muluk	28.46	Bhatar	Eruar	9.01
Bolpur	Singhee	10.12	Katwa I	Goai	5.02
Bolpur	Bahariparswa	42.28	Katwa I	Khasigram	11.5
Nanoor	Charkalgram	9.74	Katwa I	Municipality	2.51
Nanoor	Jalundi	2.65	Mangalkote	Paligram	24.45
Nanoor	Thupsara	4.25	Mangalkote	Chanak	12.56
Nanoor	Uchhkaran	8.25	Mangalkote	Lakhuria	2.28
Nanoor	Bara Saota	15.28	Mangalkote	Gothista	4.74
Nanoor	Nonagar Kadda	15.25	Ketugram II	Billeswar	40.1
Nanoor	Chandidas Nanoor	5.23	Ketugram II	Ketugram	15.67
Illambazar	Illambazar	22.25	Ketugram II	Nabagram	42.52
Aushgram I	Aushgram	22.23	Ketugram II	Nirol	5.25

Block	GP	Flood affected area (sq. km) gauge	Block	GP	Flood affected area (sq. km) gauge
Aushgram I	Beranda	45.25	Ketugram II	Gangatikuri	22.24
Aushgram I	Ukta	30.25	Ketugram II	Sitahati	23.1
Aushgram I	Guskara II	10.26	Ketugram II	Mougram	5.25
Aushgram I	Dignagar II	18.56	Ketugram I	Gopalpur	8.26
Aushgram I	Guskara Municipality	7.25	Ketugram I	Palita	11.15
Aushgram II	Bhedia	5.16	Ketugram I	Pandugram	21.25
Aushgram II	Amarpur	10.23	Ketugram I	Rajor	6.28
Aushgram II	Ramnagar	34.25	Ketugram I	Kandara	4.16
Bhatar	Mahata	8.12			

(Source-Calculated by researcher)

6.2.4.5 Comparison of average flood area with flood area in different return periods

Based on recorded flood data, the maximum number of blocks frequently affected is in the lower Ajay basin area. Considering the topographic conditions and flood intensity during different return periods is crucial for predicting flood-prone areas and significantly beneficial for flood management. The results of flood intensity across different return periods indicate that the average flood area is almost the same with a 5-year return period, while it reaches its maximum with a 25-year return period (Table 6.31). From the recorded flood data, Illambazar, Kanksa, and Nanoor blocks are less susceptible to flooding under normal conditions. However, during the 10-year and 25-year return periods, these blocks become highly susceptible to flooding (Figure 6.20).

Table 6.31 Comparison of average flood area with flood area in different return periods

Blocks	Average flood area	Estimated flood area in sq. km (5 years)	Estimated flood area in sq. km (10 years)	Estimated flood area in sq. km (25 years)
Illambazar	0	10.06	15.63	25.32
Kanksa	0	1.86	3.26	5.02
Aushgram II	22.65	25.04	32.56	53.52
Aushgram I	65.28	70.28	95.65	133.28
Mangalkote	34.52	35.16	39.03	44.034
Bolpur	48.72	55.54	67.68	80.86
Nanoor	0	10.38	25.42	60.25
Ketugram I	12.58	10.83	39.56	51.1
Ketugram II	107.65	110.82	124.08	146.2
Katwa I	9.07	9.46	10.47	19.03
Bhatar	10.25	11.53	12.58	18.25
Labhpur	0	3.12	6.75	11.25

(Source-Average flood area collected from the Report of Irrigation and Waterways, Govt. of West Bengal)

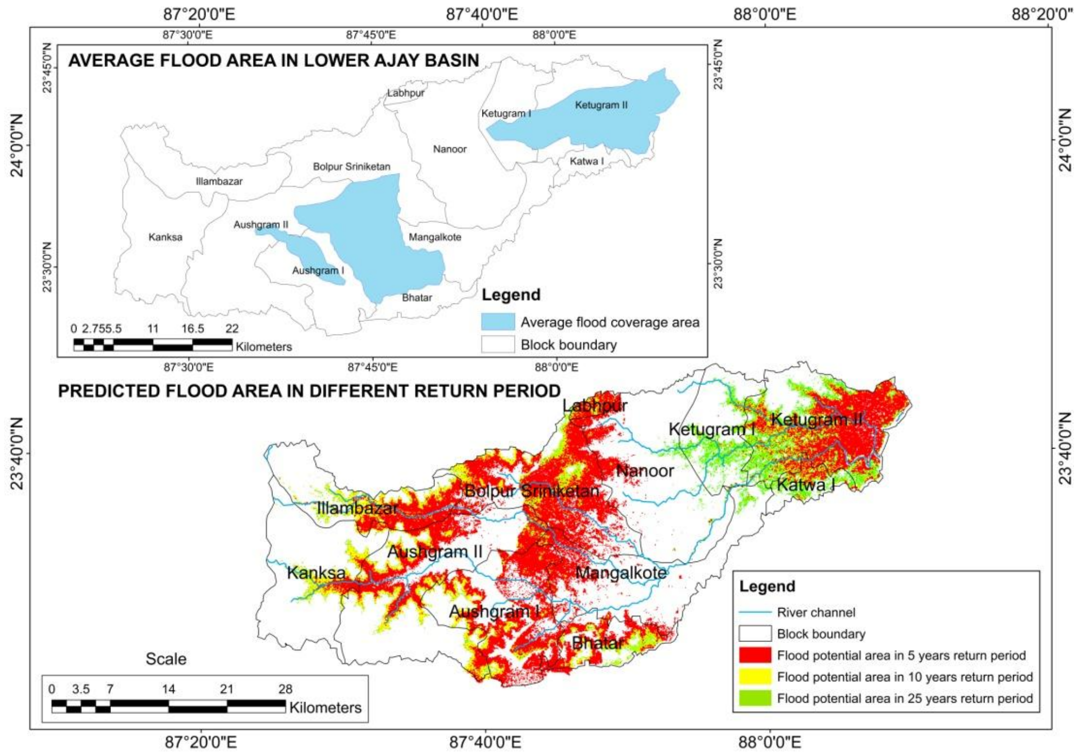


Figure 6.20 Comparison of average flood area with the predicted flood area at different return periods

(Source –Average flood area collected from the report of Irrigation and waterways, Govt. of West Bengal and flood prediction area prepared by researcher)

6.2.4.6 Validation of the result

Validation of a model is indeed crucial prior to its implementation. The overall accuracy result of 93.91% indicates the correctness of points relative to total points, as per Equation 4.5. However, relying solely on overall accuracy may not fully validate the model. For enhanced reliability, the Kappa (KHAT) statistic (as per Equation 4.6) is utilised, resulting in an 84.04% validation rate (refer to Table 6.32). Both these results collectively validate the model effectively, ensuring its acceptance and reliability for further use.

Table 6.32 Error matrix for validation the topography based flood prediction model

Type	Flood	Non flood	Row total (Xi+)
Flooded points	81	04	85
Non flooded points	05	25	30
Total ($X+_i$)	86	29	115

(Source-Calculated by researcher)

Over all accuracy= 108/115 = 93.91 %

KAPPA= (12420-8180)/(13225-8180)

= 84.04%

6.2.5 Flood area prediction by HEC-HMS and HEC-RAS platform

6.2.5.1 Use of HEC-HMS for simulation of flow

In an un-gauged river or inadequate gauge stations River like the Ajay River, utilising software such as HEC-HMS is crucial for determining hydrological parameters and obtaining accurate results. This software allows for the extraction of hydrological values at various points along the river. In the case of the Ajay River, the lower reach where important tributaries join has a significant impact on the river's hydrological characteristics (refer to Figure 6.21). Understanding the flow pattern at each junction in the river basin is vital for flood prediction and also indicates the potential water resources available.

Simulation-based results provide insights into water resource availability, especially on a sub-watershed basis, which aids in further planning and management. During the lean season, tributaries like Kunur, Hinglow, and Khnadar have low flow, but during the peak season following heavy rainfall, flow rates significantly increase. Utilising Curve Number and daily rainfall data from gauge stations like Sikatia, Illambazar, and Ketugram, simulations show a nearly fourfold increase in peak flow compared to non-flood years (refer to Figures 6.22 & 23).

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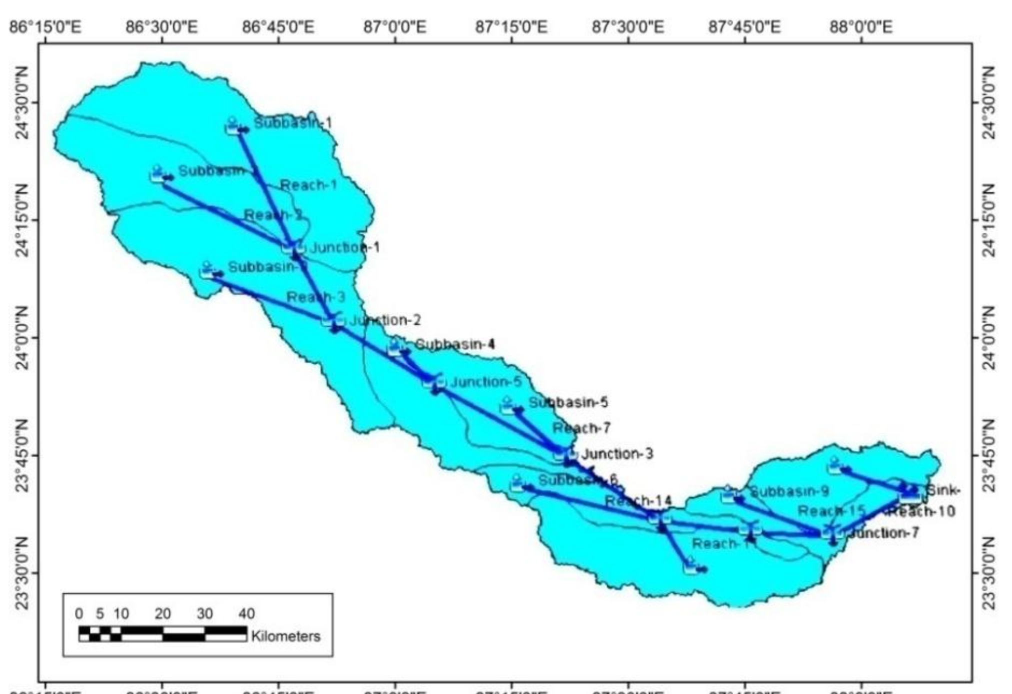


Figure 6.21 Sub-watershed in Ajay basin

(Source - Basin and channel prepared from SRTM DEM, 30 m data and sub-watershed divided in HEC-HMS platform)

However, due to seasonal flow patterns and the improper utilisation of tributary channels, the channel intake capacity is gradually decreasing. Consequently, during peak flow seasons, water flow is impeded, leading to flooded junction regions. It's worth noting that the water level in the main channel tends to be higher than that of tributary channels, causing it to act like distributaries.

Table 6.33 Watershed wise area and Curve Number

Watershed	Area sq. km	CN value
1	803.85	71
2	733.83	70
3	809.04	69
4	546.96	71
5	481.63	71
6	869.19	70
7	750	72
8	754.89	73
9	482.04	73

(Source - Curve Number calculated by researcher)

Table 6.34 Watershed wise hydrological soil properties

Watershed	Soil	Property	HSG (Hydrological Soil Group)
W_1	Loamy skeletal-typic Ustochrepts	Moderate texture, moderate drained	B
W_2	Loamy skeletal-typic Ustochrepts	Moderate texture, moderate drained	B
W_3	Loamy skeletal-typic Ustochrepts	Moderate texture, moderate drained	B
W_4	Loamy skeletal-typic Ustochrepts	Moderate texture, moderate drained	B
	Fine loamy-typic Ustochrepts	Fine texture	C
W_5	Loamy skeletal-typic Ustochrepts	Moderate texture, moderate drained	B
	Fine loamy-typic Ustochrepts	Fine texture	C
W_6	Fine vertic Ochraqualfs	Moderate drained,	B
	Fine vertic Halpaqualts & Fine loamy Palastalfs	Fine texture	C
	Fine loamy Ustifluvents	Clayey, impervious material near surface	D
W_7	Fine vertic Ochraqualfs	Moderate drained	B
	Fine loamy Ustifluvents	Clayey, impervious material near surface	D
	Fine vertic Halpaqualts	Fine texture	C
W_8	Fine vertic Ochraqualfs	Moderate drained	B
	Fine loamy Ustifluvents	Clayey, impervious material near surface	D
W_9	Fine vertic Ochraqualfs	Moderate drained	B

(Source - Based on micro regional soil data NBSS & LUP and classified according to Soil Conservation Services, 1969, Viji et al., 2015)

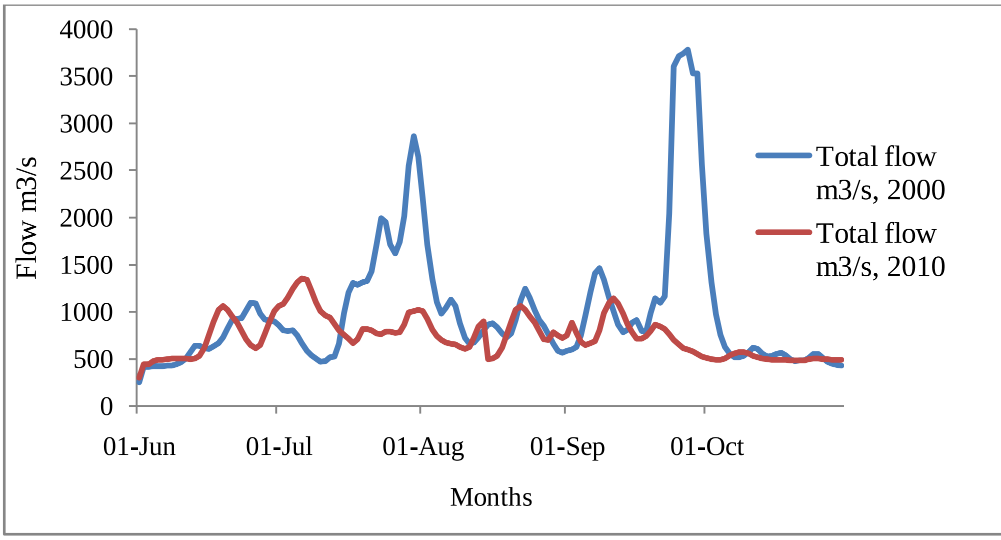


Figure 6.22 Comparison of Discharge in the confluence region (Katwa) in flood year (2000) and non flood year (2010) from the simulation result
(Source - Simulated result by the researcher)

The basin area of approximately 6235 sq. km is divided into 9 watersheds based on tributary junctions and main channel flow. Watershed 6 covers the maximum area, while watershed 9 covers the minimum area (refer to Table 6.33). However, the discharge characteristics show an intriguing pattern, with watershed 3 exhibiting the maximum simulated discharge. This variation in discharge can be attributed to differences in rainfall patterns and Curve Number values across the watersheds, highlighting the complex interplay of hydrological factors within the basin.

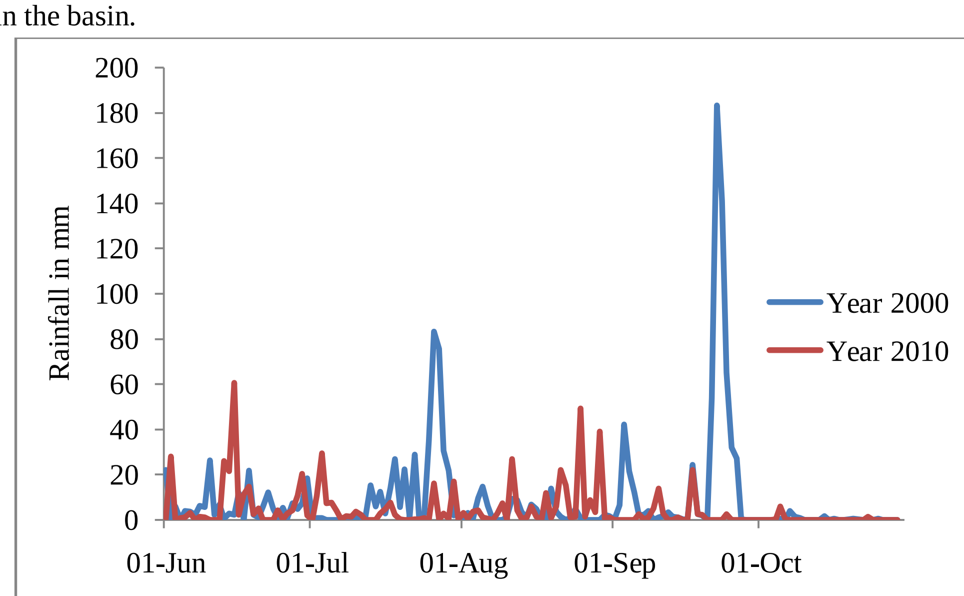


Figure 6.23 Comparison of rainfall pattern in flood year (2000) and non flood year (2010)

(Source - Grid rainfall data, IMD, Katwa, 2000, 2010)

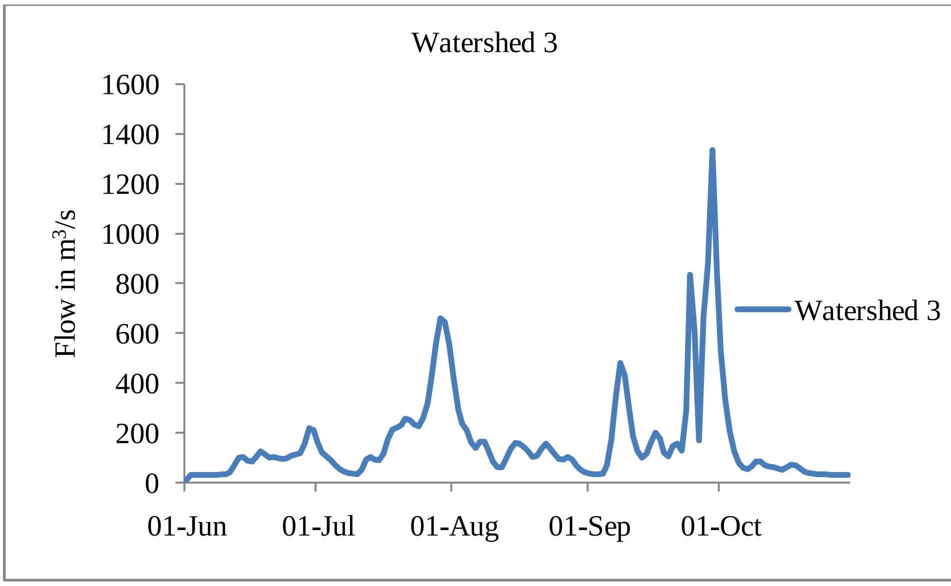


Figure 6.24 Simulated flow pattern of watershed-3 in the year, 2000

(Source - Prepared by researcher)

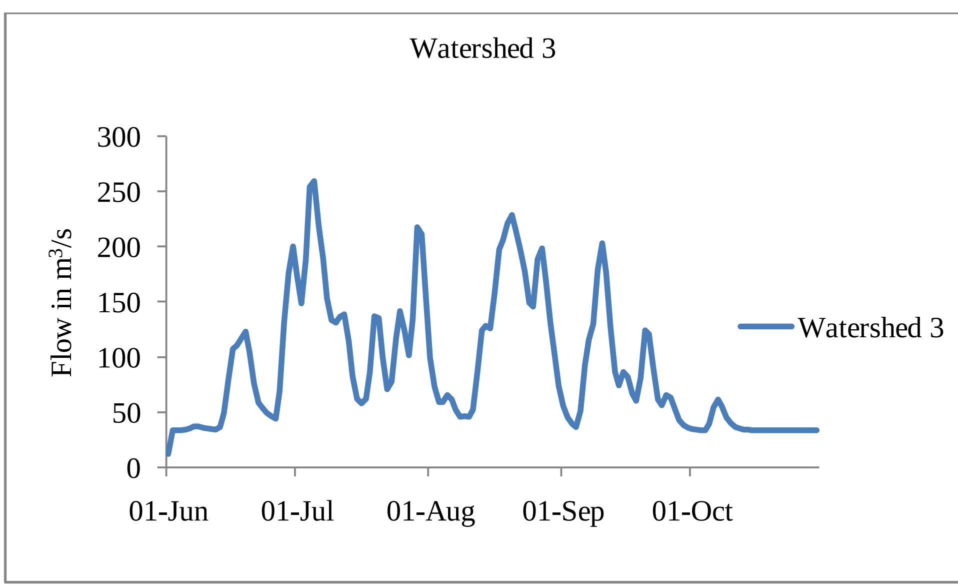


Figure 6.25 Simulated flow pattern of watershed-3 in the year, 2010

(Source - Prepared by researcher)

Moreover Bhagirathi-Hugli River water level comparatively high from the main channel of Ajay river so huge volume of water channalise through the Ajay River main channel. It makes the hazardous condition more complex.

The simulation results for the high flood year 2000 show that watershed 3 experienced the maximum flow of 1400 m^3/s almost (refer to Figures 6.24 & 25). The flow scenario across all watersheds is detailed in Table 6.35. The volume of water discharged is influenced by various factors such as watershed size and spatial rainfall distribution. Understanding the potential of each watershed and analysing the flow patterns, including seasonal variations, are critical for effective flood control measures.

In the case of the Ajay River basin, there are limited opportunities to directly measure the flow pattern in each sub-watershed. Therefore, empirical studies of flow patterns are significant, but validation through real-world data is essential for a comprehensive understanding of the hydrological scenario at various points within the basin.

Table 6.35 Watershed wise water flow scenario (m^3/s) (simulation year, 2000)

	Sub-watershed							
Date	W 1	W 2	W 3	W 5	W 6	W 7	W 8	W 9
01-Jun	12.7	12.7	12.7	12.7	50	50	50	50
02-Jun	34	34	34	34	70	70	70	70
03-Jun	34	34	34	34	70.1	70	70.1	70
04-Jun	34	34	34	34	70.3	70.2	71.7	71.7
05-Jun	34	34	34	34	70.7	70.4	74.6	72.4
06-Jun	34	34	34	34	71.3	70.9	74.6	71.2
07-Jun	34	34	34	34	72	71.6	73.3	71.3
08-Jun	34	34	34.1	35.1	73	72.4	72.8	71.5
09-Jun	34	34	34.5	36.9	74.3	73.5	75.3	77.2
10-Jun	34.3	34.1	35.8	37.8	76.1	74.9	82.3	85.4
11-Jun	39.4	37.3	44	41.8	81.5	78.8	89	88
12-Jun	53.1	45.7	70.7	53.2	90.3	84.9	90.3	82.9
13-Jun	64.3	52.1	102.8	63.9	100.5	93.4	85.2	76.3
14-Jun	64.9	51.8	104.8	61.1	104.5	99.2	79.6	73.5
15-Jun	60.2	48.9	90.7	55	103.6	101.3	75.9	72.1
16-Jun	61	49.9	88.3	54.6	99	99.8	74.6	74.1
17-Jun	60.2	49.5	108.2	61.7	95.1	97.6	77.7	79.7
18-Jun	65.9	53.3	127.2	68.5	94.9	95.3	83	79.5
19-Jun	99.9	76.2	115.8	63.3	99.5	97.9	85.9	87.1
20-Jun	157.2	113	101.6	53.3	106.2	102.1	92.3	94
21-Jun	211.1	145.5	104.5	46.9	113.5	108.3	95.6	88
22-Jun	222.3	149.4	99.3	46.9	113.8	111.3	95.2	85.7
23-Jun	218.6	146.1	96.1	60.6	111.8	111.7	97	89.6
24-Jun	252.6	170.5	101	75.3	112.3	111.5	100.9	88
25-Jun	296.2	198.2	110.8	74.6	112.8	112.7	99.9	90.2
26-Jun	295.1	193.5	115.3	65.3	111.9	111.6	100.2	95.7
27-Jun	241.3	156.8	121.3	55.4	108.4	109.5	98.3	90.5
28-Jun	185.1	122	159.5	51	104.5	107	96.8	89.5
29-Jun	134.5	91.4	219.4	54.1	101.6	104.3	102.7	97.2
30-Jun	95.8	68	212.1	54.1	102.7	103.3	120.2	138.4
01-Jul	75.8	57.5	164.1	51	108.1	106.2	139.9	153.5
02-Jul	79.7	61.7	121.9	58.7	116	111.5	135.8	114.7
03-Jul	94.5	72.1	107.1	74.8	122	117.1	115.3	93.6
04- Jul	128.4	94.4	91.4	66.8	118.4	117.8	100.6	87
05-Jul	136.3	97.7	72	51.1	109.6	113	92.1	78.5
06-Jul	119.1	84.5	55.9	44	99.1	105.4	84	74
07-Jul	95.4	70.1	46.2	39.4	89.3	96.9	77.5	72.1
08-Jul	80.4	61.3	40.6	36.5	83.1	88.8	74	70.8
09-Jul	68.2	53.8	37.4	35.2	78.8	83.5	72.1	70.3
10-Jul	56.3	46.6	35.5	34.8	75.8	79.6	71.1	70.1

	Sub-watershed							
Date	W 1	W 2	W 3	W 5	W 6	W 7	W 8	W 9
11-Jul	50.1	43.2	54.2	34.9	74.1	76.8	70.9	70.7
12-Jul	50.4	44	94.9	34.6	73.5	75.3	71.4	70.9
13-Jul	50.5	44	103.9	34.3	73.9	74.9	71.7	70.9
14-Jul	119.8	92.3	95.7	35.3	77.8	77	78.8	80
15-Jul	289.4	205.5	91.1	37.8	86.8	82.5	96.3	93.9
16-Jul	373.7	251.2	118.3	44.4	101	92.9	113.1	109.8
17-Jul	369.7	239.7	175.7	57.7	112.8	103.7	127.9	116.2
18-Jul	313.3	203.6	214.6	74.9	122.4	113.9	130.9	107.9
19-Jul	271.2	176.8	223.9	86.8	132.3	124.1	147.7	147
20-Jul	227	149.5	233.6	76.2	146.1	136	186.1	171.2
21-Jul	240.1	161.7	257.6	64.1	162.7	150.3	208.3	180.2
22-Jul	400.8	273.3	254.5	66.4	171	160.8	218.2	173.3
23-Jul	600.7	400.8	234.9	72.6	177.7	169.5	197.6	139.1
24-Jul	607.1	388.5	228.9	81.7	177.9	173.4	173	120.6
25-Jul	453.9	280.5	261.1	85.1	175.5	174.4	152	130
26-Jul	284.6	176.3	320.5	75.3	170.4	171.5	178.9	238.7
27-Jul	182.3	116.7	423.9	96.5	188.1	182.1	255.2	295.4
28-Jul	126.8	85.5	559.1	160.1	252.3	220.4	330.8	277.1
29-Jul	129.1	91.6	660.3	197.5	341.8	287.2	445.1	398.4
30-Jul	203.9	144.2	647.2	179.9	409.7	352.1	527.6	396.4
31-Jul	281.3	192.9	553.9	142.8	420.3	386.6	444.6	220.3
01-Aug	285.1	189.1	415	115.4	379.4	381.3	299	133.2
02-Aug	227.8	149	294	93.7	309.2	341.4	197.9	99.1
03-Aug	163	108.7	238.7	81.3	241.5	284.6	142.8	83.3
04-Aug	125.8	87.6	212.4	67.1	190.5	230.1	111.2	76.7
05-Aug	136.2	97.6	165.2	52.5	156.3	189.6	97.7	83.1
06-Aug	188	133	139.8	59	139.6	162.9	103.8	112.1
07-Aug	195.7	134.5	165.9	88.1	137.1	150.4	124.3	133.9
08-Aug	157.3	106.5	167.1	98.1	138.7	145.8	133.5	115.6
09-Aug	108.7	76.6	129.8	78.8	134.5	141.1	117.1	88.5
10-Aug	84.6	63	87.9	57.3	123.3	132.3	96	77.1
11-Aug	75.6	58.7	62.9	46.8	109.2	121	88.9	93.1
12-Aug	84.9	65.8	64	50.3	99.1	110.3	96	101.6
13-Aug	94.3	72	99.7	70.8	98.1	104	97.6	87.1
14-Aug	101.5	76	138.8	87.9	104.3	104.6	94.8	94.9
15-Aug	107.3	79.9	160.4	83.5	109.6	108.1	100.1	111.9
16-Aug	107.2	79.2	159.6	76.4	110.9	110.4	111.4	123.6
17-Aug	94.8	70.5	146.8	68.1	110	110.6	119.2	115.9
18-Aug	89.9	68.2	127.1	56.3	108.6	109.8	112	92.9
19-Aug	102.6	77.5	105.6	46.1	105.3	107.2	98.1	82.1
20-Aug	121.2	89.4	109	43.6	102.7	104.6	95.3	101.3
21-Aug	148	106.6	138.7	54.9	104.1	104	115.6	140.4
22-Aug	211.2	149	158.1	65	108.5	106.7	150.9	170.7
23-Aug	302.8	207.9	141	57.4	108.8	107.7	167.9	149.9

	Sub-watershed							
Date	W 1	W 2	W 3	W 5	W 6	W 7	W 8	W 9
24-Aug	314.7	209.2	117.4	46.8	104.6	105.7	144.3	102.5
25-Aug	283.3	185.1	97.3	43.6	98.5	101.9	113.5	86.3
26-Aug	240.1	159.1	95.1	45.1	93.2	97.7	96.5	80.3
27-Aug	214.3	142.9	104	45.2	91.1	93.7	86.5	74.3
28-Aug	173	116.5	94.4	44.3	88.5	90.7	79.2	71.7
29-Aug	132.7	91.1	72.2	44.4	84.8	87.5	74.8	70.6
30-Aug	104.3	74.8	54	43.6	80.8	84.1	72.8	71.3
31-Aug	101.9	75.2	44.6	40.1	77.6	81	72.6	72.9
01-Sep	117.9	86.8	39.5	37.4	76.9	78.8	72.8	72.5
02-Sep	124	89.9	36.8	36.8	77.8	78.3	75	79.6
03-Sep	128.9	92.7	35.8	36.6	79.9	79.6	82.4	87.9
04-Sep	145.8	104.8	38.8	39.2	92.8	87.9	104.2	131.8
05-Sep	153.3	108.4	71.6	68.6	123.6	107.5	145	179.8
06-Sep	144.6	101.5	174.2	116.2	165.4	139.3	172.2	192.9
07-Sep	140.5	99.6	346	125.7	191.6	167.2	173.3	163.6
08-Sep	141.8	101	481.3	104.9	194.1	180.7	145.5	110.1
09-Sep	149	105.4	432.6	79.8	177.4	178.1	118.7	97.1
10-Sep	138.4	97.8	295.4	71.2	152.3	164.4	110.4	119.9
11-Sep	117.4	83.5	187.8	74.6	131.3	144.7	116.7	149.1
12-Sep	93.3	68.8	127	63.1	115.1	127.4	130.5	137
13-Sep	90.7	68.6	101.4	57.9	104.4	114.5	129.1	112.3
14-Sep	101.8	76.8	118.6	76.1	97.9	105.7	123.6	108.8
15-Sep	105.2	78	165	121.3	94	99.9	116.5	102.9
16-Sep	93.9	70	202.8	162.5	91	95.4	105.2	90.7
17-Sep	75.2	58	178.2	131.6	87.4	91.5	92.9	79
18-Sep	93.7	72.3	124.1	82	89	91.2	105.1	129.8
19-Sep	179.3	130.9	107.7	78.5	98.9	95.6	144.1	153.2
20-Sep	240.4	167	149.2	101.8	114	106	146.6	115.6
21-Sep	227.5	152.3	158.2	90.3	119.1	113.1	127.7	104.9
22-Sep	190.6	128.4	129.8	63.6	127.6	122.1	191.3	210.6
23-Sep	226.6	156.6	288.6	130.6	190.3	163.3	508.7	376.8
24-Sep	342.9	234.7	835.3	323.2	347.9	266.4	847.5	406.8
25-Sep	401.2	266.3	613.3	438.5	565.2	428.2	581.5	417.5
26-Sep	369.8	238.7	171.1	426.2	721.1	585	863.8	360.1
27-Sep	294.9	190.2	667.8	374.8	757.1	673.3	588	232.8
28-Sep	257	168.8	881.3	301.7	687.5	676.4	397.4	160.4
29-Sep	246.2	164.2	1335.9	243	558.8	611.5	263.5	105.7
30-Sep	207.9	137.7	845.7	182.6	425.8	503.1	173.7	82.9
01-Oct	149.4	99.7	531.5	137.9	317.7	394.6	123.7	74.2
02-Oct	99.6	70.3	334	98.5	236.4	306.1	98.2	71.3
03-Oct	72.3	54.9	208.8	65	179.2	238.2	84.6	70.4
04-Oct	55.9	45.5	129	48.5	142.2	187.6	76.8	70.1
05-Oct	46.4	40.2	82.7	40.7	117.9	152.9	72.6	70
06-Oct	41.7	38	60.6	36.9	101.8	128.6	71.6	71.9

	Sub-watershed							
Date	W 1	W 2	W 3	W 5	W 6	W 7	W 8	W 9
07-Oct	40.5	37.7	55.7	36.5	91.4	111.4	72.3	72.7
08-Oct	41.9	38.9	67.1	38.8	85.6	100.2	72.1	71.2
09-Oct	42.2	39	88	40.3	83.5	93.3	71.7	71.4
10-Oct	49.7	44.2	85.9	38.9	83.7	89.8	82.2	99.1
11-Oct	67	56	72.3	42.5	83.1	87.8	102.3	109.6
12-Oct	72.9	58.7	66.4	49.4	81.2	85.8	101.6	86.6
13-Oct	65.8	53	63.6	46.1	78.5	83.1	89.2	77.1
14-Oct	57.8	48.2	58	39.7	75.7	80	82.9	81.1
15-Oct	57.3	48.4	54.9	46.2	74.1	77	86.3	84.8
16-Oct	60.2	50.4	64.1	60.5	73.6	75.1	88.4	79
17-Oct	61.3	51	74.3	58.3	74	74.5	86.6	80.3
18-Oct	56.1	47.2	70.7	47.5	74.1	74.3	86.3	80.9
19-Oct	48.1	42	57.9	40.9	73.9	74	82.6	74.5
20-Oct	41.6	38.2	46.9	37.3	73.2	73.6	81.8	84.7
21-Oct	38.3	36.3	40.8	35.5	72.6	73.2	89.1	95.1
22-Oct	42.7	39.6	37.6	34.7	72.5	72.8	92.3	90.6
23-Oct	68.2	57.2	35.9	34.3	72.5	72.6	88.3	82.4
24-Oct	101.6	78.7	35	34.2	72.4	72.5	81.4	74.9
25-Oct	107.4	80	34.5	34	72	72.2	76.2	72.1
26-Oct	88	65.8	34.3	34	71.6	71.9	73.4	71.3
27-Oct	64.7	51.3	34.1	34	71.5	71.7	72.2	70.7
28-Oct	51	43.4	34	34	71.5	71.6	71.4	70.3
29-Oct	43.4	39.1	34	34	71.4	71.5	70.7	70.1
30-Oct	39.2	36.7	34	34	71.1	71.3	70.4	70

(Source - Simulated result, 2000, calculated by researcher)

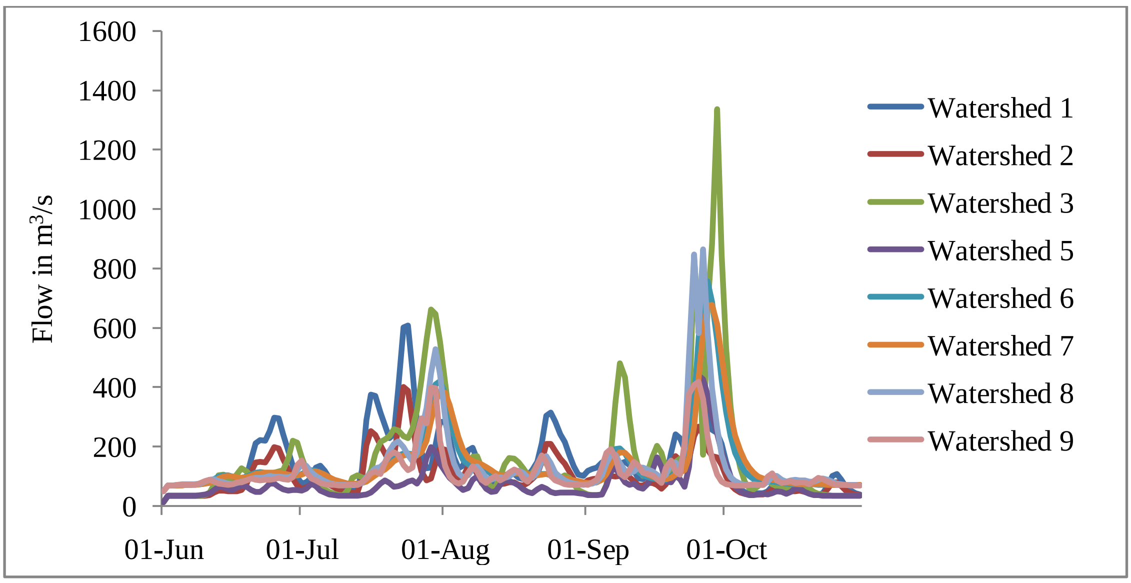


Figure 6.26 Watershed wise discharge pattern in 2000 from the simulation result

(Source - Prepared by researcher)

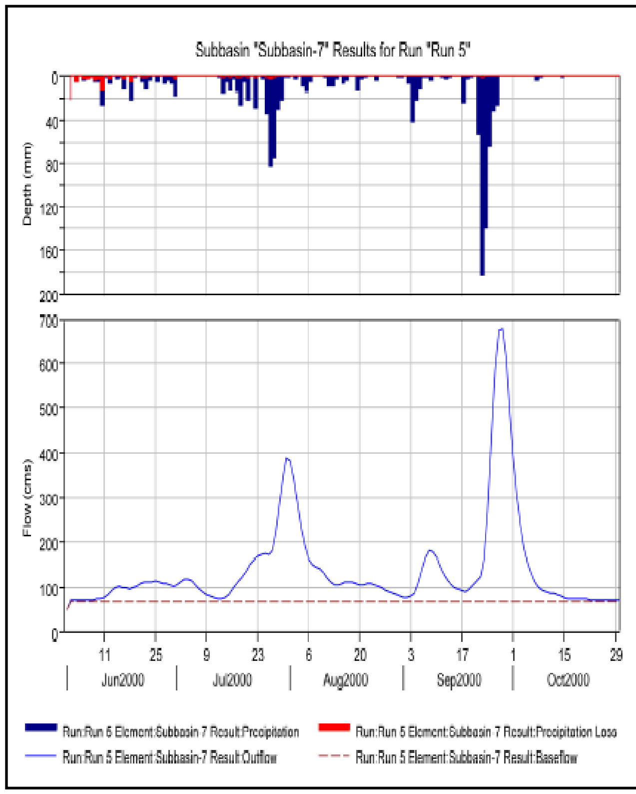


Figure 6.27 Water flow potentiality from the Kunur sub-basin (simulation year 2000)

(Source - Prepared by researcher)

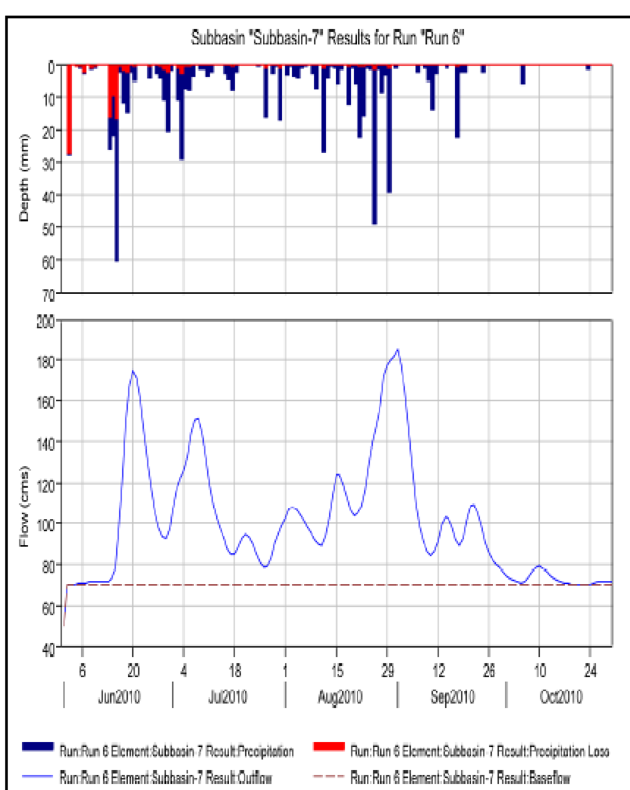


Figure 6.28 Water flow potentiality from the Kunur sub-basin (simulation year 2010)

(Source - Prepared by researcher)

The year 2000, saw a significant flood disaster, so simulations were conducted for both 2000 and a non-flood year, 2010. The peak discharge in Katwa in 2000 reached about 3800 m^3/s, whereas in 2010, it was much lower at 1000 m3/s. This difference is attributed to the maximum rainfall, which was 243 mm in 2000 compared to only 60.51 mm in 2010. Besides peak rainfall, factors such as rainfall duration and cumulative rainfall also play crucial roles.

In 2000, the total rainfall 788 mm over 4 days, leading to a continuous rise in water levels above the Extreme Danger Level (EDL). This prolonged and intense rainfall event contributed significantly to the high discharge and subsequent flood levels observed in Katwa during that year.

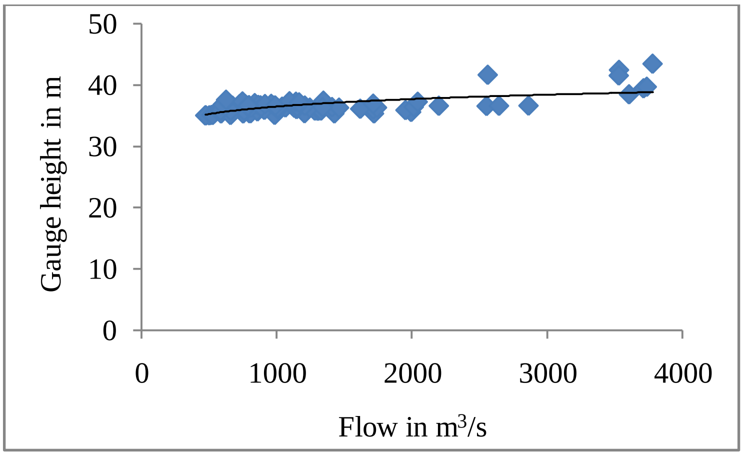


Figure 6.29 Rating curve in Budra gauge station in Ajay River

(Source - Based on simulated flow data, 2000 and recorded gauge height data in Budra gauge station)

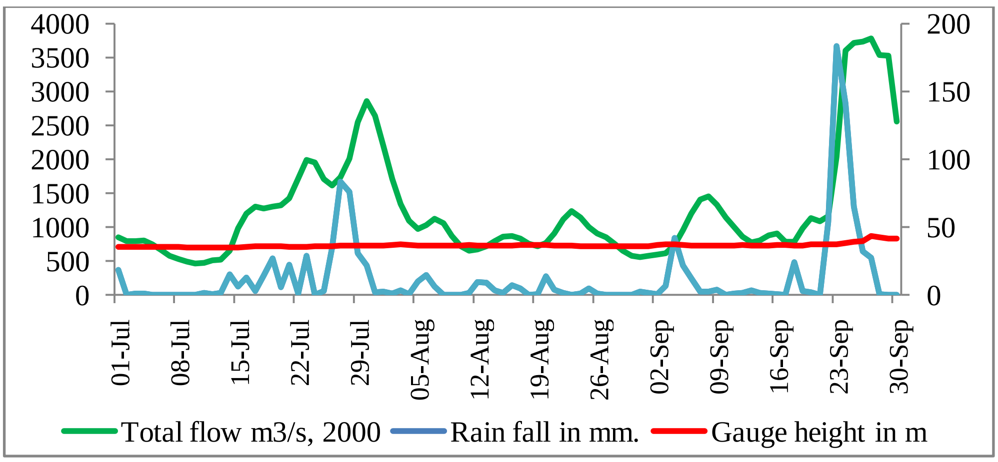


Figure 6.30 Relation between rainfall, flow and gauge height

(Source - Simulated flow data, 2000; Rainfall data, IMD grid data, Gauge height in Budra gauge station)

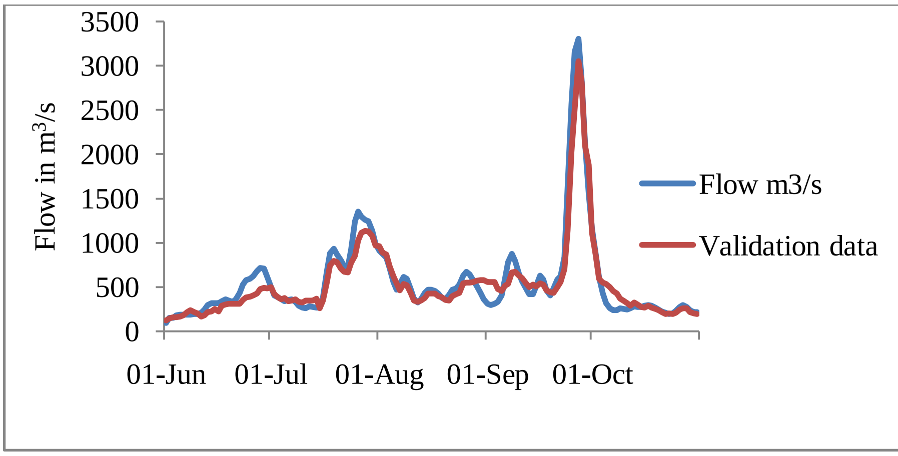


Figure 6.31 Validation of simulated discharge in Nutanhut gauge station in the year 2000

(Source -Validated with data measured by Irrigation and Waterways Department, Govt. Of West Bengal)

6.2.5.2 Use of HEC-RAS for the prediction of flood potential area

The flood plain simulation conducted using HEC-GEO RAS integrated discharge and topographic features of the basin area. Ketugram II emerged as the block with the highest flood coverage, while Billeswar Gram Panchayet experienced maximum inundation within the basin (Table 6.36) (Figure 6.33). Notably, Ketugram II, Ketugram I, Katwa I, and other areas were flood-prone due to their proximity to confluence regions, whereas Aushgram I, Aushgram II, Mangalkote blocks faced flood risks owing to their junction points with the Kunur tributary in the lower stretch of the main channel.

Comparison of flood years, such as 2000 and non-flood years like 2010, revealed significant differences in peak water flow in the Kunur sub-basin (Figures 6.27 & 28). This variation was attributed to interactions between water flows from the main channel and additional flow from tributary channels, leading to heightened water levels during flood events.

The rating curve drawn at the Budra gauge station depicted a consistent relationship between river flow and gauge height, indicating the reliability of simulated flow data compared to secondary gauge height data. Graphical representations further highlighted a direct correlation between rainfall, flow data, and gauge height, particularly emphasising the increase in river flow with rising rainfall (Figure 6.29).

Moreover, validation of the simulated discharge data with actual records from the Department of Irrigation and Waterways, West Bengal, affirmed the accuracy of the simulation results (Figure 6.30). This validation provided a robust foundation for flood plain mapping and informed flood management strategies. In the study of Ajay River shows that the maximum discharge in the Ajay River was above 3000 m³/s at Nutanhut gauge station in 2000 (Bandyopadhyay et al, 2016), according to data from the Irrigation and Waterways Department, Government of West Bengal. The simulation results indicate a peak discharge of approximately 3300 m³/s for the same year. The close agreement between these values validates the accuracy of the simulation results.

In the year of 2000, the water level in Bhagirathi-Hugli River in Katwa was 15.59 m where as in 2010 is only 13.25 m (Irrigation and Water Ways, Government of West Bengal, 2000-

2015). From the hydrological study and estimated discharge during the peak season indicating the high potentiality of the flood. Huge difference of the gauge height in flood year and non-flood year indicates the high flood potentiality.

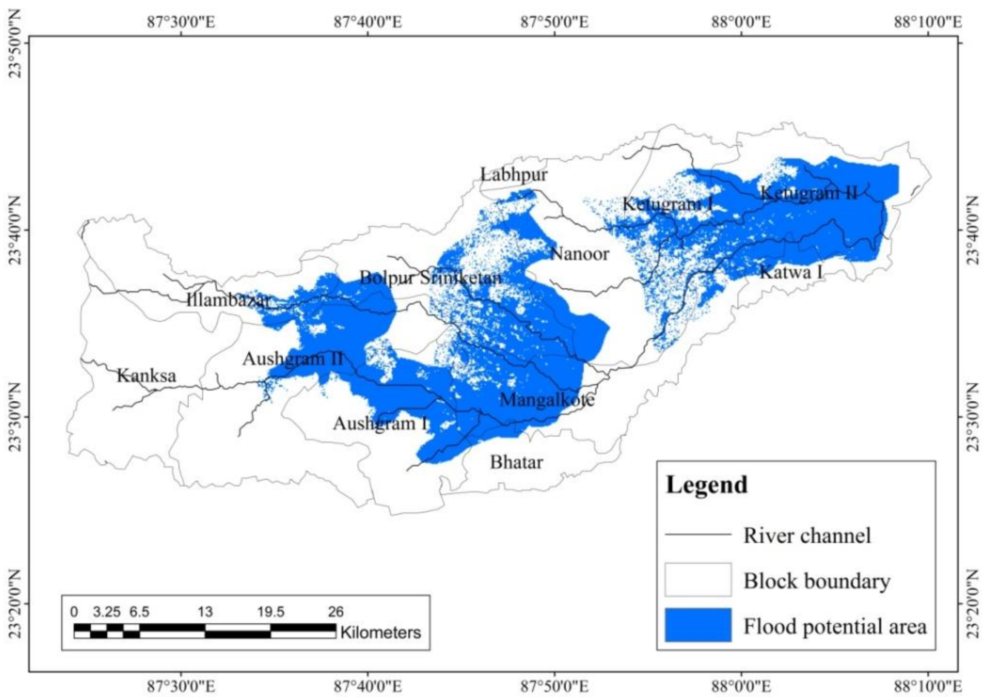


Figure 6.32 Block wise simulated flood potential area estimation

(Source - Prepared by researcher)

The estimation of spatial flood variation, with reference to channel discharge, is crucial for flood control measures. The flood area is simulated and measured block-wise and Gram Panchayat (GP) wise (Figures 6.32 & 34). This approach allows for micro-level hazard estimation, accounting for flood area at both block and GP levels (Tables 6.36 & 6.37). Additionally, flood depth parameters are simulated using these tools. The average flood depth per Gram Panchayat is calculated using the grid method (Figures 6.35 & 6.36). These GP-wise flood area and depth data are further utilised for vulnerability and risk assessments.

The maximum flood depth of 2 meters is recorded in Gangatikuri, Mougram GP within the Ketugram II block (Table 6.38). Notably, the topographic pattern in the lower Ajay River basin significantly influences flood depth patterns. Illambazar region experiences minimal flooding due to its higher elevation, whereas the Ketugram and Aushgram regions exhibit maximum flood depths owing to their lower elevations (Figure 6.33). This observation underscores the strong correlation between flood depth and topographic characteristics.

To validate the simulated results, several points were randomly selected, and their depths were estimated by field experience. The estimated depths closely matched the simulated results, demonstrating the accuracy and reliability of the simulation (Appendices F & G for detailed comparisons).

Table 6.36 Block wise flood potential area estimation in HEC-RAS platform

Blocks	Area in sq. km.
Illambazar	20.26
Ausgram II	54.4
Ausgram I	121.31
Mangalkote	54.34
Bolpur	101.48
Nanoor	75.46
Ketugram I	55.7
Ketugram II	154.13
Katwa I	16.08
Bhatar	16.23

(Source-Calculated by researcher)

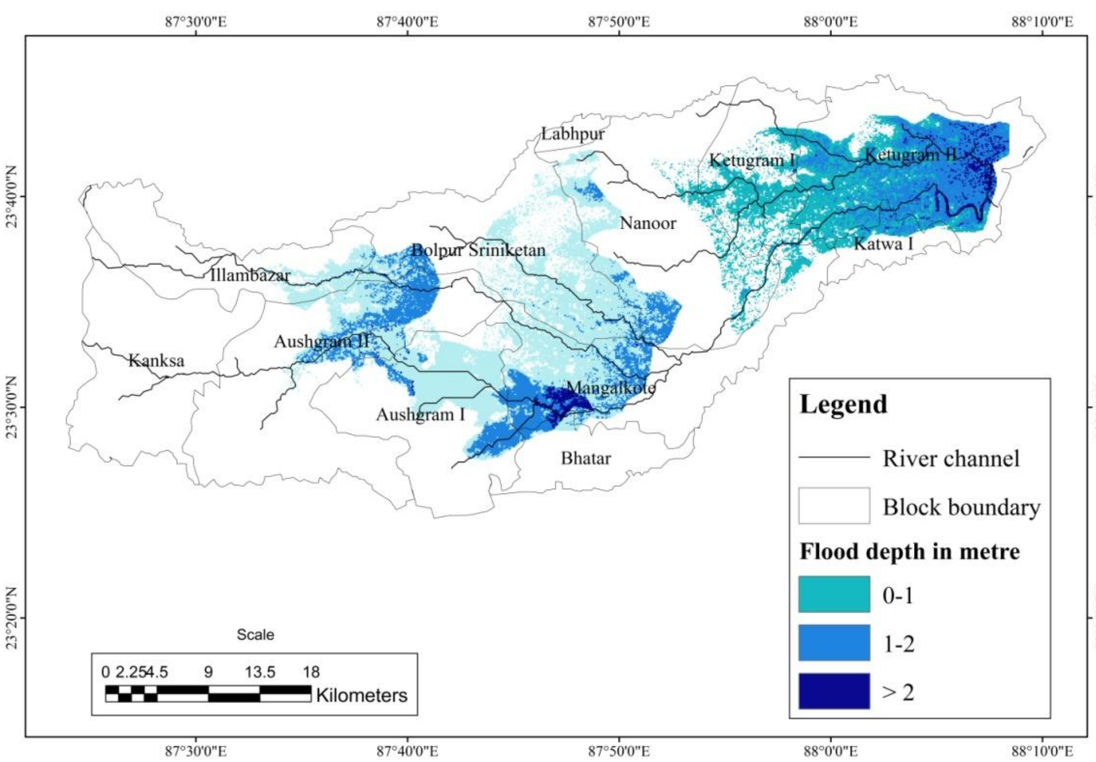


Figure 6.33 Simulation of flood depth in blocks area

(Source-Prepared by researcher)

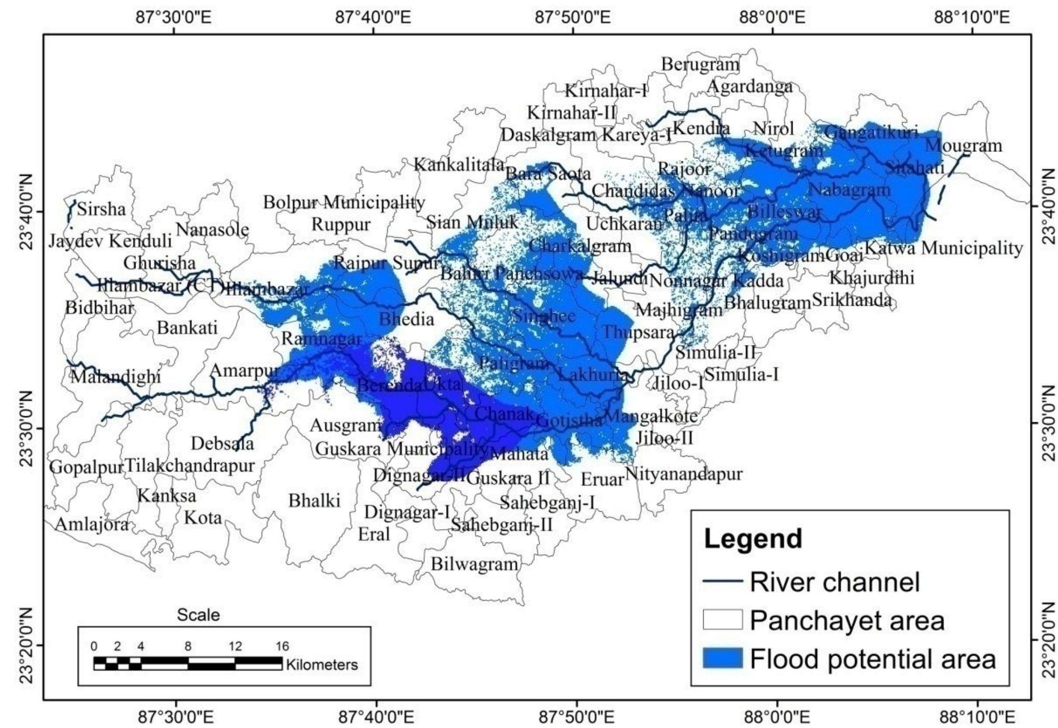


Figure 6.34 Gram Panchayet wise simulated flood potential area estimation in HEC-RAS platform

(Source-Prepared by researcher)

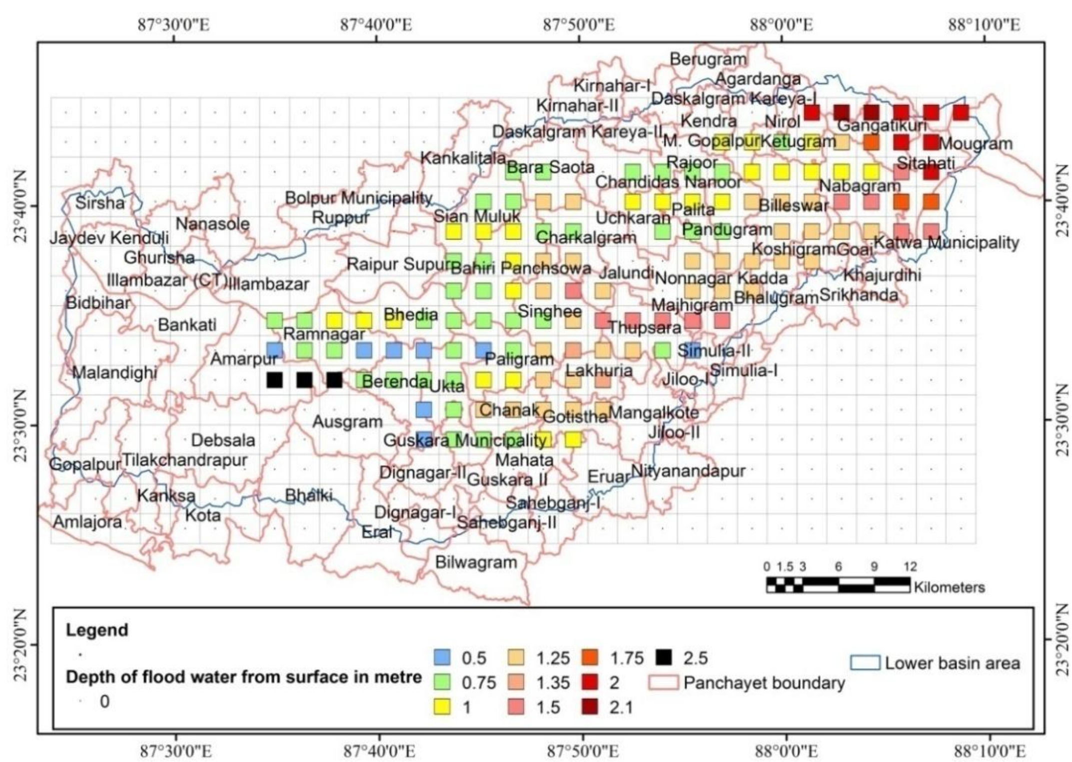


Figure 6.35 Gram Panchayet wise simulated flood depth estimation in HEC-RAS platform

(According to grid method)

(Source-Prepared by researcher)

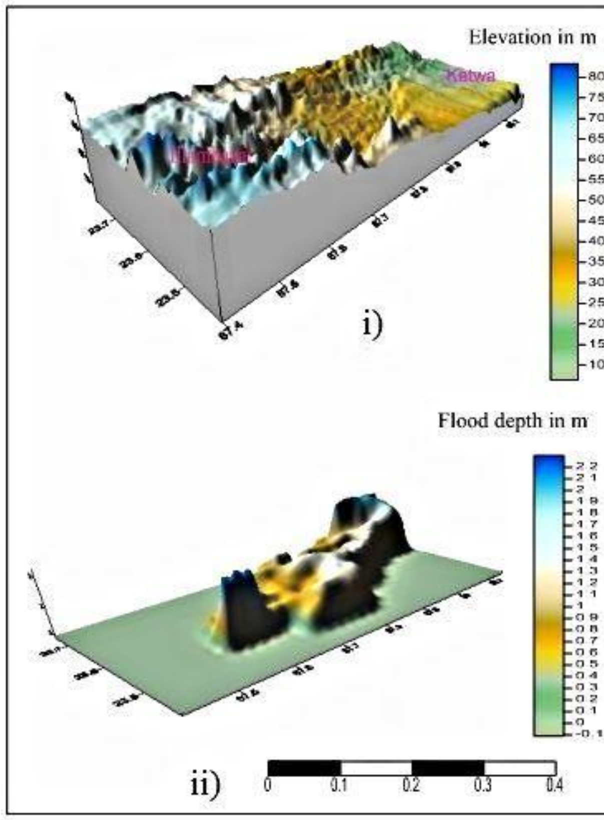


Figure 6.36 3D model for the relation of flood depth with the topography pattern: i) Topography in the lower Ajay basin ii) Flood depth

(Source-Topographic character extracted from SRTM DEM, 30 m, and flood depth result extracted by researcher)

Table 6.37 Gram Panchayet wise flood potential area estimatation

Block	GP	Area in sq. km	Block	GP	Area in sq. km
Bolpur	Sian muluk	23.59	Mangalkote	Paligram	8.36
Bolpur	Singhee	40.82	Mangalkote	Chanak	4.75
Bolpur	Bahariparswa	37.57	Mangalkote	Lakhuria	9.9
Nanoor	Charkalgram	10.36	Mangalkote	Gothista	1.43
Nanoor	Jalundi	3.45	Ketugram II	Billeswar	18.89
Nanoor	Thupsara	9.95	Ketugram II	Ketugram	10.23
Nanoor	Uchhkaran	11.21	Ketugram II	Nabagram	14.48
Nanoor	Bara saota	11.54	Ketugram II	Nirol	10.74
Nanoor	NonagarKadda	21.32	Ketugram II	Gangatikuri	40.23
Nanoor	Chandidas Nanoor	7.63	Ketugram II	Sitahati	12.04
Illambazar	Illambazar	20.26	Ketugram II	Mougram	42.09
Aushgram I	Aushgram	20.64	ketugram I	Gopalpur	5.13
Aushgram I	Beranda	40.75	Ketugram I	Palita	20.55

Block	GP	Area in sq. km	Block	GP	Area in sq. km
Aushgram I	Ukta	34.8	Ketugram I	Pandugram	22.9
Aushgram I	Guskara II	3.62	Ketugram I	Rajor	3.26
Aushgram I	Dignagar II	10.33	Ketugram I	Kandara	7.46
Aushgram I	Guskara Municipality	5.52	Bhatar	Eruar	10.86
Aushgram II	Bhedia	11.12	Katwa I	Goai	20.91
Aushgram II	Amarpur	8.78	Katwa I	Khasigram	13.03
Aushgram II	Ramnagar	34.5	Katwa I	Municipality	3.44
Bhatar	Mahata	7.87			

(Source-calculated by researcher)

Table 6.38 Gram Panchayet wise flood depth estimation

Block	GP	Depth of the flood (m)	Block	GP	Depth of the flood (m)
Bolpur	Sian muluk	0.96	Mangalkote	Paligram	1
Bolpur	Singhee	1.05	Mangalkote	Chanak	1.25
Bolpur	Bahariparswa	0.95	Mangalkote	Lakhuria	1.14
Nanoor	Charkalgram	0.91	Mangalkote	Gothista	1.25
Nanoor	Jalundi	1.5	Ketugram II	Billeswar	1.125
Nanoor	Thupsara	1.5	Ketugram II	Ketugram	1
Nanoor	Uchhkaran	0.875	Ketugram II	Nabagram	0.875
Nanoor	Bara saota	1	Ketugram II	Nirol	0.875
Nanoor	Nonagar Kadda	0.875	Ketugram II	Gangatikuri	2
Nanoor	Chandidas Nanoor	0.875	Ketugram II	Sitahati	1.75
Illambazar	Illambazar	0.875	Ketugram II	Mougram	2
Aushgram I	Aushgram	1.5	ketugram I	Gopalpur	1
Aushgram I	Beranda	1	Ketugram I	Palita	0.875
Aushgram I	Ukta	0.95	Ketugram I	Pandugram	1
Aushgram I	Guskara II	0.5	Ketugram I	Rajor	0.875
Aushgram I	Dignagar II	0.625	Ketugram I	Kandara	1
Aushgram I	Guskara Municipality	1	Bhatar	Eruar	1
Aushgram II	Bhedia	0.625	Katwa I	Goai	1.25
Aushgram II	Amarpur	1.83	Katwa I	Khasigram	1.25
Aushgram II	Ramnagar	1	Katwa I	Municipality	1
Bhatar	Mahata	0.875			

(Source-calculated by researcher)

Table 6.39 Error matrix for validation of the flood prediction model in HEC-RAS platform

Type	Flood	Non flood	Total (Xi+)
Flood	79	06	85
Non flood	02	28	30
Total (X_{+i})	81	34	115

(Source-calculated by researcher)

Over all accuracy= 107/115= 93.043%

Kappa =(12305-7905)/(13225-7905)

82.70%

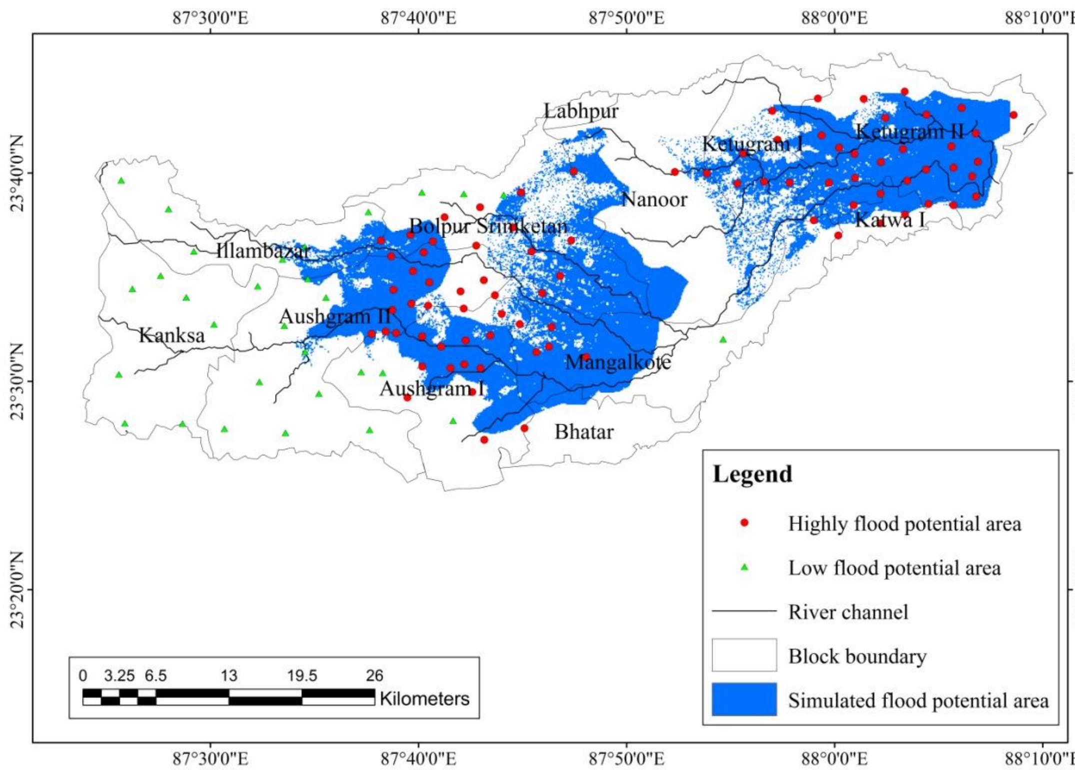


Figure 6.37 Calibration of the spatial flood area by using the HEC-RAS model

6.2.5.3 Validation of the result

Validation of the model is a crucial step in ensuring its reliability and acceptance. The overall accuracy assessment, with a result of 93.04%, indicates a high level of model acceptance (Eq. 4.5) (Appendix F). However, while overall accuracy evaluates correct points in relation to total points, it may not provide a comprehensive assessment. To enhance reliability, KAPPA or KHAT statistics are employed (Eq. 4.6) (Lillesand et al., 2004), yielding a result of 82.70% (Table 6.39), further confirming the model's acceptance. Both results, exceeding 75%, substantiate the model's validity (Congalton, 2001).

The prediction of floods is a critical aspect based on simulated discharge and topographic factors. However, in the lower Ajay basin, the influx of water from the Bhagirathi-Hugli River into the main Ajay River channel can significantly change the scenario. The volume of backflow water is variable and challenging to measure accurately due to changing peripheral conditions. Consequently, flood intensity and spatial variations vary annually. Combining the study of flow patterns with gauge height characteristics in the lower reach area may yield more accurate predictions. Including micro-level topographic variations and flow pattern prediction of the flood potential area significantly contribute in this area. The results of both simulations are used to perform final vulnerability predictions.

Chapter - 7

Flood Vulnerability, Resilience and Risk Analysis in the Lower Ajay Basin Area

7.1 General over view

The comprehensive vulnerability analysis considers physical, social, and economic factors to provide a holistic view of the flood and post-flood scenarios (Balica, 2012). This analysis not only identifies vulnerabilities but also aids in enhancing resilience and reducing vulnerability risks. In this study, vulnerability is assessed based on potential flood area, flood depth and affected population, along with deep considerations of social and economic impacts. The analysis also includes resilience factors, and by comparing vulnerability scales with resilience levels, conclusions are drawn regarding the Gram Panchayet's risk status. Instances where low resilience leads to high risk and vice versa are observed.

Graphical representations depict the population growth trends in 10 blocks, showcasing linear and steady growth patterns for each block (Figure 7.1). An exception is seen in Bolpur block, where the trend exhibits fluctuations (Figure 7.2). The high population growth in Bolpur from 1991 to 2001 can be attributed to rapid urbanisation. However, all blocks show steady growth during this period, suggesting a continuation of this trend in the next decade. Although the 2011 census data is used due to the unavailability of the 2021 report, past trends indicate that the population growth pattern will remain steady. While the intensity of vulnerability may vary, the overall vulnerability and risk scenario is expected to remain consistent.

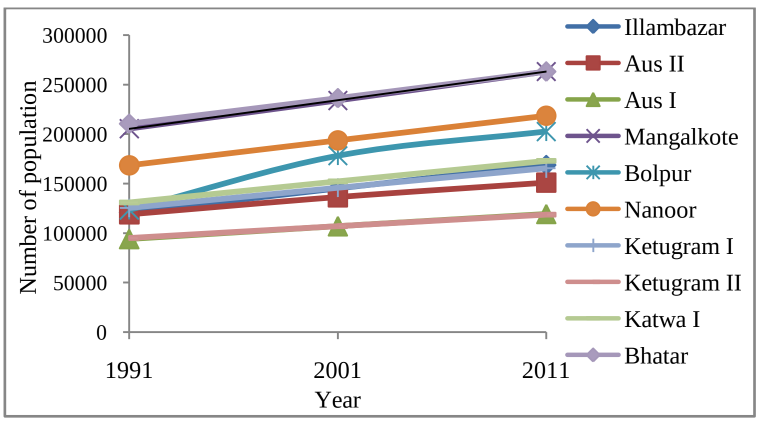


Figure 7.1 Population growth trend in different blocks of the lower Ajay basin
(Source - Census of India, 1991-2011)

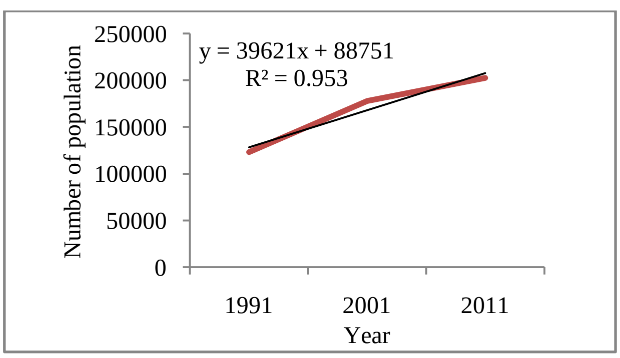


Figure 7.2 Population growth trend in Bolpur block from 1991-2011
(Source - Census of India, 1991-2011)

7.2 Physical vulnerability

When evaluating vulnerability concerning flood-related physical components, it falls under the category of physical vulnerability (Karmaoui, 2016). This assessment includes factors such as flood potential area, flood depth, and population density. Gram Panchayets (GPs) with extensive flood coverage are deemed highly physically vulnerable, as seen in Gangatikuri, Sitahati, Ukta, Khasigram, Ramnagar, etc. (Figures 7.3 and 7.4) (Table 7.1). However, some GPs like Billeswar, Ukta, etc., show high physical vulnerability but overall vulnerability is moderate to low. This is because despite being flood-prone, these GPs have developed socio-economic statuses, reflecting in their vulnerability assessment. Areas highly affected by floods are typically highly physically vulnerable.

GPs with low vulnerability in economic and social components indicate high resilience and a capacity for quick recovery. Notably, GPs like Gangatikuri and Sitahati exhibit flood depths of about 2 m, contributing to their high physical vulnerability. Many GPs experience flood depths exceeding 1 m, directly impacting agricultural fields, especially paddy crops. Mud houses prevalent in these areas pose a high risk of collapse. Although Jhalundi and Thupsara GPs have low flood potential coverage, their high flood depth and population density result in physical vulnerability above 0.7.

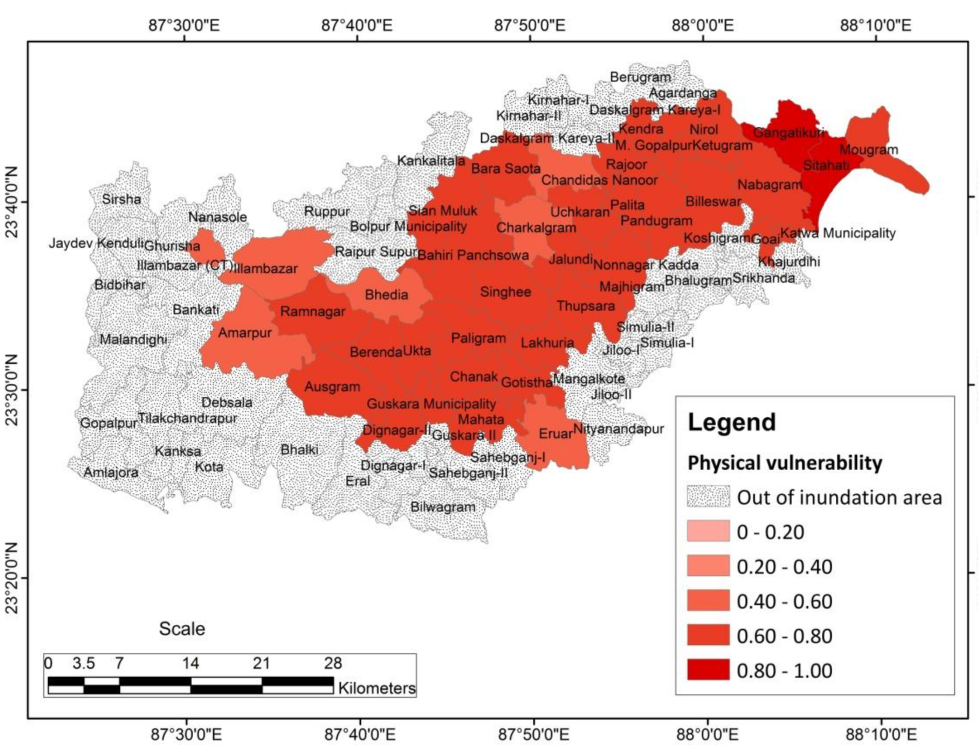


Figure 7.3 Physical vulnerability in the lower Ajay basin area (GP wise calculation in 0-1 scale)

(Source - Prepared by researcher)

High values of physical vulnerability signify a higher potential for vulnerability. The equal distribution class result of physical vulnerability shows that most GPs fall in the range of 0.6 to 0.8 (Figures 7.3 & 7.4). However, there are exceptions, such as Amarpur, Bhedia, Illambazar, Chandidas Nanoor, where physical vulnerability is less than 0.6, and in GPs like Gangatikuri, Sitahati, Khasigram, where it exceeds 0.8.

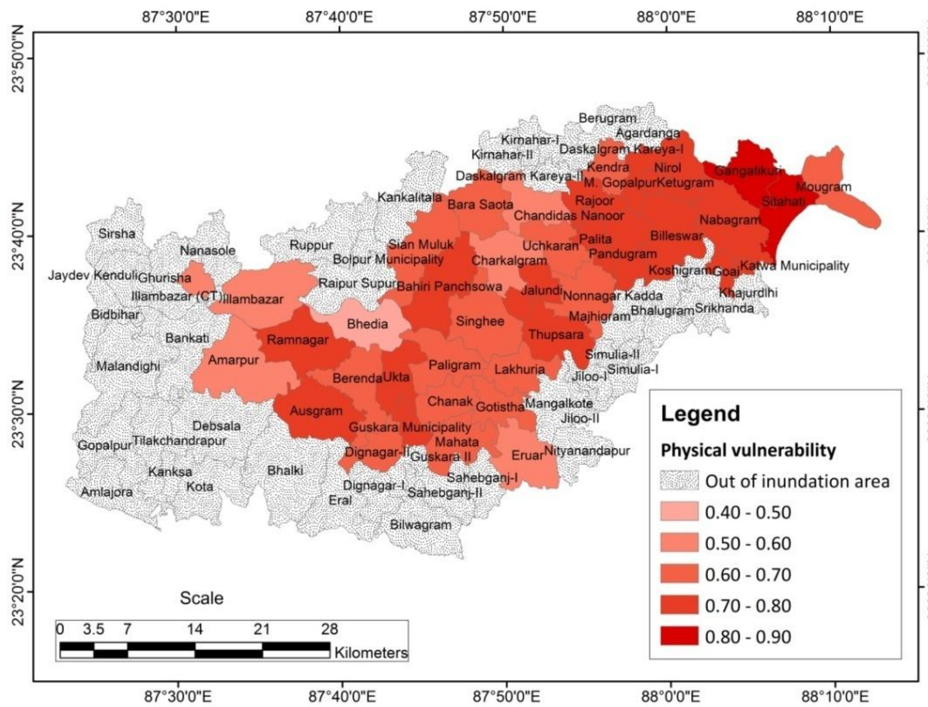


Figure 7.4 Physical vulnerability in the lower Ajay basin area (GP wise calculation according to maximum-minimum value)

(Source - Prepared by researcher)

7.3 Socio-economic vulnerability

Socio-economic vulnerabilities are gauged based on their impact on demographic structure, access to essential services like drinking water, education levels, land use land cover, occupational structure, non-working population ratio, and building types.

Demographic structure plays a crucial role, with children and females being the most vulnerable groups. The accessibility of drinking water becomes challenging during floods, especially in GPs like Sian Muluk, Bahari Parswa, Illambazar, Mahata, Eruar, etc., where 40% of households fetch drinking water from distances as far as 200 m from their homes. Education status significantly affects socio-economic vulnerability, with many GPs reporting moderate to poor educational conditions. A concerning trend is evident in areas like Sian Muluk, Singhee, Charkalgram, Uchkaran, where 40% or more of the population is illiterate, directly contributing to increased socio-economic vulnerability during floods due to lack of awareness and knowledge.

The study area predominantly comprises agricultural land, leading to substantial economic losses during floods. A large portion of the population works as agricultural labourers and cultivators, resulting in loss of livelihood and income during flood events. Building types also influence economic vulnerability, with mud houses being prone to collapse, causing significant economic setbacks. Given the high percentage of agricultural land and labourers, the socio-economic vulnerability index is notably high. Mud houses remain prevalent in many GPs, constituting over 80% of total house buildings in some areas. In most GPs, socio-economic vulnerability exceeds 0.6, indicating moderate to high vulnerability levels. GPs such as Eruar, Mahata, Rajor, Thupsara, Ukta, Charkalgram demonstrate particularly high socio- economic vulnerability (Figures 7.5 & 7.6).

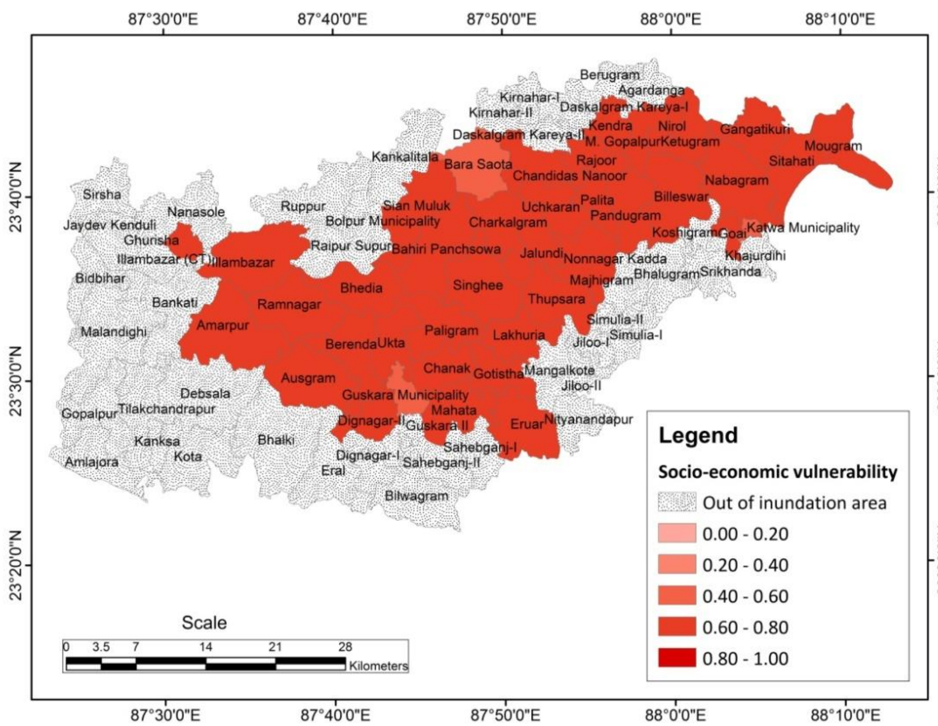


Figure 7.5 Socio-economic vulnerability in the lower Ajay basin area (GP wise calculation in 0-1 scale)

(Source - Prepared by researcher)

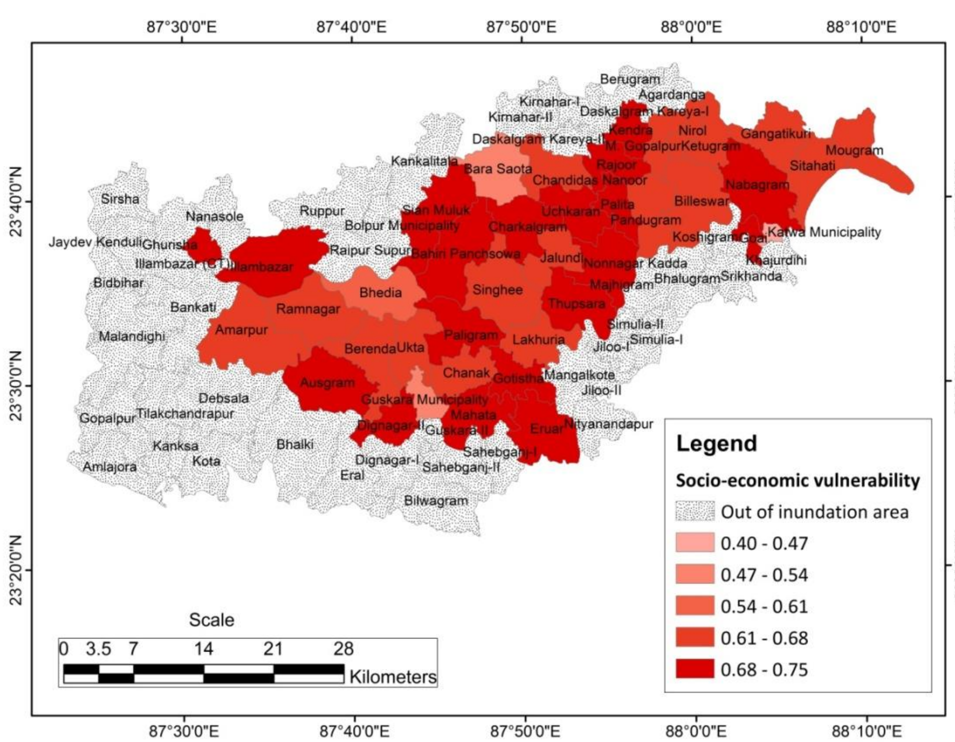


Figure 7.6 Socio-economic vulnerability in the lower Ajay basin area (GP wise calculation according to maximum-minimum value)

(Source - Prepared by researcher)

7.4 Vulnerability

Vulnerability is influenced by both physical and socio-economic factors. While hydrological characteristics provide insights, it may not fully estimate actual damages. Socio-economic impacts are deeply rooted and challenging to quantify accurately. Therefore, an overall vulnerability analysis based on social and economic damage estimation reveals the true vulnerability status.

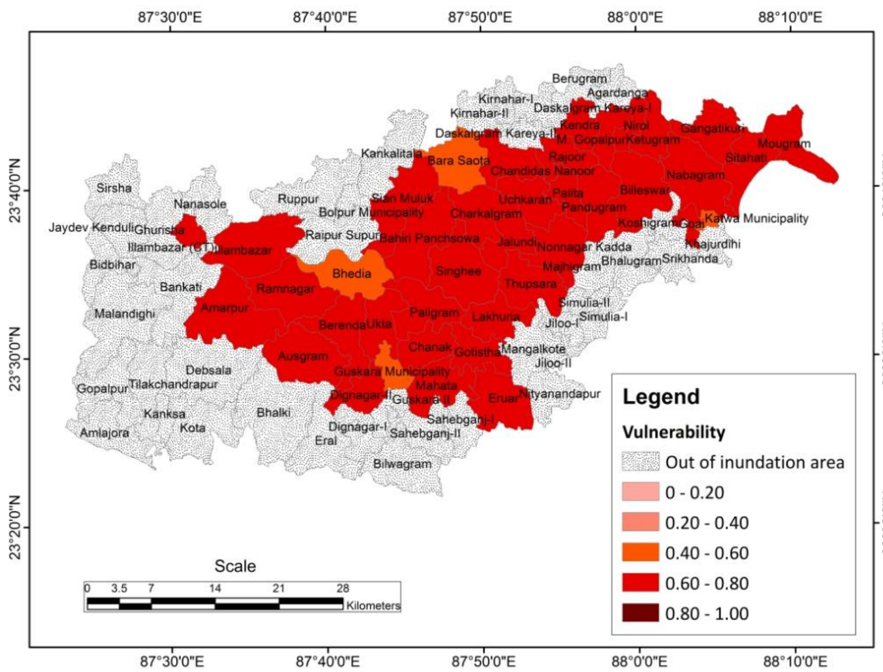


Figure 7.7 Vulnerability in the lower Ajay basin area (GP wise calculation in 0-1 scale)

(Source - Prepared by researcher)

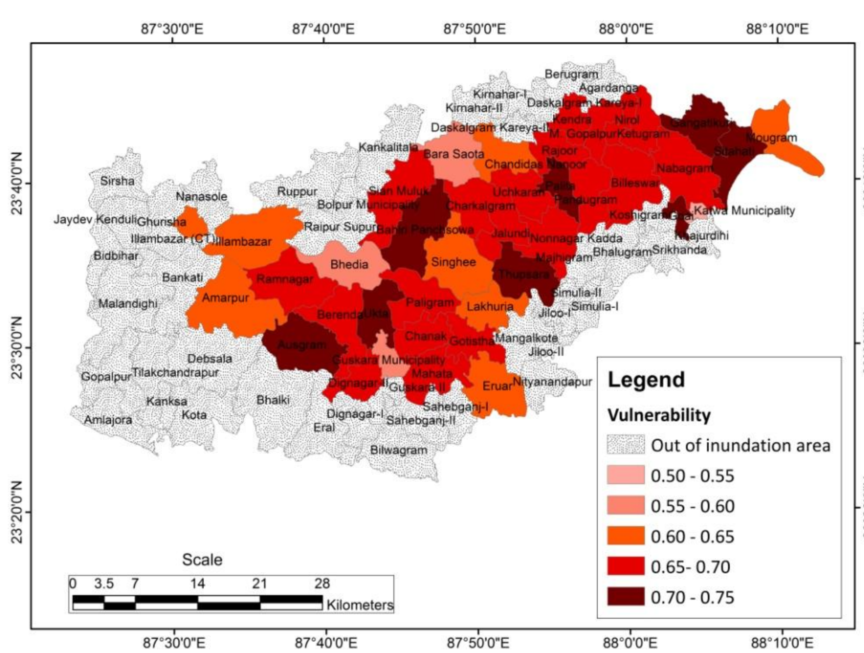


Figure 7.8 vulnerability in the lower Ajay basin area (GP wise calculation according to maximum - minimum value)

(Source - Prepared by researcher)

The vulnerability assessment shows that most GPs range from moderate to high vulnerability values (0.6-0.8). GPs with high vulnerability values (above 0.7) include Bahari Parswa, Thupsara, Ukta, Goai, Khasigram, Palita, Rajoor, among others (Figures 7.7 & 7.8) (Table 7.1).

7.5 Resilience

To mitigate flood effects, various measures are undertaken. Structural interventions like embankments are constructed, with their length and height progressively increased for better flood protection. However, structural measures can fail during severe floods, leading to extensive inundation. Enhancing resilience in the study area can help minimise flood impacts. Three resilience factors—flood shelters, road density, and health centre facilities—are considered to measure current resilience capacity.

Areas with high resilience factors, such as Jalundi, Illambazar, Guskara II, Ketugram, Nabagram, Mougram, Palita, and Kandara, exhibit reduced risk and damage (Table 7.1) (Figures 7.9 & 7.10). Conversely, GPs with low resilience like Charkalgram, Uchkaran, Aushgram, Beranda, Ukta, Amarpur, Chanak, Lakhuria, and Gothista face higher risk. The absence or insufficient number of flood shelters, especially in GPs like Aushgram, Berenda, and Paligram, contributes to lower resilience. In areas without flood shelters but with over 10,000 people at flood risk, resilience is significantly compromised.

Post-flood health hazards are a concern due to inadequate health centres and high population density, further lowering resilience and increasing risk. Overcrowding of affected people post-flood, coupled with limited health services, prolongs health hazards. Poor road connectivity also reduces resilience in areas like Aushgram, Beranda, and Ukta, leaving many disconnected from safe shelters and relief facilities. Improving road conditions is essential to minimise risk and enhance resilience.

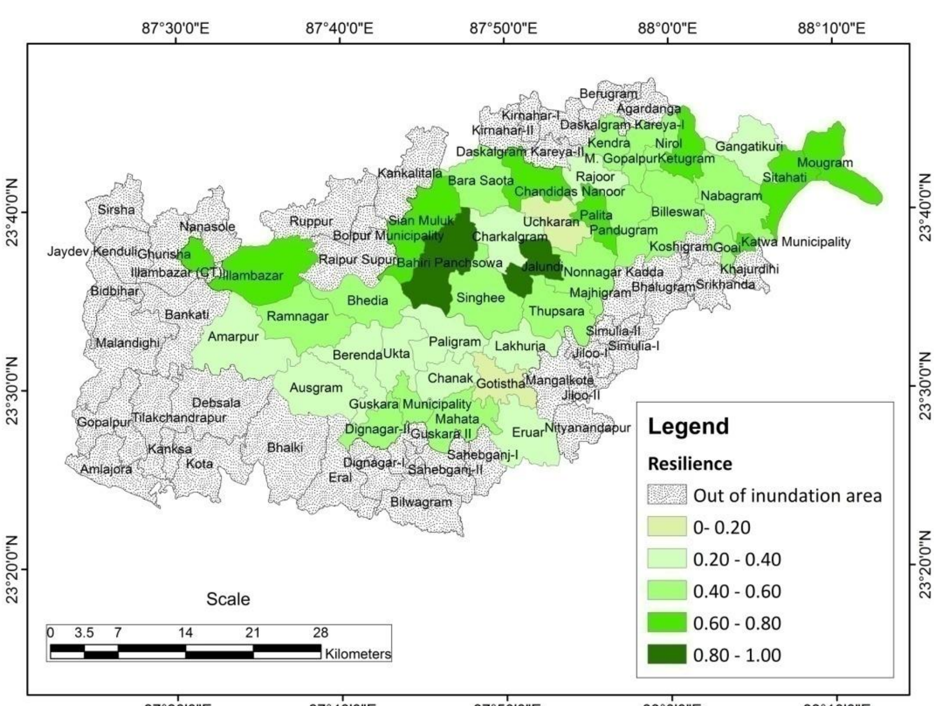


Figure 7.9 Resilience in the lower Ajay basin area (GP wise calculation in 0-1 scale)

(Source - Prepared by researcher)

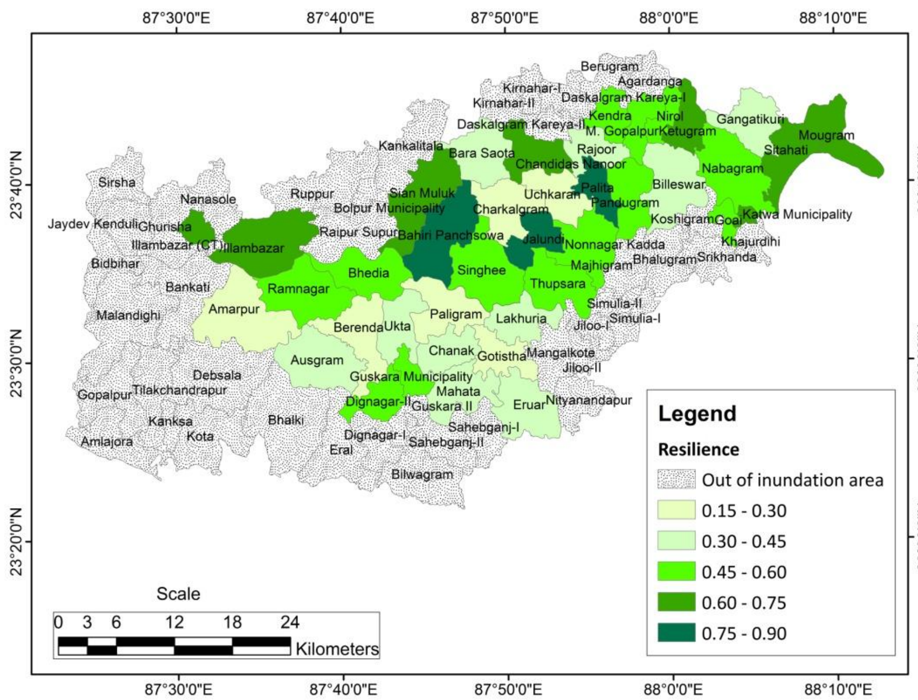


Figure 7.10 Resilience in the lower Ajay basin area (GP wise calculation according to maximum-minimum value)

(Source - Prepared by researcher)

7.6 Risk

Risk is quantified through the comparison of vulnerability and resilience factors. A higher value signifies greater risk, while a lower value indicates lower risk. By enhancing resilience relative to vulnerability, risk can be mitigated. Risk levels are categorised into four classes based on this comparison: 0-1 for risk-free, 1-2 for low risk, 2-3 for moderate risk, and 3-4 for high risk (Figure 7.11) (Table 7.2).

Study reveals that, risk values exceeding 1 indicate a higher vulnerability compared to resilience, suggesting a propensity for risk. Evaluating resilience not only reveals risk potential but also reflects current infrastructural conditions. Areas with poor resilience highlight the need for infrastructure improvements and strategic resource planning to reduce risk. Even, though the risk values are categorised into three classes (low risk, moderate risk, and high risk), the fact that all values are above 1 means that every GP is inherently at some level of risk. This highlights the importance of implementing risk management strategies and measures across the entire study area to address the varied levels of risk and vulnerabilities present.

Table 7.1 Calculation of physical vulnerability, socio-economic vulnerability, overall vulnerability, resilience and risk

GP	Physical vulnerability	Socio-economic vulnerability	Vulnerability	Resilience	Risk
Sian muluk	0.68	0.70	0.69	0.67	1.031
Singhee	0.66	0.63	0.64	0.58	1.098
Bahari parswa	0.77	0.70	0.73	0.83	0.882
Charkalgram	0.53	0.70	0.61	0.25	2.452
Jalundi	0.57	0.64	0.61	0.83	0.727
Thupsara	0.61	0.70	0.65	0.58	1.118
Uchhkaran	0.62	0.69	0.66	0.17	3.931
Bara Saota	0.58	0.52	0.55	0.42	1.318
Nonagar Kadda	0.64	0.68	0.66	0.58	1.135
Chandidas Nanoor	0.49	0.66	0.57	0.75	0.765
Illambazar	0.49	0.68	0.58	0.67	0.876
Aushgram	0.70	0.68	0.69	0.33	2.070
Beranda	0.74	0.64	0.69	0.25	2.763
Ukta	0.82	0.66	0.74	0.33	2.220
Guskara II	0.54	0.67	0.61	0.67	0.912
Dignagar II	0.64	0.69	0.66	0.50	1.324
Guskara Municipality	0.68	0.48	0.58	0.50	1.162
Bhedia	0.40	0.61	0.50	0.50	1.008
Amarpur	0.48	0.64	0.56	0.25	2.241
Ramnagar	0.77	0.64	0.71	0.50	1.415
Mahata	0.54	0.70	0.62	0.50	1.247
Eruar	0.49	0.71	0.60	0.33	1.795
Goai	0.72	0.68	0.70	0.50	1.401
Khasigram	0.83	0.67	0.75	0.42	1.795
Katwa Municipality	0.67	0.45	0.56	0.67	0.839
Paligram	0.69	0.69	0.69	0.25	2.756
Chanajk	0.62	0.67	0.64	0.33	1.933

GP	Physical vulnerability	Socio-economic vulnerability	Vulnerability	Resilience	Risk
Lakhuria	0.58	0.64	0.61	0.33	1.830
Gothista	0.59	0.67	0.63	0.17	3.772
Billeswar	0.79	0.65	0.72	0.42	1.730
Ketugram	0.73	0.66	0.70	0.67	1.045
Nabagram	0.78	0.67	0.73	0.50	1.457
Nirol	0.65	0.65	0.65	0.50	1.298
Gangatikuri	0.81	0.66	0.74	0.33	2.212
Sitahati	0.88	0.64	0.76	0.58	1.298
Mougram	0.52	0.64	0.58	0.67	0.875
Gopalpur	0.66	0.66	0.66	0.58	1.135
Palita	0.74	0.71	0.72	0.75	0.966
Pandugram	0.74	0.64	0.69	0.50	1.386
Rajor	0.66	0.69	0.68	0.33	2.027
Kandara	0.53	0.68	0.61	0.42	1.452

(Source - Calculated by researcher)

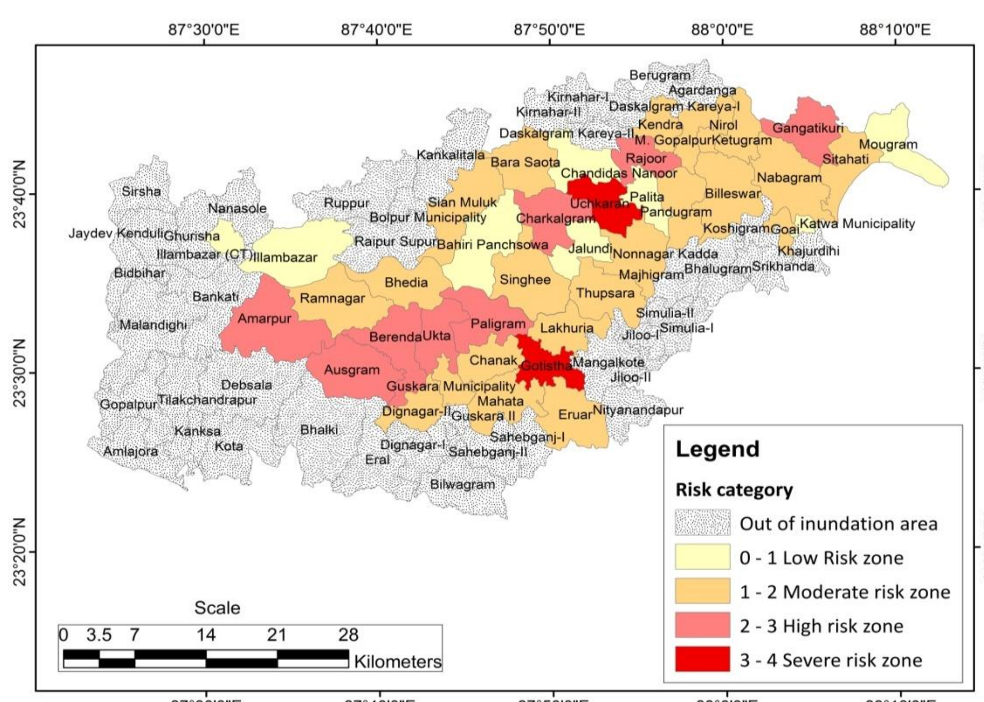


Figure 7.11 Risk in lower Ajay basin area (GP wise calculation in equal class distribution)

(Source - Prepared by researcher)

Table 7.2 Categorisation of risks

Risk free zone (0-1)	Low risk zone (1-2)	Moderate risk zone (2-3)	High risk zone (3-4)
Jalundi, Chandidas Nanoor, Katwa-I, Mougram, Illambazar, Bahari parswa, Guskara II, Palita	Bhedia, Sian muluk, Ketugram, Singhee, Thupsara, Gopalpur Nonagar Kadda, Guskara Municipality, Mahata, Sitahati, Nirol, Bara Saota , Dignagar II, Pandugram , Chanajk, Lakhuria, Khasigram, Eruar, Billeswar, Nabagram, Kandara, Ramnagar, Goai	Rajor, Aushgram, Gangatikuri, Ukta, Amarpur, Charkalgram, Paligram, Beranda	Gothista , Uchhkaran

(Source - Calculated by researcher)

In the 2015-2016, Disaster Management & Action Plan for Bardwan district, the predicted flood vulnerability and risk scenarios were compared to actual flood events in the Ajay basin area. This comparison showed a significant match between the estimated risk values and the actual flood risk areas, indicating a good correspondence between the calculated risk and the present scenario (Table 7.3). In the report of Disaster Management & Action Plan for Bardwan district several GP areas were identified as risk to flooding in the Ajay basin. The estimated risk values and the identified flood risk areas matched significantly, indicating the accuracy of the calculated risk index and the actual scenario. The calculated results show that all the GPs in actual risk have a risk index above 1.

Table 7.3 Comparison of actual risk and estimated risk index

GP	Risk index value
Paligram	2.75
Gothista	3.77
Lakhuria	1.83
Nabagram	1.45
Gangatikuri	2.21
Billeswar	1.73
Sitahati	1.29
Ukta	2.20
Barenda	2.76
Pandugram	1.38

(Source -Actual risk data from the report of Disaster Management & Action Plan for Bardwan District, 2015-16)

Chapter - 8

Sustainable Flood Management through Build of Resilience

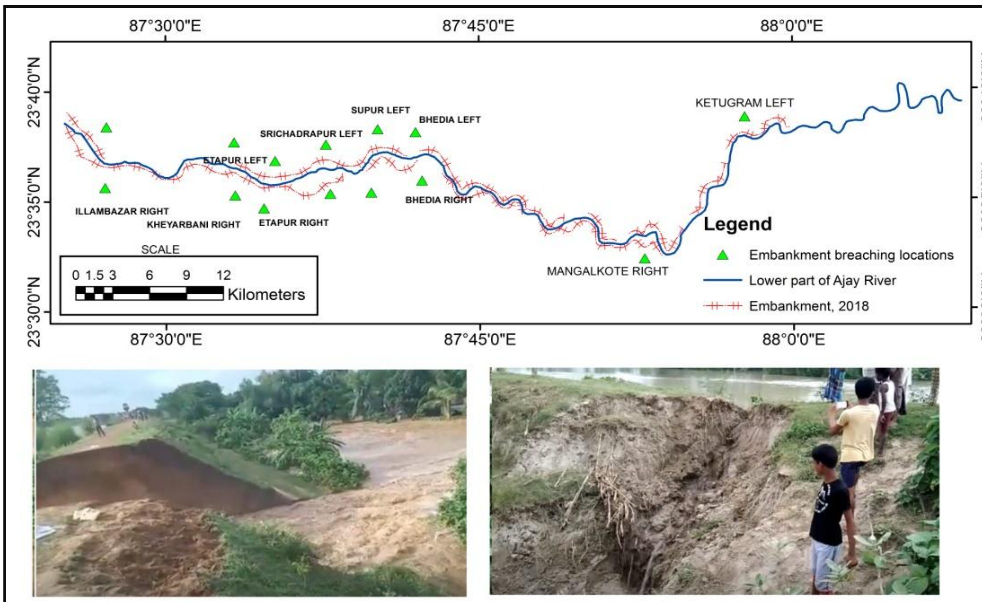
8.1 Structural resilience: embankment condition analysis

The flood history of the Ajay River was dated back long ago. Earthen embankment construction was started during the Zamindari period to protect the Zamindari land and ensure the agricultural fields and settlement are protects so that proper taxes (khajna) can be collected uninterruptedly. Due to this, the embankment was discontinued, restricted to zones in construction. During British colonialism, the older earthen embankments construction were repaired in many areas and newly constructed in various locations. But in the 1978 flood, the embankment proved to be a false sense of security and totally collapsed. After the 1978 flood, the Irrigation Department of West Bengal took the initiative to reconstruct the earthen embankments in different vulnerable locations following more technical process (Figure 8.2).

But history reveals that during high peak flows, embankments cannot protect the bank dwellers and due to the collapse of the embankments the population become more vulnerable. In this study, the analysis of existing resilience is considered through embankment stability analysis. In the laboratory, the grain size distribution of 42 samples was determined and results indicate that all of the samples are sandy in nature (Table 8.1). Grain size distribution for all the samples are presented in Appendix H. From this results using Allen Hazen empirical method permeability values were estimated. The results varying between 10^{-1} to 10^{-4} (Table 8.2), which indicates a good drainage condition through sandy soil (Murthy, 1992). Being good-quality permeable soil, any kind of water sinking into the system will quickly flow out to the drier region by following the natural hydraulic flow line. Thus, in normal circumstances, the embankment is considered good in terms of stability. But problems may arise if there sudden lowering of river water levels, because in that case the river water level will be lower than the submerged water level of the embankment and thus the embankment water may rapidly flow towards this river through also draining out cracks and voids.

Figure 8.1 Soil sample collection 23°39'32.67"N, 88° 6'35.99"E and sample preparation in Jadavpur University laboratory

(Source - Field photograph, 05.01.2019)



Collapse of embankment and flood situation in Ketugram and Mangalkote, 2 nd October, 2021

Figure 8.2 Embankment breaching locations in lower Ajay River

(Source - Embankment breaching location data collected from Disaster Management & Action Plan, Bardwan, Birbhum, 2015-2016 and 2016-2017 and photograph from the field)

Table 8.1 Calculation of soil quality

Station	% <75 micron	Soil character
Illambazar left opposite	0.5	
Illambazar left embankment	1.5	
Illambazar left water side	1	
Illambazar right opposite	3	
Illambazar right embankment	0.5	
Illambazar right water side	2.5	
Bhedia left opposite	1.5	
Bhedia left embankment	2.5	
Bhedia left waterside	0.5	
Bhedia right opposite	0.5	
Bhedia right embankemnt	2	
Bhedia right water side	0.5	Sandy in nature
Nelegarh left opposite	0.5	
Nelegarh left embankment	3	
Nelegarh left water side	2.5	
Nelegarh right opposite	3	

Station	% <75 micron	Soil character
Nelegarh right embankment	1	Sandy in nature
Nelegarh right water side	3.5	
Srichandrapur left opposite	0.5	
Srichandrapur left embankment	3	
Srichandrapur left water side	0.5	
Srichandrapur right opposite	2.5	
Srichandrapur right embankment	1.5	
Srichandrapur right water side	3	
Supur left opposite	1	
Supur left embankment	1	
Supur left water side	1.5	
Supur right opposite	1	
Supur right embankment	1.5	
Supur right water side	0.5	
Kheyerbani left opposite	9	
Kheyerbani left embankment	5	
Kheyerbani left water side	8	
Kheyerbani right opposite	2.5	
Kheyerbani right embankment	4	
Kheyerbani right water side	2	
Sakai right opposite	1	
Sakai right embankment	4.5	
Sakai right water side	3.5	
Begun Khola right opposite	1	
Begun Khola right embankment	1	
Begun Khola right water side	4.5	

(Source - Calculated by researcher)

Table 8.2 Calculation of D_{10} and maximum, minimum value of permeability

Station	D_{10}	*K*	C=150	*K*	Range
Illambazar left opposite	0.02	4.00E-02	3	6.00E-02	4.0-6.0
Illambazar left embankment	0.017	2.89E-02	2.55	4.34E-02	2.89-25.5
Illambazar left water side	0.06	3.60E-01	9	5.40E-01	36-54
Illambazar right opposite	0.013	1.69E-02	1.95	2.54E-02	1.69-2.535
Illambazar right embankment	0.015	2.25E-02	2.25	3.38E-02	2.25-3.375
Illambazar right water side	0.08	6.40E-01	12	9.60E-01	64-96
Bhedia left opposite	0.009	8.10E-03	1.35	1.22E-02	0.81-1.215
Bhedia left embankment	0.065	4.23E-01	9.75	6.34E-01	42.25-63.375
Bhedia left waterside	0.01	1.00E-02	1.5	1.50E-02	1-1.5
Bhedia right opposite	0.05	2.50E-01	7.5	3.75E-01	25-37.5
Bhedia right embankemnt	0.06	3.60E-01	9	5.40E-01	36-54
Bhedia right water side	0.08	6.40E-01	12	9.60E-01	64-96
Nelegarh left opposite	0.05	2.50E-01	7.5	3.75E-01	25-37.5
Nelegarh left embankment	0.05	2.50E-01	7.5	3.75E-01	25-37.5
Nelegarh left water side	0.03	9.00E-02	4.5	1.35E-01	9-13.5
Nelegarh right opposite	0.015	2.25E-02	2.25	3.38E-02	2.25-3.375
Nelegarh right embankment	0.03	9.00E-02	4.5	1.35E-01	9-13.5
Nelegarh right water side	0.015	2.25E-02	2.25	3.38E-02	2.25-3.375
Srichandrapur left opposite	0.06	3.60E-01	9	5.40E-01	36-54
Srichandrapur left embankment	0.02	4.00E-02	3	6.00E-02	4.0-6.0
Srichandrapur left water side	0.018	3.24E-02	2.7	4.86E-02	3.24-4.86
Srichandrapur right opposite	0.016	2.56E-02	2.4	3.84E-02	2.56-3.84
Srichandrapur right embankment	0.017	2.89E-02	2.55	4.34E-02	2.89-4.335
Srichandrapur right water side	0.015	2.25E-02	2.25	3.38E-02	2.25-3.375
Supur left opposite	0.02	4.00E-02	3	6.00E-02	4.0-6.0
Supur left embankment	0.025	6.25E-02	3.75	9.38E-02	6.25-9.375
Supur left water side	0.026	6.76E-02	3.9	1.01E-01	6.76-10.14
Supur right opposite	0.03	9.00E-02	4.5	1.35E-01	9-13.5
Supur right embankment	0.04	1.60E-01	6	2.40E-01	16-24
Supur right water side	0.015	2.25E-02	2.25	3.38E-02	2.25-3.375
Kheyerbani left opposite	0.028	7.84E-02	4.2	1.18E-01	7.84-11.76

Station	D_{10}	*K*	C=150	*K*	Range
Kheyerbani left embankment	0.03	9.00E-02	4.5	1.35E-01	9-13.5
Kheyerbani left water side	0.03	9.00E-02	4.5	1.35E-01	9-13.5
Kheyerbani right opposite	0.032	1.02E-01	4.8	1.54E-01	10.24-15.36
Kheyerbani right embankment	0.032	1.02E-01	4.8	1.54E-01	10.24-15.36
Kheyerbani right water side	0.035	1.23E-01	5.25	1.84E-01	12.25-18.375
Sakai right opposite	0.03	9.00E-02	4.5	1.35E-01	9-13.5
Sakai right embankment	0.02	4.00E-02	3	6.00E-02	4.0-6.0
Sakai right water side	0.06	3.60E-01	9	5.40E-01	36-54
Begun khola right opposite	0.025	6.25E-02	3.75	9.38E-02	6.25-37.5
Begun khola right embankment	0.025	6.25E-02	3.75	9.38E-02	6.25-9.375
Begun khola right water side	0.01	1.00E-02	1.5	1.50E-02	1-1.5
Minimum value		8.10E-03		1.22E-02	
Maximum value		6.40E-01		9.60E-01	

(Source - Calculated by researcher)

As the Ajay River is a non-tidal river, a certain change in water level is uncommon unless during drawdown after floods, mainly in case of flash flood and due to human interference and other factors may lead to the failure of the embankment.

Geotechnical engineering methods indicate that the embankment is stable. But improper and unscientific maintenance weakening the embankment and bank dweller’s lack of consciousness enhances the chances of failure of the embankment. Certain others factors also weaken the embankment and makes landmass behind the embankment vulnerable to flooding and inundation. In many locations agriculture is practised, embankment stability is compromised due to unplanned vehicle travel, sand mining at the toe of embankments is one of the major cause for embankment collapse. Most significantly, it was observed during the field visit that due to unplanned human interference and unscientific practises on or near the embankment, the life of the embankment became shorter. Although it is known that embankment is not a permanent solution to protect against flood, but a strong, good sustainable embankment may reduce the risk to some extent.

8.2 Paradigm shifting from construction based approach to resilience build up

The hazards resistance to risk minimisation approach has gained popularity as it is considered more sustainable compared to traditional construction-based methods. This shift is driven by the advantages offered by cost-benefit analysis and resilience building, which aim to reduce risks and enhance infrastructural facilities without directly interfering with natural systems.

Traditional construction approaches, such as building dams and levees, often disrupt natural fluvial systems and can lead to catastrophic failures. When such structures fail, the resulting disasters can be devastating. In contrast, resilience building focuses on enhancing the capacity of communities and systems to withstand and recover from adverse events, thereby minimising risks without altering natural processes.

In the context of India, there is significant potential for the development of resilience-based infrastructure. During the XI five-year plan, the Indian government approved a budget of 8000 crores to support states in creating flood-resistant structures. This allocation increased to 10,000 crores during the XII five-year plan, highlighting the growing emphasis on resilience (Mohanty, 2020).The preference for resilience over construction is also supported by the understanding that human science and technology cannot fully control natural systems. Therefore, investing in infrastructural development that enhances resilience and prediction-based management systems is more reliable. Such strategies not only mitigate risks but also promote sustainable development by aligning with the natural environment.

Overall, the move towards a resilience-based approach represents a more holistic and sustainable method for managing hazards, emphasising the importance of adaptability and preparedness in the face of natural disasters.

8.3 Flood shelter development

To enhance resilience and minimise the risk, scope of resilience capacities are calculated, considering factors such as the availability of flood shelters and health facilities. By including flood shelters in the resilience calculations, the overall resilience values increase, leading to a reduction in risk (Figure 8.6). Initially, the construction of proposed flood shelters converts high-risk Gram Panchayats (GPs) into moderate-risk GPs (see Table 8.3 for details).

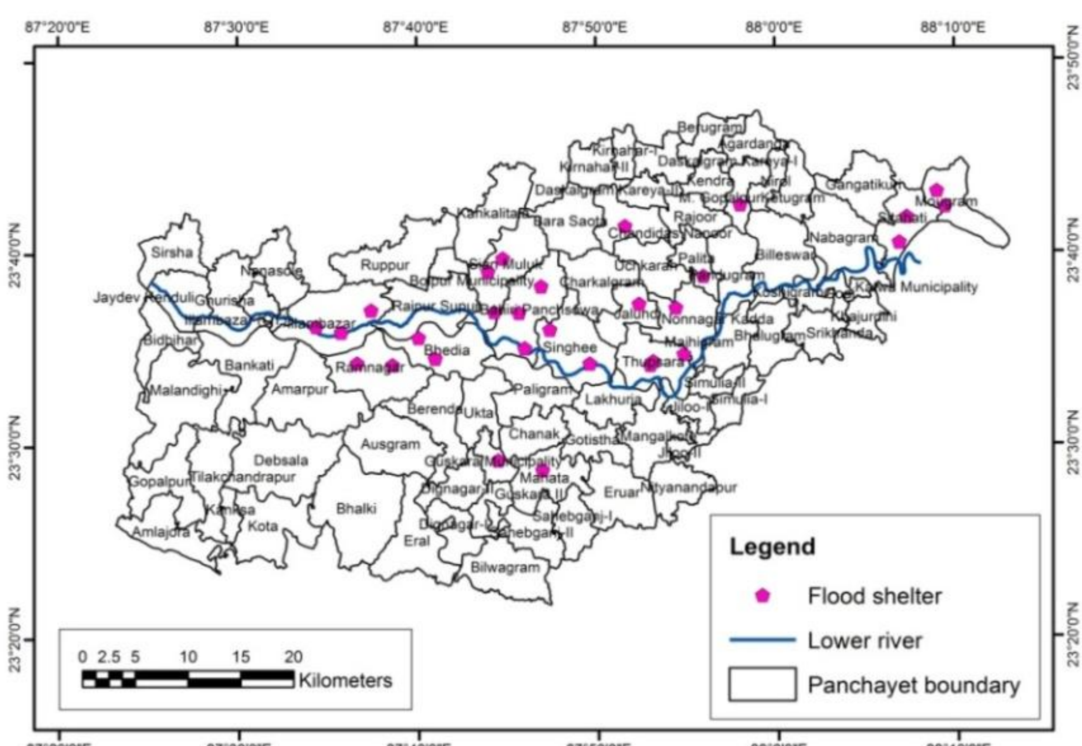


Figure 8.3 Existing flood shelter in the lower Ajay River basin

(Source - District Disaster Management Plan, Bardwan and Birbhum, 2015-2016 & 2016-2017)

Furthermore, increasing the number of health centres is proposed to further reduce the risk factor. As health facilities improve, resilience increases, transforming the risk level from moderate to low (refer to Table 8.4). For instance, in cases like the Beranda and Ukta GPs, the introduction of flood shelters adjusts the risk to a moderate level. In several Gram Panchayats (GPs), the absence or inadequate number of flood shelters significantly increases the risk to the local population during floods. In particular, GPs such as Charkalgram and Uchhkaran in the Nanoor block face heightened risks due to the lack of flood shelters. As a solution, it has been proposed to utilise existing high school buildings or any other government building for the development of flood shelters, leveraging available infrastructure to provide immediate safety and relief to affected communities. For example, in Uchhkaran GP, due to the absence of a high school building, the GP building has been designated as the best location for a flood shelter. Therefore, the construction of this building should prioritise its use as a flood shelter. For instance, the locations for flood shelters have been proposed in these two blocks (Figures 8.4 & 8.5). With moderate to high scores in health facilities, additional proposals such as road development are considered. Through calculations of proposed road length, resilience is estimated, ultimately reducing the risk from moderate to low (as outlined in Table 8.4).

These steps illustrate a comprehensive approach to risk reduction, emphasising the importance of multi-faceted infrastructure development. By strategically enhancing flood shelters, health facilities, and road infrastructure, the resilience of communities is bolstered, thereby minimising risks associated with natural disasters. This approach not only addresses immediate vulnerabilities but also contributes to long-term sustainability and preparedness.

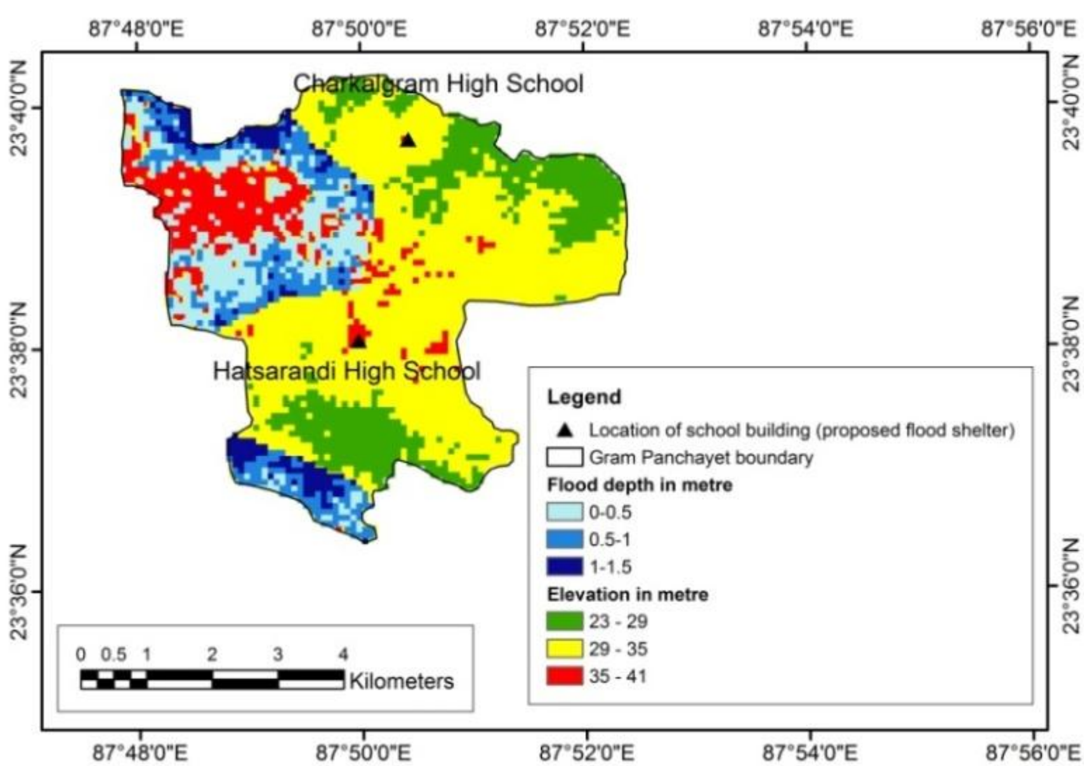


Figure 8.4 Proposed flood shelter location in Charkalgram GP

(Source - School location identified from Institutional Strengthening of Gram Panchayats (ISGP) Program)

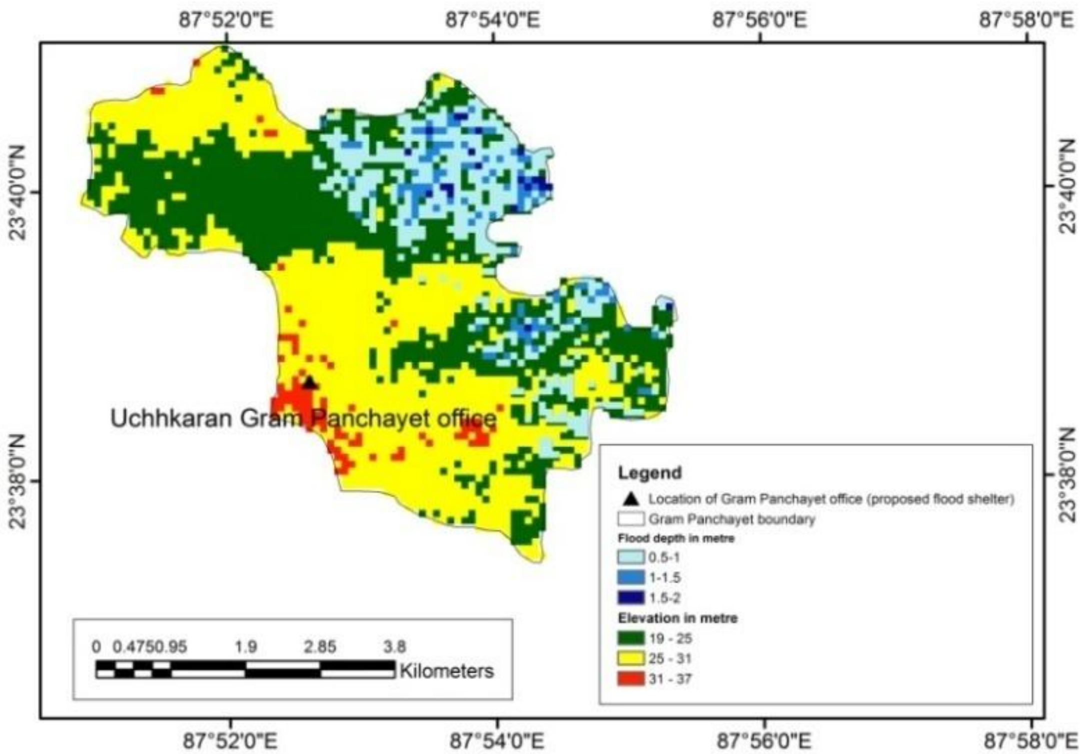


Figure 8.5 Proposed flood shelter location in Uchhkaran GP

(Source - GP location identified from Institutional Strengthening of Gram Panchayats (ISGP) Program)

Table 8.3 Calculation of risk by improving the resilience (adding flood shelter)

Block	GP	Actual risk	Risk after resilience increase
Nanoor	Charkalgram	2.452	1.471
Nanoor	Uchhkaran	3.931	2.621
Aushgram I	Aushgram	2.070	1.656
Aushgram I	Beranda	2.763	2.072
Aushgram I	Ukta	2.220	1.776
Aushgram II	Amarpur	2.241	1.681
Mangalkote	Paligram	2.756	1.181
Mangalkote	Gothista	3.772	2.514
Ketugram II	Gangatikuri	2.212	1.474
Ketugram I	Rajor	2.027	1.621

(Source - Calculated by researcher)

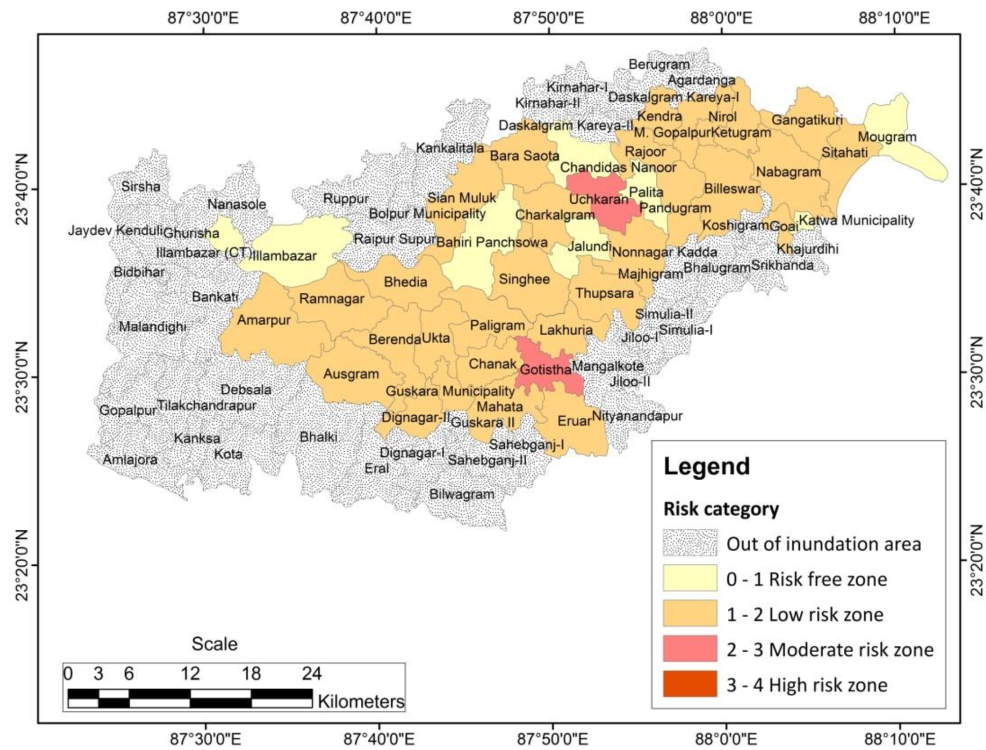


Figure 8.6 Modification of high risk Panchayet into moderate and low risk (modified by flood shelter)

(Source - Prepared by researcher)

Table 8.4 Calculation of risk by improving the resilience (increases the number of flood shelter and health centre)

GP	Actual risk	Risk after modified flood shelter	Risk after modified health centre
Charkalgram	2.452	1.471	1.226
Uchhkaran	3.931	2.621	1.965
Ukta	2.220	1.681	1.776
Paligram	2.756	2.514	1.181
Gangatikuri	2.212	1.621	1.474
Rajor	2.027	1.471	1.351

(Source - Calculated by researcher)

8. 4 Improvements of health facilities and road network

The road is a primary indicator of development in any area. Developing road facilities in rural areas is challenging for India. Maintaining road connectivity during any hazard is a difficult but essential task. During natural hazards like floods, the road network is often destroyed, isolating rural areas from the main centre. Therefore, proper road network development and alternative options are crucial for rescue and rehabilitation purposes. The **'Pradhan Mantri Gram Sadak Yojana'** rural road development plan can reduce risk during floods. In this study, risk minimisation is calculated by improving road facilities. In GPs like Berenda and Ukta, where road facilities are very poor and risk is high, improvements to road density at a moderate level help minimise risk (Table 8.5).

Investing in the road development of Bhedia and Singhee Gram Panchayats is crucial to addressing the current road infrastructure deficits. The proposed improvements will not only enhance connectivity and economic prospects but also build a more resilient to support during the flood (Figures 8.7 & 8.8).

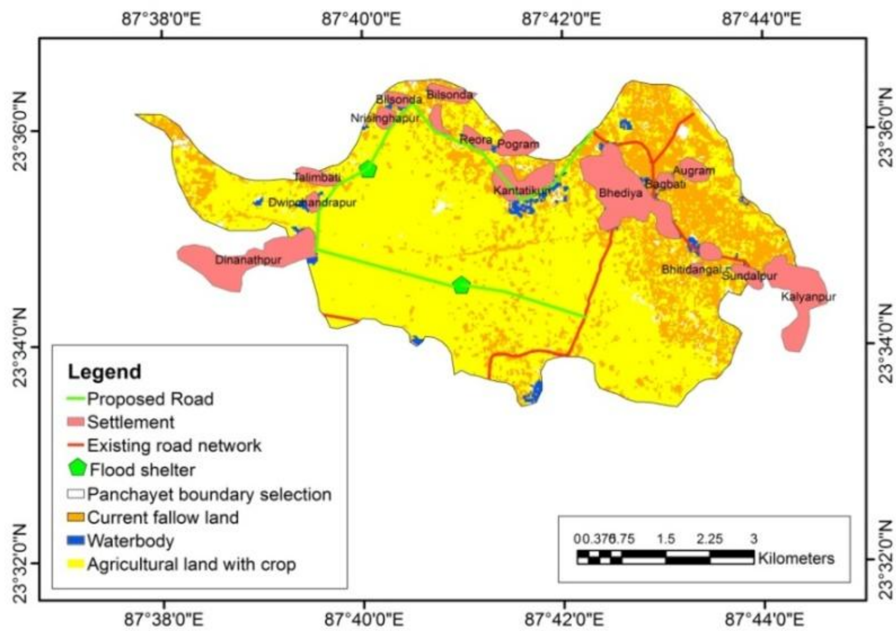


Figure 8.7 Proposal of road network improvement in Bhedia GP

(Source - Prepared by researcher in GIS platform)

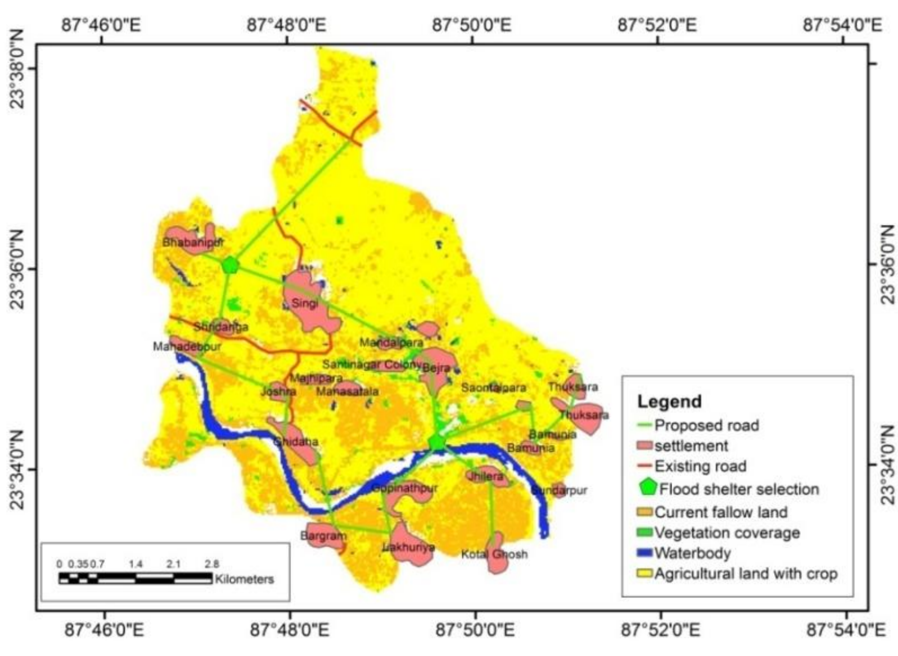


Figure 8.8 Proposal of road network improvement in Singhee GP

(Source-Prepared by researcher in GIS platform)

Health centre facilities are a primary indicator of infrastructural development. During hazard and post-hazard periods, affected populations face health crises. Therefore, the number of health centres is a critical factor in estimating health facilities. Improvements to health centres reduce the number of risk factors. In Uchhkaran, Gothista, and Gangatikuri GPs, the low number of health centres results in a high risk factor. By increasing the number of health centres, the risk value is reduced. The data shows that most of the GPs like Gangatikuri, Rajoor, Paligram, Ukta etc. are having low number of health centres. Due to excessive population pressure it is suggested to increase the number of health centre to provide the better service during the flood and post-flood scenario. During the extension of the road network in regularly flood-affected areas, flood level studies should be incorporated. In this research, flood area prediction with flood depth study is an important part of resilience-based flood management.

Table 8.5 Calculation of risk by improving the resilience (health centre and road length)

GP	Actual risk	Risk after adding health centre	Risk after increase the road length
Uchhkaran	3.931	1.965	1.310
Aushgram	2.070	1.656	1.182
Beranda	2.763	2.072	1.381
Ukta	2.220	1.776	1.268
Amarpur	2.241	1.681	1.120

(Source-Calculated by researcher)

8.5 Building quality improvement

The majority of houses in rural areas are still made of mud. Due to mud houses, it is more vulnerable during floods. Mud houses collapse and life loss is a common phenomenon. In this study area, the dominant portion is covered by a mud wall, which directly influences the vulnerability factors (Figure 8.9).

Mud houses in Ajay River bank

Figure 8.9 Mud houses in Ajay River bank near Bolpur -23°36'52.85"N, 87°40'32.93"E

(Source - Field photograph dated 11.01.2020)

However, the government is now introducing different schemes for the improvement of the quality of the houses. For those who have mud houses, the government is regulating a scheme called "**Pradhan Mantri Awas Yojana**." Through this scheme, a single concrete room with all facilities is constructed. This also acts as a risk preventing factor during the flood.

Table 8.6 Socio-economic vulnerability after the conversion of 50% mud houses into concrete

GP	Actual socio-economic vulnerability	Projected Socio-economic vulnerability
Bahari Parswa	0.7	0.68
Sian Muluk	0.7	0.67
Charkalgram	0.7	0.68
Thupsara	0.7	0.65
Mahata	0.7	0.62
Palita	0.71	0.65
Eruar	0.71	0.64

(Source-Calculated by researcher)

In the case of moderate risk values, flood shelters are proposed at the primary level and then resilience values are estimated. The estimated resilience is increased and risk is reduced to low. In this study area, economic values are high (Table 7.2) and during the post-flood scenario, a huge economic crisis occurs. A large number of GPs are inhabited by mud houses which are more vulnerable and risky during the flood scenario. In the case of the high economic risk GP area, 50% of the mud houses are proposed to be converted into concrete and if this is done, economic vulnerability may reduce (Table 8.6).

8.6 Agricultural modification

During the monsoon season, the entire area is cultivated with paddy, and almost 315 sq. km of cultivated land is significantly affected by floods. As paddy fields are washed away during floods, the backbone of the rural economy collapses, severely impacting cultivators and agricultural labourers. Modifying agricultural practices may reduce this damage. A successful research project is conducted in Rice Research Station, Chinsurah, Hooghly, West Bengal has developed a special type of paddy seed, SWARNA SUB-1, which can survive under submergence for almost 10–14 days.

Flooding typically occurs during the productive stage of paddy cultivation. Paddy cultivation begins in early July with the arrival of the monsoon, and it takes 100 to 110 days from germination to production (Bhowmik et al., 2014). Most flooding occurs in late September or early October due to the late monsoon and the fully saturated soil conditions. Unfortunately, the timing of the flooding often coincides with the paddy's production stage, leading to the destruction of entire fields. However, recent research shows that SWARNA SUB-1 can survive 10–14 days under submergence, allowing paddy fields to survive and maintain high production rates (Bhowmik et al., 2013). By using SWARNA SUB-1 seeds, it is estimated that almost 77800 acres of cultivated paddy fields, which is about 50% of the flood-affected area in the study region, could be saved.

8.7 Crop insurance

Crop insurance is a very essential for sustaining farmers' lives. Vast agricultural land areas are affected and farmers face huge losses. Most importantly, a significant number of farmers have no land of their own in the Indian scenario. That is why surveillance is too difficult for them. But with the implementation of crop insurance among farmers, risk factors may be reduced. In Indian scenario crop insurance practiced is first introduced in 1979 by Prof. V.M.Dandekar who is known as the father of crop insurance in India. In India national-wide crop insurance was started in 1985 by the Comprehensive Crop Insurance Sheme (CCIS) (Kaur et al., 2021). Now to mitigate the draw backs one single policy-"**Pradhan Mantri Fasal Bima Yojana"** is introduced in our country by the homogeneous premium and coverage system. In this insurance policy involvement of the modern geospatial technology like GPS system, satellite image uses, drone mapping are using for accurate measurement. The West Bengal state government is now trying to protect the farmers by introducing the "**Bangla Fasal Bima Yojona"**. The estimated flood-affected agricultural land is 77800 acres in the study area. By the minimum premium cost of 1930/- per acre of paddy field during the monsoon season, it comes in to the coverage of about rupees 40,500/acre area (‘**Pradhan Mantri Fasal Bima Yojana’** & ‘**Bangla Fasal Bima Yojana’, 2022**). For this study area, 77,800 acres of cultivated land are is estimated potential flood-affected and considering the premium rupees, a total of 15 crore is required, but it may protect the 77800 acres cultivated area.

8.8 Drinking water facilities development

The availability of drinking water facilities during the flood is an important criterion for livelihood. Even at the present scenario, 40% of the houses in the region collect drinking water away from their houses (House listing & Housing census data, 2011). During the flood, most of the tube well and tap water are submerged under water. So during the post-flood scenario, it seriously affects the health of livelihoods. More significantly, the tap water supply should be above the flood level. To minimise the risk during the flood, drinking water supplies should be within the premises. Now in our country, the "**Jal Jeevan Mission"** project has started to reach the drinking water facilities in every house within 2024. Hopefully it will help to reduce the risk. But during the installation of the running water system it ought to be kept in mind that its position should be higher from the high flood level in case of the flood potential area.

8.9 Channel improvement in main channel and tributaries

Channel improvement is very important for controlling the flood, but it is difficult to manage. But the cost burden is one of the significant barriers to de-siltation. During the field study in different parts of the river basin, it is clearly observed that human encroachment on the river bed, bed-cultivation (Figure 8.10), illegal construction, etc are being practiced. Most of the tributary channels have lost their natural carrying capacity. During the flood condition, tributaries act as distributaries, so flood area in the basin is maximised. Specially, improvements are required in the Kunur tributary region, Khandar tributary, etc., which can change the scenario. By the improvements of those channels carrying capacity of the channel and drainage system will improve so that the excessive water can pass out.

Figure 8.10 Bed cultivation in Ajay River bed near Bhedia

(Source - Field photograph dated 10.01.2020)

8.10 Land use and land cover planning

The analysis of land use and land cover change in Chapter 5, Table 5.6, indicates a decreasing rate of natural vegetation cover and an increase in settlement areas. This shift contributes to the gradual increase in flood risk. Scientific management of land use and land cover can significantly mitigate this risk. By identifying hazard-prone areas and implementing sustainable land use practices, the risk scenario can be altered favourably.

Firstly, preserving and restoring natural vegetation cover is crucial. Natural vegetation, such as forests and wetlands, plays a significant role in absorbing excess rainfall and reducing surface runoff, which can mitigate flood risks. Reforestation and forestation projects, alongside the protection of existing green spaces, are essential strategies.

Secondly, the planning and development of settlements must be managed to avoid high-risk areas. Planning of new settlement should incorporate flood risk assessments to ensure that new developments are located outside flood-prone zones. This can include zoning regulations that restrict building in areas prone to flooding and the creation of buffer zones with vegetation to absorb floodwaters.

Thirdly, promoting sustainable agricultural practices can reduce vulnerability. Crop rotation, the use of flood-resistant crops, and improved irrigation techniques can help maintain agricultural productivity without exacerbating flood risks. For instance, as discussed previously, the cultivation of flood-resistant paddy varieties like SWARNA SUB-1 can help farmers maintain their livelihoods even in flood-prone areas.

8.11 Trend of risk increase and minimisation of risk

Higher population growth is recorded in Bolpur, Mangalkote, Illambazar, and Nanoor blocks (Figure 8.11) and lower population growth is recorded in Ketugram II and Aushgram I blocks (Table 8.7). In all the blocks that are flood-prone, the population growth is also high. To reduce the loss and minimise the risk potential, settlement encroachment on river banks, especially in the valley area, should be prohibited. Due to the fertile land and high density of the population, the tendency of settlement development on the bank side should be restricted so that the intensity of the vulnerability decreases during the flood.

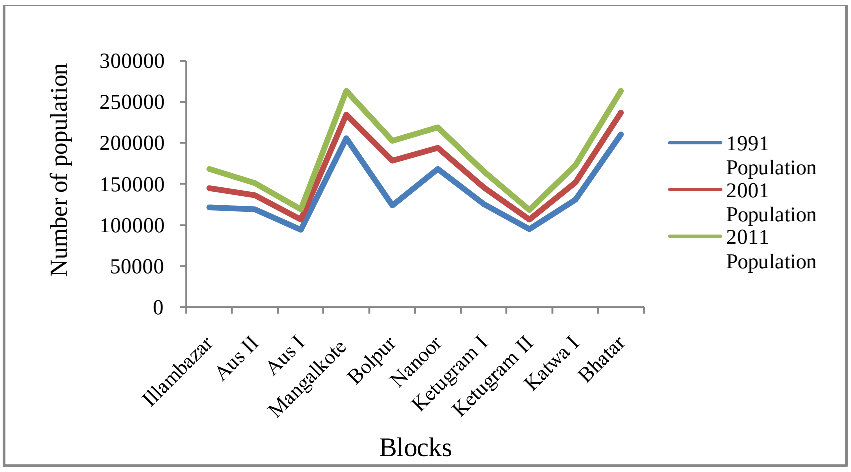


Figure 8.11 Population increase trends in different blocks (1991-2011),

(Source-Census data, 1991-2011)

Table 8.7 Yearly trend of population increase (1991-2011)

Blocks	Yearly increase of the population (1991-2011)	Flooded area in sq. km.
Illambazar	2390	20.26
Aus II	1593	54.4
Aus I	1273	121.31
Mangalkote	2888	54.34
Bolpur	3962	101.48
Nanoor	2514	75.46
Ketugram I	1997	55.7
Ketugram II	1185	154.13
Katwa I	2115	16.08
Bhatar	2630	16.23

(Source-Census data, 1991-2011)

8.12 Participation of the stakeholders

Flood management has traditionally been undertaken by qualified professionals or groups. However, by any activities or management process directly impacts on local peoples. Actually, stakeholders are those who are benefited or suffer due to any activities (Samuels, 2006). In primitive era, flood was accepted as the result of 'nature', but during the 18th and 19th century man dominating philosophy was evoked which brought forth fighting against flood, defence and prevention by the giant construction. But adverse effect on nature was realised and the perception of flood fighting has changed over the time. All professionals are now agree with the participation of society and trained individuals. By the participation of the local people involved the 'local knowledge' which enhances the successfulness of the management process. Many cases by the top-down of the technocratic approaches the project was failed. But recent time, the paradigm is shifted and the involvement of the stakeholders is in the front row that promotes the consciousness and effectiveness. By the framing of a new policy or management process the acceptance of the stakeholders plays a key role to succeed the project (Thaler and Levin-Keitel, 2016). By the pilot survey among the stakeholders gives the different idea about the demand and suggestion which includes in the planning. In case of the Ajay basin area the embankment was constructed from the very old days to control the flood. Recent times most of the cases vast areas are flooded due to embankment failure. During the field study it is observed that the intake capacity of the channel is gradually decreasing by the aggradational process (Figure 8.12). But in local level, due to lack of consciousness among the stakeholders the bed cultivation, encroachment of the settlement on the river bed increases causing the high flood potentiality. Involvement of the stakeholders in case of the management will increase the consciousness and built up a community perception.

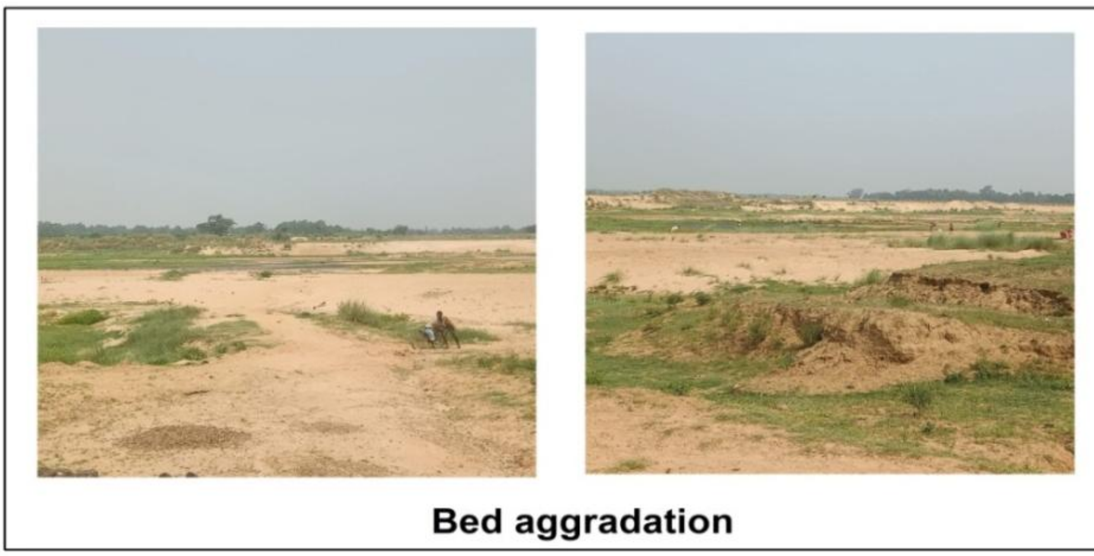


Figure 8.12 Bed aggradation- 23°36'31.95"N, 87°38'15.55"E

(Source-Field photograph dated 12.01.2020)

8.13 Occupational support for community empowerment

By the occupational support during the vulnerability enhance the power of resistant and recovery quickly. Occupational support helps in longer time for the improvement of the resilience capacity (Srivastava & Shaw, 2015). In this study area maximum area is covered by the agricultural field and most of the people are engaged in agricultural sectors so alternative occupational support during the recovery period is essential one.

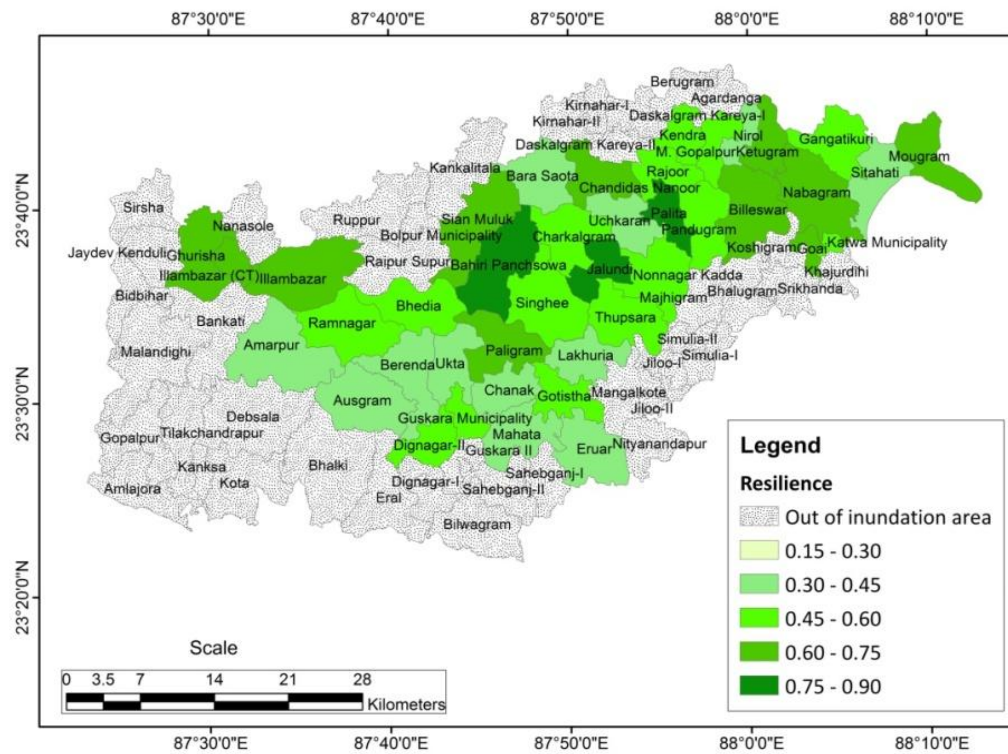


Figure 8.13 Modified resilience capacities

(Source-Prepared by researcher)

Even government can engage the agricultural labours into the recovery of infrastructure like rural road development, drainage repairing etc. by minimum training.

Many factors are discussed qualitatively. In this study, based on quantitative data such as flood shelter development, health centre development, and road network improvements, resilience capacities are increased (Figure 8.13) and risk is reduced. Enhancing resilience capacity will ultimately contribute to sustainable development in the long run and another side it will reduce the flood risk.

Chapter 9

Conclusion, Summary and Future Scope of Work

9.1 Summary of the work

This research undertakes a comprehensive analysis of the Ajay basin, focusing on its regional physical and socio-economic characteristics, fluvio-hydrological traits, flood history, and flood hazard management. By utilising various primary and secondary data sources, the study aims to understand the interplay between physical parameters and fluvial characteristics, alongside socio-economic vulnerability and flood management strategies.

The regional physical aspects of the Ajay basin are analysed through geology, soil, geomorphological and drainage characteristics. The basin is segmented into three distinct geological formations: the upper Ajay Basin, dominated by Granitoid Gneiss; the middle Ajay Basin, comprised of Gondwana sedimentary formations; and the lower Ajay Basin, characterised by new alluvium deposits. These physical aspects significantly influence the fluvial characteristics of the basin. The geomorphology reveals an erosional plain with monadnocks in the upper part, an erosional landscape with gully marks in the middle part, and a depositional alluvial plain in the lower part.

Socio-economic analysis at the block level provides insight into the vulnerability and fragility of the region. Special emphasis is placed on the lower Ajay basin, highlighting the socio-economic challenges and their relation to flood vulnerability.

The fluvio-hydrological characteristics are examined by analysing the channel and morphometric features of the basin. This includes linear characteristics such as the length and pattern of the river, areal characteristics such as basin area and shape (notably elongated), and relief characteristics such as elevation and slope variations across the basin. GIS platforms and geospatial data facilitate this morphometric analysis, revealing detailed insights into the river's behaviour and potential flood zones.

Flood history is scrutinised using past records, and flood frequency is calculated using statistical methods such as the Gumble distribution. This helps estimating flood intensity at different return periods and contributes to potential flood area estimations. Rainfall patterns (monsoon, pre-monsoon, and post-monsoon) are analysed, showing that combined monsoon and post-monsoon rainfall exacerbate flood vulnerability.

A qualitative flood model is developed due to data limitations, supplemented by simulation-based hydrological data. This model is validated spatially to determine its applicability. The vulnerability model considers social, economic, and physical aspects up to the GP (Gram Panchayat) level, with detailed mapping to illustrate spatial patterns of vulnerability. Risk calculation also includes resilience potential.

The study discusses flood vulnerability management strategies, emphasising both quantitative resilience-based methods and qualitative analysis. Existing protective measures, such as embankments, are evaluated for permeability and seepage, with laboratory tests indicating sandy soil texture, which is generally good for drainage but problematic during peak floods. The research advocates for a shift from structural to non-structural approaches for sustainable flood management. Suggested measures include flood shelters, improved road connectivity, enhanced hospital facilities, crop insurance, and modified agricultural practices, building quality improvements, and proper land use management.

The research highlights the complexity of managing flood hazards in the Ajay basin. By integrating physical, socio-economic, and hydrological analyses with innovative management strategies, it aims to provide a holistic approach to reducing flood vulnerability and enhancing resilience in the region.

9.2 Conclusion

The study area frequently suffers from flood hazards and due to floods; the socio-economic structure is severely affected. Surrounding all the basins, Damodar and Mayurakshi are flood-prone and during flood conditions, agricultural fields are mostly affected. The backbone of the rural economy collapses in this whole region. The actual loss is immeasurable. The marginal farmers and agricultural labourers are mostly affected and the poor becomes poorer. During the recovery period, they suffer most and without government support, they cannot survive. Frequent strikes of the flood destroy the social strata. Social unrest and malnutrition has immerged as more common problems. The agricultural labourers become unemployed for two or three months and marginal farmers sometimes lose their own land, so the number of migrant labourers also increases. Children's education is directly hampered and the dropout rate also increases. Social loss is specially deep. So in this work, social parameters are included and quantified. Actual losses cannot be measured by simple quantification. But quantification and simplification of spatial area-based analysis are the most important steps towards effective planning.

The research work is mainly done to find the actual scenario behind a result. In this study, flood scenarios and their long-term effects are analysed. Most crucially, this study identifies the potential flooded area and tries to find the reason behind it.

This study is focused on the physical characteristics and tries to relate with the present fluvial dimension. The nature of outcrop study reveals that the Ajay River passes through the several geological formation like Archean formation, Gondwana formation and recent Cenozoic formation. Imprint on channel character, variation of the channel width in the lower flood plain areas are high. Due to high yielding of the sediment, bar formation is common in the lower part of the channel. Specially, human encroachment on river bed, unscientific sand mining etc. are also enforcing for the sedimentation which is negatively affecting on river's carrying capacity. Along with the gentle slope,human encroachment in the lower part of the river is causing the flood potentiality.

This study is focused on developing a spatial flood area-based model for this region. Specially to overcome the shortage of data, a suitable flood model development is tried. Both qualitative and quantitative model are developed to predict the spatial flood area in the lower part of the Ajay river basin. In case of the qualitative based model, factor based weightaged method is adopted in the geospatial platform. Quantitative hydrological model is simulated based on the available past gauge height data and topographical pattern. For more accurate result the simulation based daily discharge is extracted on the basis of daily rainfall data, hydrological soil characteristics and land use land cover analysis. By using the simulation data spatial pattern of the flood area is predicted. The results are validated with the past flooded data. Comparing all the models proves that simulation based result in the HEC-RAS platform is the most suitable but others methods are also indicating the satisfactory result.

In this study area, the tropical monsoon behaviour plays a pivotal role in shaping the hydrological dynamics, particularly concerning flood events. The synthesis of the tributary channel in the lower part of the basin is considered a significant contributing factor to flooding.

During periods of heavy rainfall, typical of tropical monsoon climates, there's an excessive inflow of water into the main channel and additional water from tributaries in the lower reaches of the basin. This surplus of water leads to a substantial increase in the inundation area. The flood situation is exacerbated by the inability of this excessive flow to drain out efficiently due to backflow from the surrounding regions.

One critical element contributing to this flood scenario is channel cut-offs, particularly notable in the Kana Ajay region. Channel cut-offs occur when a river changes its course, abandoning its previous channel and creating a new path. In the context of flooding, this can lead to altered flow patterns, increased sedimentation, and changes in channel morphology, all of which can contribute to elevated flood risk, especially in downstream areas.

The combination of tropical monsoon behaviour, tributary channel synthesis, excessive flow during floods, and channel cut-offs, notably in the Kana Ajay region, creates a complex interplay of factors that significantly impact flood occurrences in the lower regions of the basin. Understanding these dynamics is crucial for developing effective flood management strategies and mitigating the adverse impacts of flooding on communities and infrastructure in the study area.

Most significantly, through the micro-level study, a vulnerability index is developed, which will be helpful for any further study or flood mitigation planning in this region. Addressing the overall aspects of the region—social, physical, and economic components are included. In many cases, the qualitative parameters are converted into quantitative measures by adopting few methodologies, which will open new dimension for flood vulnerability analysis. To understand the all over scenario physical, social and economic vulnerability index are prepared. Combined result is indicating the vulnerability index. Most importantly, the different kinds of resilience based sustainable solutions are suggested for the risk minimisation. More comprehensively risk and resilience scope are analysed for each Gram Panchayet area.

A holistic approach is accepted to the analysis of flood behaviour, especially fluvial characteristics, in relation to flooding. The present art of technology, specially geospatial technology like remote sensing GIS platforms, is used for the prediction of hazards and vulnerabilitiesin spatial scale considering the Gram Panchayet scale. The use of remote sensing and GIS platform reduces the cost and time as well. Most significantly, accessibility in inaccessible locations is the biggest advantage of the tools.

Finally, sustainable resilience-based management solutions are framed for risk reduction. Non-structural based resilience infrastructural plans are suggested to reduce the risk potentiality. By the improvement of the infrastructural facilities like road network extension, increases of the health facilities, flood shelter construction will reduces the risk in one side and in another side it will enhance the development process. By the framing of the sustainable management plan natural fluvial course is not hampered in long run which is healthy for the nature of fluvio-geomorphology.Uses of the geospatial technology help to reduce the risk and predict accurately.Continuous research can provide a way to frame a plan. Social awareness and proper knowledge transformation may be helpful to overcome the problems.

The existing structural solution embankment conditions are checked. Comprising the grain size distribution measurement the soil quality is proved sandy in nature which is good for embankment health condition. During the high saturation level it is easy to passes the flowing water. But due to lack of consciousness of bank dwellers, the uses of the embankment are very unscientific manner. So sometimes embankment is collapsed and increases the risk volume. So in this work, including the analysis of the embankment breaching the most crucial part uses of the embankment also emphasised.

For the results of the actual research, a comprehensive approach from the government, local people and funding agencies is required. But we hope for a positive approach from the decision-maker to reduce the potential risk. Continuous research and study may open a new dimension for risk reduction and sustainable management planning.

Finally, to maintain the natural course of the river and framing the sustainable management solution the perception of "living with flood" a new dimension of the study is adopted.

9.3 New Findings

- **Distinct Geological Zonation and Fluvial Influence**
  The segmentation of the Ajay basin into three zones as per geological, geomorphological characteristics (Granitoid Gneiss, Gondwanasedimentaries, and new alluvium) provided a new perspective on how geology influences fluvial behaviour and flood vulnerability in each sub-region of Ajay River.
- **Revealed Morphometric Flood Susceptibility Using GIS**
  The use of morphometric analysis via GIS platforms showed that the elongated shape and slope variation across the basin directly correlate with potential flood zones – this spatial understanding of susceptibility for Ajay River is a key advancement.
- **Pre-Monsoon, Monsoon and Post-Monsoon Rainfall Interaction Identified as Potential Risk Factor**
  The study established that combined seasonal rainfall is a critical factor exacerbating flood events –this specific conclusion was previously underrepresented in regional flood assessments.
- **Tributary Channel Synthesis**
  The **combined impact** of monsoon rains, tributary inflow in lower reach of the main channel, excessive discharge, and channel cut-offs lead to a multifactorial flood scenario that is difficult to predict and manage without integrated analysis.
- **Development of Qualitative Flood Model**
  Despite data limitations, a spatially validated qualitative flood model has been developed which is a noteworthy methodological innovation for data-scarce regions, enabling risk mapping even without full hydrological datasets.
- **Impact of micro topographical changes on spatial flood analysis**
  Spatial flood prediction was made for lower Ajay Basin area depending on micro topographical changes. This is a value addition to planning for flood management even due to micro level changes.
- **Block-Level Socio-Economic Vulnerability Mapping to GP Scale**
  A detailed vulnerability assessment down to the Gram Panchayat (GP) level, incorporating social, economic, and physical indicators, brings in a micro-level spatial understanding of flood risk—this level of granularity is a new contribution.

- **Resilience based measures**

The study offers critical insights into human induced factors as important cause of embankment failure and pushes for a strategic shift from only structural to non-structural and combined solutions, such as flood shelters, improved infrastructure, crop insurance, and sustainable land use. This highlights resilience over resistance as an important sustainable model.

9.4 Future scope of work

- The study of sedimentation for analysis of the geomorphological condition of the river with the relation of aggradational process.
- Micro-level analysis of topography and geological formation in relation to the present river basin character.
- Flood character analysis and spatial distribution in each sub-watershed
- Physical and social character analysis by considering the sub-watershed.
- Embankment engineering condition analysis in various parts of the basin.
- Drainage condition analysis in each sub-watershed.
- Addressing social perception through more social data collection.
- Land use and land cover analysis up to the micro-level and its impact on fluvial character.
- Analyse of the scope of resilience building by considering more components.
- Analysis of the flood, including the neighbour basins like Mayurakshi, Damodar, Bhagirathi- Hugli.
- There is a large scope of research on the linking project between neighbouring basins in this region.
- Study on the behavioural changes of the land use and land cover and relation with flood risk.
- Study on the revival of tributary channels to control the flood in the lower Ajay River, like Kana Ajay tributary, Khandar Nala, etc.
- An integrated flood management plan development, including all the hydrological conditions of neighbouring basins in this region.

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Appendices

Appendix A: Calculation for hypsometric integral

					Hypso metric intregal	
Contours	Relative height	h/H(Y)	Area covered Of its and above	a/A(x)	Y.x+1	x.y+1
450	400	1	0	0		
400	350	0.875	80	0.0128	0.0128	0
350	300	0.75	530	0.085	0.0743	0.0096
300	250	0.625	1323	0.212	0.159	0.0531
250	200	0.5	2523	0.404	0.252	0.106
200	150	0.375	3194	0.512	0.256	0.1414
150	100	0.25	3835	0.615	0.230	0.128
100	50	0.125	4935	0.695	0.173	0.0768
50	0	0	6235	1.0	0.125	0
					1.2821	0.5149

(Source-Calculated by researcher)

Appendix B: Expert and stakeholders opinion for preparation of AHP matrix

AHP scale according to Thomas Saaty (1980) 1=Equal importance, 3=Moderate importance, 5=Strong importance, 7= Very strong importance, 9=Extreme importance (2,4,6,8- Values in between)

Criteria		How much more								
Criteria	Criteria	Equal/1	2	3	4	5	6	7	8	9
Rainfall	Slope			3						
Rainfall	Altitudes				4					
Rain fall	Soil				4					
Rain fall	Groundwater table height				4					
Rain fall	Distance from river			3						
Rainfall	Drainge system			3						
Rain fall	Carrying capacity			3						
Rain fall	Run off		2							
Slope	Altitudes		2							
Slope	Soil			3						
Slope	Groundwater table height			3						
Slope	Distance from river		2							
Slope	Drainage system	1								
Slope	Carrying capacity	1								
Slope	Run off		1/2							
Altitudes	Soil		2							
Altitudes	Groundwater table height			3						
Altitudes	Distance from river		2							
Altitudes	Drainage system	1								
Altitudes	Carrying capacity	1								
Altitudes	Run off		1/2							
Soil	Groundwater table height		2							
Soil	Distance from river		1/2							
Soil	Drainage system		1/2							
Soil	Carrying capacity		1/2							
Soil	Run off			1/3						
Criteria		How much more								
Groundwater table height	Distance from the river		1/2							
Groundwater table height	Drainage system		1/2							
Groundwater table height	Carrying capacity		1/2							
Groundwater table height	Run off			1/3						
Distance from river	Drainage system	1								
Distance from river	Carrying capacity	1								
Distance from river	Run off		1/2							
Drainage system	Carrying capacity		1/2							
Drainage system	Run off		1/2							
Carrying capacity	Run off		1/2							

(Source-Calculated by researcher)

Appendix C: Stakeholder's opinion for preparation of AHP matrix

Criteria		How much more								
Criteria	Criteria	Equal/1	2	3	4	5	6	7	8	9
Rainfall	Slope			3						
Rainfall	Altitudes			3						
Rain fall	Soil				4					
Rain fall	Ground water table height				4					
Rain fall	Distance from river		2							
Rainfall	Drainage system			3						
Rain fall	Carrying capacity		2							
Rain fall	Run off		2							
Slope	Altitudes		2							
Slope	Soil			3						
Slope	Ground water table height				4					
Slope	Distance from river			3						
Slope	Drainage system		2							
Slope	Carrying capacity			3						
Slope	Run off		1/2							
Altitudes	Soil			3						
Altitudes	Ground water table height			3						
Altitudes	Distance from river			3						
Altitudes	Drainage system		1/2							
Altitudes	Carrying capacity			3						
Altitudes	Run off			1/3						
Soil	Ground water table height		1/2							
Soil	Distance from river		1/2							
Soil	Drainage system		1/2							
Soil	Carrying capacity		1/2							
Soil	Run off				1/4					
Ground water table height	Distance from the river		1/2							
Ground water table height	Drainage system		1/2							
Criteria		How much more								
Ground water table height	Carrying capacity		1/2							
Ground water table height	Run off					1/5				
Distance from river	Drainage system	1								
Distance from river	Carrying capacity		1/2							
Distance from river	Run off				1/4					
Drainage system	Carrying capacity		1/2							
Drainage system	Run off			1/3						
Carrying capacity	Run off			1/3						

(Source-Calculated by researcher)

Appendix D: Calculation of SCS-Curve Number (CN)

	HSG	LULC	Area (in Acre) Ar	CN	CN=(Ar* CN)/TA	Total watershed area	Weighted Ultimate curve no	Approx CN
		Water body	7925.15	98	3.881			
		Sand	8291.33	95	3.936			
		Agriculture Land with crop	85581.1	72	30.790			
		Agriculture Land	70400.61	72	25.329			
Water shed-1	**B**	Natural Vegetation	12950.24	33	2.135			
		Rocky Surface	14970.59	70	5.236		71.3	71
						809.85		
			200119.12		71.309			
		Water body	12857.152	98	6.920			
		Sand	8191.33	95	4.273			
		Agriculture Land with crop	43281.18	72	17.115			
Water shed-2	**B**	Agriculture Land	81350.66	72	32.169			
		Natural Vegetation	22914.24	33	4.153	736.83	69.81	70
		Rocky Surface	13480.95	70	5.182			
			182075.53		69.814			
		Settlement	158.72161	77	0.060			
		Water body	6925.15261	98	3.382			
		Sand	2577.33039	95	1.220			
Water shed-3	**B**	Agriculture Land with crop	47684.8962	72	17.109		68.67	69
		Agriculture Land	81950.16133	72	29.404	812.04		
		Natural Vegetation	21214.24643	33	3.488			
		Rocky Surface	40150.95166	70	14.006			
			200661.4602		68.673			
		Water body	1292.15261	98	1.936			
		Sand	8291.33039	95	12.047			
Water shed-4	**B**	Agriculture Land with crop	34451.8962	72	37.941			
		Agriculture Land	8935.16133	72	9.840	264.57		

	HSG	LULC	Area (in Acre) Ar	CN	CN=(Ar*CN)/TA	Total watershed area	Weighted Ultimate curve no	Approx CN
		Natural Vegetation	10914.24643	33	5.508		68.87	69
		Rocky Surface	1493.951655	70	1.599			
			65378.73862		68.874			
							70.5	71
		Water body	925.15261	98	1.285			
Water shed-4	**C**	Agriculture Land with crop	33400.8962	72	34.100			
		Agriculture Land	35006.16133	72	35.739		72.3	72
		Rocky Surface	1190.655	70	1.181	285.39		
			70522.86514		72.307			
Water shed-5	**B**	Water body	1092.15261	98	1.582			
		Sand	591.33039	95	0.830			
		Agriculture Land with crop	19611.8962	72	20.879			
		Agriculture Land	43506.16	72	46.318	273.68	71.28	71
		Natural Vegetation	2291.24643	33	1.118			
		Rocky Surface	535.951655	70	0.554			
			67628.73729		71.283			
								71
		Water body	1425.15261	98	2.679			
		Sand	658.33039	95	1.199			
		Agriculture Land with crop	17562.8962	72	24.257			
Water shed-5	**C**	Agriculture Land	29589.24	72	40.868		71.27	71
		Natural Vegetation	2276.24643	33	1.440			
		Rocky Surface	616.951655	70	0.828	210.95		
			52128.81729		71.274			

	HSG	LULC	Area (in Acre) Ar	CN	CN=(Ar*CN)/TA	Total watershed area	Weighted Ultimate curve no	Approx CN
		Water body	1635.15261	98	2.071			
		Agriculture Land with crop	51528.8962	72	47.959			
Water shed-6	**B**	Agriculture Land	8935.19	72	8.316			
		Natural Vegetation	12914.23	33	6.04		69.16	69
		Rocky Surface	1495.951655	70	3.939	313.06		
		settlement	850	77	0.84			
			77359.42047		69.165			
		Water body	560.15261	98	0.704			
		Agriculture Land with crop	26581.8962	72	24.568			
		Agriculture Land	43506.16133	72	40.205			
Water shed-6	**C**	Natural Vegetation	6063.29	33	2.568			
		Rocky Surface	540.23	70	0.485		69.69	70
		settlement	659.65	90	0.762			
						315.29		
			77911.38014		69.290			
		Water body	925.15261	98	1.523			
		Agriculture Land with crop	25811.65	72	31.226			
		Agriculture Land	28506.19	72	34.486		70.62	71
		Natural Vegetation	3914.2464	33	2.170	240.84		
Water shed-6	**D**	Rocky Surface	356.95	70	0.419			
		settlement	525.35	90	0.794			
			59514.18901		70.62			
		Water body	986.51	98	1.513			
		Sand	569.23	95	0.846			
Water shed-7	**B**	Agriculture Land with crop	35698.27	72	40.249			
		Agriculture	23547.12	72	26.549		71.96	72

	HSG	LULC	Area (in Acre) Ar	CN	CN=(Ar* CN)/TA	Total watershed area	Weighted Ultimate curve no	Approx CN
		Land						
		Natural Vegetation	1296.23	33	0.669	258.42		
		Rocky Surface	1100.9	70	1.206			
		settlement	660.25	90	0.930			
			63858.51		71.966			
		Water body	856.19	98	1.209			
Water shed-7	**C**	Agriculture Land with crop	40811.8962	72	42.358			
		Agriculture Land	22506.16133	72	23.359			
		Natural Vegetation	2914.24643	33	1.386			
		Rocky Surface	1495.55	70	1.509	280.73		
		settlement	786.28	90	1.020		70.84	71
			69370.32396		70.843			
		Waterbody	1325.12	98	2.492386482			
		Sand	630.28	95	1.149188402			
Water shed-7	**D**	Agriculture Land with crop	29250.16	72	40.41986374	210.85		
		Agriculture Land	19690.27	72	27.20935648		72.89	73
		Rocky Surface	1207.55	70	1.622322774			
			52103.38		72.89311787			
		Settlement	250.72161	77	0.207695663			
		Waterbody	1292.15261	98	1.36233784			
		Sand	829.33036	95	0.847610063			
		Agriculture Land with crop	50081.8962	72	38.79343131			
Water shed-8	**B**	Agriculture Land	39006.16133	72	30.21416829	376.16		
		Rocky Surface	1490.951655	70	1.122810683		72.54	73
			92951.21377		72.54805385			
								73
		Settlement	270.71	90	0.26033187			

	HSG	LULC	Area (in Acre) Ar	CN	CN=(Ar*CN)/TA	Total watershed area	Weighted Ultimate curve no	Approx CN
		Waterbody	2925.15	98	3.063054659			
Water shed-8	**D**	Sand	1291.39	95	1.310875824			
		Agriculture Land with crop	50081.82	72	38.52947835			
		Agriculture Land	38065.23	72	29.28474754	378.73		
		Rocky Surface	953.55	70	0.713217581		73.16	73
			93587.85		73.16170582			
		Selllement	12195.52	77	7.883476455			
Water shed-9	**B**	Waterbody	4010.61	98	3.29961474			
		Agriculture Land with crop	70084.61	72	42.36252951			
		Agriculture Land	32826.13	72	19.84170135	482.04		
			119116.87		73.38732205			
							73	73

(Source-calculated by researcher)

Appendix E: Daily rainfall in Ajay basin region in the year 2000

Days	Sikatia Rainfall (mm)	Illambazar Rainfall (mm)	Ketugram Rainfall (mm)
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0
16	1.193	0.974	0

Days	Sikatia Rainfall (mm)	Illambazar Rainfall (mm)	Ketugram Rainfall (mm)
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0.213	0	0
24	0	0	0
25	0	0	0
26	0	0	0
27	0	0	0
28	0	0	0
29	0.263	0	0
30	0	0	0
31	0	0	0
32	0	0	0
33	0.283	0.865	0
34	3.337	0.214	2.0
35	0	0.455	0
36	4.698	10.129	23
37	12.016	7.845	15
38	2.08	0	0
39	0	0	0
40	0	0	0.5
41	0.069	0.036	0
42	0	0.728	0
43	9.414	2.215	11.5
44	1.861	0	0
45	0	0	0
46	0	0	0
47	0	0	0
48	0	0	0
49	0	0	0
50	0	0	0
51	0	0	0
52	0	0	0
53	0.544	0	0
54	0	0	0
55	0	0	0
56	0	0	0
57	0	0	0
58	0	0	0
59	0	0	0

Days	Sikatia Rainfall (mm)	Illambazar Rainfall (mm)	Ketugram Rainfall (mm)
60	0	0	0
61	0	0	0
62	0	0	0
63	0	0	0
64	0	0	0
65	0	0	0
66	0	0	0
67	0	0	0
68	8.408	0	0
69	0.944	2.169	0
70	0	0	0
71	0	0	0
72	0	0.493	0
73	0	0	0
74	1.067	0	0
75	0	0	0
76	0	0	0
77	0	0	0
78	0	0	0
79	0.033	0	0
80	0.03	0	0
81	0	0	0
82	0	0	0
83	0	1.327	0
84	0.176	0	0
85	0	0	0
86	0	0	0
87	0	1.003	0
88	0.08	0	0
89	0	0	0
90	0	0	0
91	0	0	0
92	0	0	0
93	0	0	0
94	0	0	0
95	0	0	0
96	0	0	0
97	0	0	0
98	0	0	0
99	0	0	0
100	0	0	0
101	0	0.369	0
102	0.173	0.049	0

Days	Sikatia Rainfall (mm)	Illambazar Rainfall (mm)	Ketugram Rainfall (mm)
103	0.245	2.734	0
104	0	0	0
105	0	0.363	0
106	0.038	5.796	0
107	12.421	2.828	13
108	0	0	0
109	0	0.211	0
110	0.057	0	0
111	0	4.339	0
112	1.266	0.988	0
113	1.06	1.151	0
114	7.2	5.965	5
115	0	5.382	0
116	10.597	6.304	2.5
117	0.254	0	0
118	0	1.128	0
119	0	0.535	0
120	0.307	0	9
121	12.501	5.275	22
122	0	5.058	0
123	2.023	0.199	0
124	1.4	0	0
125	3.57	0	0
126	0	0	0
127	0	0.142	0
128	0	4.736	0
129	4.51	0	0
130	0.082	0.473	0
131	0.388	0.24	5
132	6.679	0	11
133	0.291	0	0
134	0	0.665	0
135	2.67	0	5
136	2.584	0.314	0
137	2.263	0.127	0
138	1.125	8.701	0
139	14.582	0.2	6
140	0.735	1.545	0
141	20.646	8.49	25
142	0.374	0.288	0
143	39.906	20.205	12
144	29.44	8.544	18
145	8.434	0.24	0

Days	Sikatia Rainfall (mm)	Illambazar Rainfall (mm)	Ketugram Rainfall (mm)
146	0.451	0.14	0
147	0	7.143	0
148	1.955	0	0
149	10.579	3.513	7.1
150	21.998	0	4
151	0.887	0	0
152	6.001	0	9
153	0	0.257	0
154	3.975	20.078	0
155	3.601	9.983	0
156	2.2	0	0
157	6.242	0.981	0
158	5.652	18.308	0
159	26.306	21.745	6
160	2.321	2.243	0
161	6.687	1.756	0
162	0.568	2.252	4
163	2.782	6.663	2
164	2.153	8.406	0
165	11.804	2.09	22
166	0	3.594	0
167	21.768	13.554	0
168	2.13	0.372	0
169	1.244	3.789	0
170	5.905	2.714	0
171	12.139	6.482	8
172	4.783	4.758	5
173	1.24	6.918	10
174	5.271	24.517	0
175	0.78	44.519	0
176	7.368	10.781	0
177	4.832	6.361	23
178	7.294	17.835	0
179	18.415	2.513	0
180	0	0	0
181	0.903	0.337	0
182	0.802	0	0
183	0	0	0
184	0	0	0
185	0	0.133	0
186	0	0	0
187	0	2.98	0
188	0	11.224	0

Days	Sikatia Rainfall (mm)	Illambazar Rainfall (mm)	Ketugram Rainfall (mm)
189	1.218	0.466	0
190	0.628	3.108	0
191	1.421	0	0
192	15.157	12.419	11
193	6.018	19.712	0
194	12.602	11.624	6
195	2.772	9.016	3
196	14.244	22.998	9
197	26.851	31.829	15
198	5.677	15.641	0
199	22.324	13.286	0
200	1.059	3.083	0
201	28.905	16.268	18
202	0	17.036	0
203	2.704	58.431	0
204	34.728	14.154	10
205	83.257	46.24	58
206	75.762	5.509	94
207	30.587	34.371	42
208	21.776	10.571	0
209	1.927	3.111	0
210	2.456	3.774	0
211	1.052	9.494	0
212	3.09	4.14	0
213	0.464	0.915	0
214	9.715	30.406	5.7
215	14.751	2.785	0
216	6.217	1.091	2.5
217	0	0	0
218	0	0.082	0
219	0.056	0.577	0
220	1.353	2.321	0
221	9.303	3.248	5.8
222	8.784	20.011	22.5
223	3.403	6.845	0
224	1.204	3.598	0
225	6.928	4.889	2
226	4.934	0.034	0
227	0	9.811	0
228	0.458	20.274	11
229	13.749	28.371	0
230	3.655	2.738	0
231	1.37	3.404	0

Days	Sikatia Rainfall (mm)	Illambazar Rainfall (mm)	Ketugram Rainfall (mm)
232	0	3.387	0
233	0.924	1.225	0
234	4.841	5.393	8
235	0.901	0.422	0
236	0.128	0	0
237	0.062	0	0
238	0	0.124	0
239	0	0	0
240	2.298	0.888	0
241	1.628	0.396	11.7
242	0.364	0.562	0
243	6.592	8.326	9.4
244	42.074	28.592	42.74
245	21.453	39.609	16
246	12.132	61.134	5.3
247	2.251	5.817	0
248	2.382	0.362	0
249	3.859	0.832	0
250	0.042	0.07	6.1
251	1.154	2.001	0
252	1.583	5.923	0
253	3.419	14.077	47.2
254	1.385	12.794	3
255	1.082	2.172	0
256	0.248	0	0
257	0	0	0
258	24.236	20.1	9.9
259	2.6	3.106	5
260	2.077	0.973	0
261	0.044	12.995	0
262	53.724	155.718	52.2
263	183.27	85.191	160.32
264	141.034	140.804	136.42
265	65.128	285.217	44.17
266	31.95	52.909	30.05
267	27.112	19.332	0
268	0.384	12.913	0
269	0.06	5.864	0
270	0	4.527	0
271	0	0	0
272	0	0	0
273	0	0	0
274	0	0	0

Days	Sikatia Rainfall (mm)	Illambazar Rainfall (mm)	Ketugram Rainfall (mm)
275	0	2.188	1.8
276	0.506	5.166	0
277	0	4.557	0
278	3.849	4.046	0
279	1.339	0	0
280	0.846	3.112	0
281	0	1.223	0
282	0	0.755	0
283	0	0	0
284	0	1.265	0
285	1.585	0.781	0
286	0	0	0
287	0.596	0	0
288	0	0	0
289	0	0	0
290	0.355	0	0
291	0.473	0	0
292	0.288	1.135	0
293	0	0	0
294	0	0	0
295	0.025	0	0
296	0.571	0	0
297	0	0	0
298	0	0	0
299	0	0	0
300	0.064	0	0
301	0	0	0
302	3.325	0	0
303	0.914	0	0
304	0	0	2
305	0	0	0
306	0	0	0
307	1.41	0	0
308	0	0	0
309	0	0	0
310	0	0	0
311	0	0	0
312	0	0	0
313	0	0	0
314	0	0	0
315	0	0	0
316	0	0	0
317	0	0	0

Days	Sikatia Rainfall (mm)	Illambazar Rainfall (mm)	Ketugram Rainfall (mm)
318	0	0	0
319	0	0	0
320	0	0	0
321	0	0	0
322	0	0	0
323	0	0	0
324	0	0	0
325	0	0	0
326	0	0	0
327	0	0	0
328	0	0	0
329	0	0	0
330	0	0	0
331	0	0	0
332	0	0	0
333	0	0	0
334	0	0	0
335	0	0	0
336	0	0	0
337	0	0	0
338	0	0	0
339	0	0	0
340	0	0	0
341	0	0	0
342	0	0	0
343	0	0	0
344	0	0	0
345	0	0	0
346	0	0	0
347	0	0	0
348	0	0	0
349	0	0	0
350	0	0	0
351	0	0	0
352	0	0	0
353	0	0	0
354	0	0	0
355	0	0	0
356	0	0	0
357	0	0	0
358	0	0	0
359	0	0	0
360	0	0	0

Days	Sikatia Rainfall (mm)	Illambazar Rainfall (mm)	Ketugram Rainfall (mm)
361	0	0	0
362	0	0	0
363	0	0	0
364	0	0	0
365	0	0	0
366	0	0	0

(Source-Rainfall grid data, IMD)

Appendix F: Points for validation of flood result

Sl. no	X	Y
1	88.102	23.719
2	88.113	23.698
3	88.115	23.676
4	88.095	23.671
5	88.073	23.670
6	88.055	23.686
7	88.037	23.650
8	88.037	23.675
9	88.016	23.682
10	88.004	23.687
11	87.990	23.697
12	88.094	23.688
13	88.058	23.661
14	88.074	23.713
15	87.703	23.514
16	87.704	23.533
17	87.716	23.511
18	87.761	23.524
19	87.748	23.546
20	87.692	23.511
21	87.670	23.512
22	87.670	23.536
23	87.670	23.536
24	87.649	23.539
25	87.640	23.540
26	87.629	23.538
27	87.661	23.562
28	87.674	23.561
29	87.703	23.558
30	87.700	23.572
31	87.728	23.569
32	87.675	23.579
33	87.710	23.492
34	87.685	23.528
35	87.801	23.520
36	87.791	23.668
37	87.872	23.667

Sl. no	X	Y
38	87.749	23.651
39	87.742	23.623
40	87.660	23.617
41	87.678	23.612
42	87.637	23.613
43	87.943	23.660
44	87.922	23.658
45	87.898	23.667
46	87.733	23.554
47	87.645	23.600
48	87.646	23.557
49	87.662	23.588
50	87.647	23.573
51	87.671	23.603
52	87.719	23.453
53	87.752	23.463
54	87.713	23.609
55	87.716	23.639
56	87.789	23.613
57	87.658	23.487
58	87.964	23.659
59	87.954	23.693
60	87.927	23.682
61	87.950	23.716
62	87.995	23.659
63	88.023	23.726
64	88.056	23.732
65	88.143	23.713
66	88.056	23.633
67	88.037	23.626
68	88.015	23.641
69	87.983	23.629
70	88.095	23.641
71	88.113	23.648
72	88.110	23.664
73	88.041	23.711
74	87.987	23.726
75	88.003	23.617
76	88.016	23.663
77	87.757	23.604
78	87.780	23.584
79	87.766	23.571
80	87.773	23.544
81	87.771	23.528
82	87.724	23.537
83	87.719	23.581
84	87.688	23.631
85	88.075	23.642

(Source-GPS points collected from field)

Appendix G: Flood depth data collection by field visit for the validation of simulation result

GPS co-ordinate	Flood depth in metre
$87^0 59' 54''$ $23^0 38' 37''$	1.5-2
$88^0 2' 30''$ $23^0 37' 48''$	1.5-2
$88^0 3' 20''$ $23^0 37' 25''$	1.5-2
$88^0 8' 50''$ $23^0 44' 8''$	2
$88^0 7' 11''$ $23^0 41' 13''$	1.5
$87^0 45' 11''$ $23^0 40' 16''$	1
$87^0 48' 9''$ $23^0 40' 8''$	1
$87^0 43' 44''$ $23^0 37' 20''$	<1
$87^0 42' 16''$ $23^0 34' 45''$	1
$87^0 49' 40''$ $23^0 38' 45''$	1.25
$87^0 45' 19''$ $23^0 37' 23''$	1
$87^0 48' 12''$ $23^0 37' 27''$	1
$88^0 4' 18''$ $23^0 40' 2''$	1.5-2
$88^0 7' 9''$ $23^0 40' 2''$	1.5-2
$88^0 7' 21''$ $23^0 42' 43''$	2
$88^0 1' 22''$ $23^0 34' 45''$	1
$87^0 51' 27''$ $23^0 38' 43''$	0.5-1
$87^0 45' 19''$ $23^0 37' 23''$	1
$87^0 48' 12''$ $23^0 37' 27''$	1
$87^0 46' 29''$ $23^0 36' 8''$	1

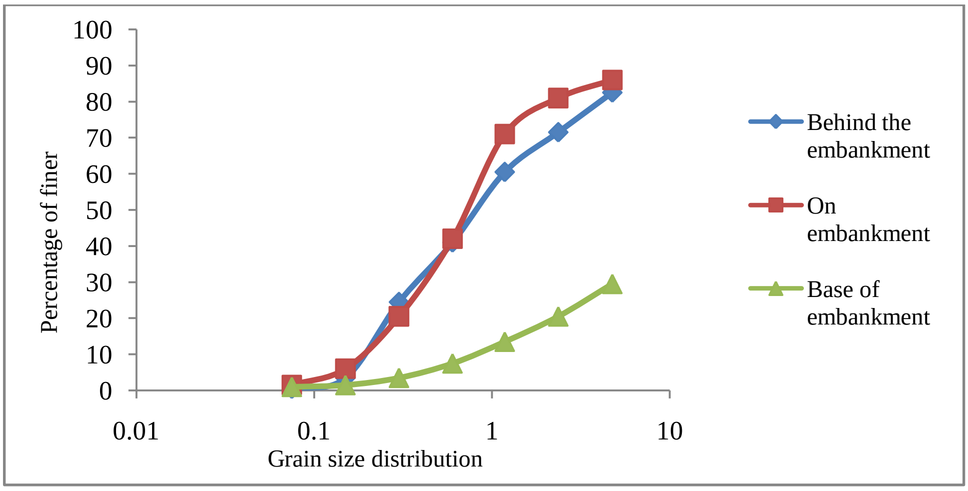
(Source-GPS points collected from field)

Appendix H: Table for calculation of ranking according to vulnerability from different expert opinion

Factors	Expert opinions										
Occupation	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10	Avg. score	Rank
Agricultural labour	8	9	8	9	8	8	9	10	9	9	8.7	1
Cultivators	7	8	7	9	7	9	8	9	10	8	8.2	2
Others	5	6	6	7	5	6	7	5	6	6	5.9	3
Land use land cover	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10	Avg. score	Rank
Agricultural land	9	8	8	9	8	8	8	9	8	9	8.4	2
Settlement	8	10	9	8	8	9	9	9	10	8	8.8	1
Others	7	8	7	6	5	7	6	7	6	5	6.4	3
Demographic structure	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10	Avg. score	Rank
Child	10	9	9	10	9	10	10	9	9	10	9.5	1
Female	9	8	8	9	8	9	8	8	7	8	8.2	2
Others	7	6	7	8	7	7	6	7	6	7	6.8	3
Working status	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10	Avg. score	Rank
Unemployed	10	9	9	9	10	9	8	9	9	9	9.1	1
Marginal worker	8	8	8	8	8	7	6	6	7	8	7.4	2
Other	7	7	6	6	6	6	4	5	6	6	5.9	3

(Source-Calculation done by researcher based on expert opinions)

Appendix I: Graphical presentation of grain size distribution



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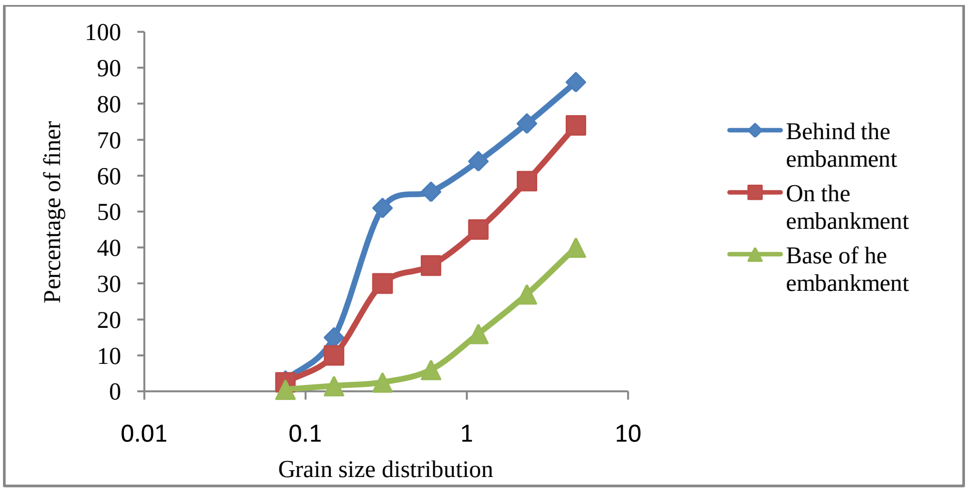

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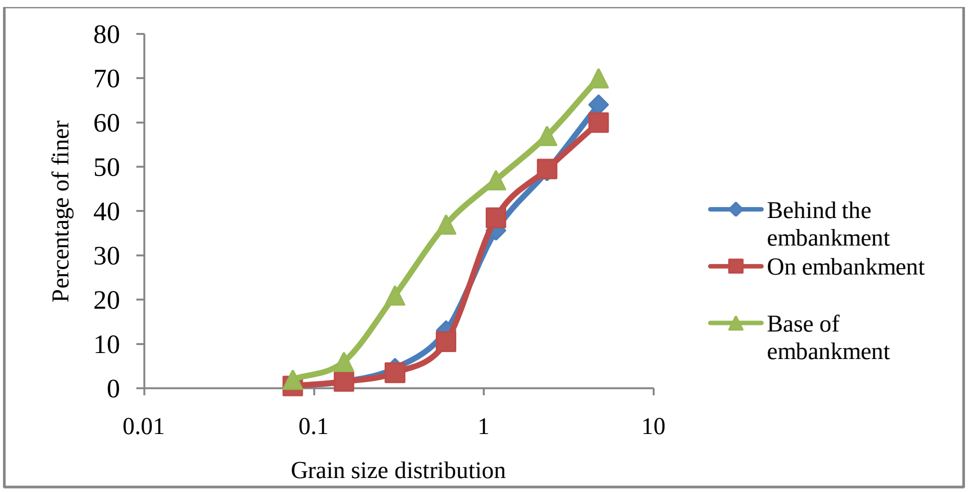

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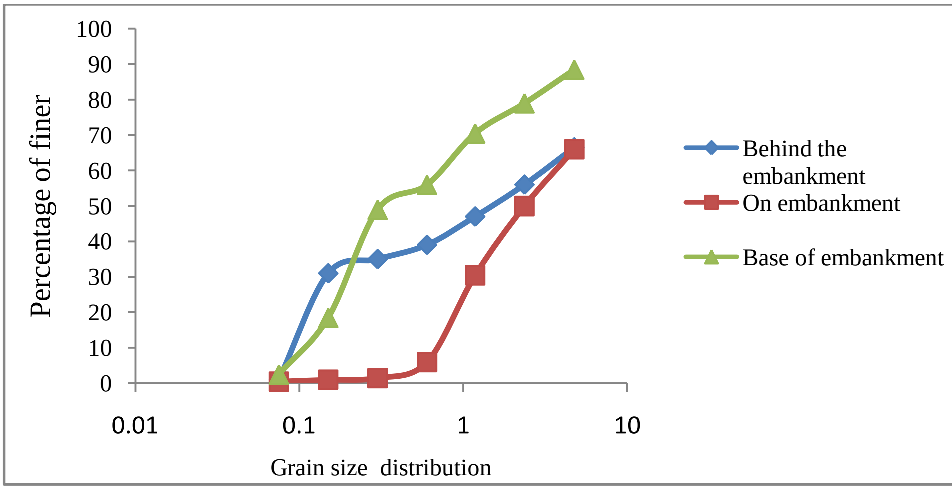

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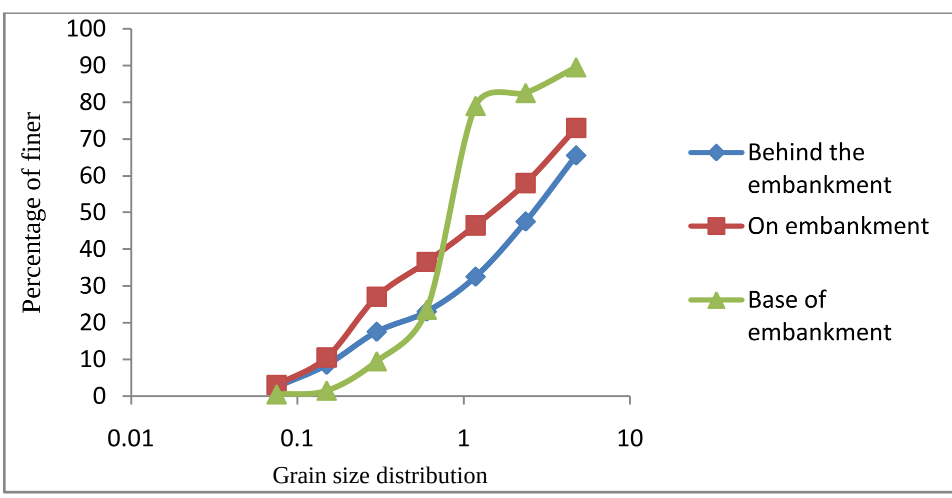
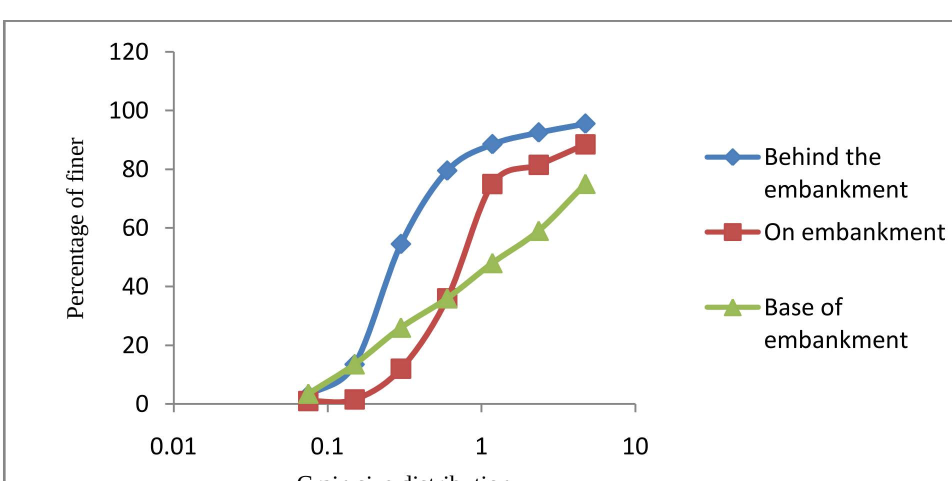
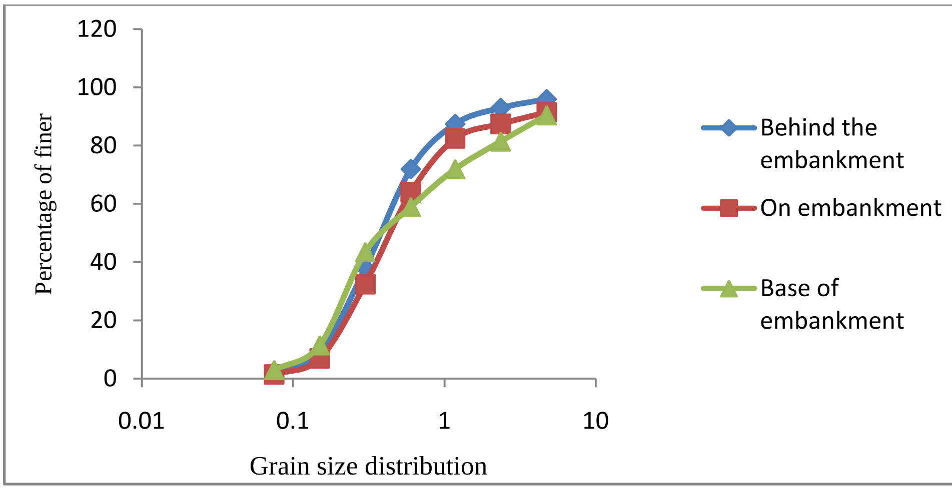


Nelegarh left



Nelegarh right



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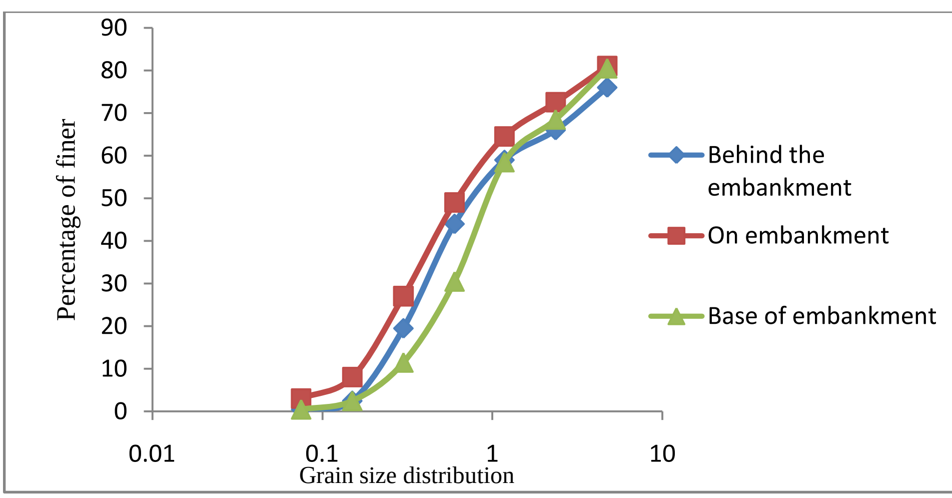

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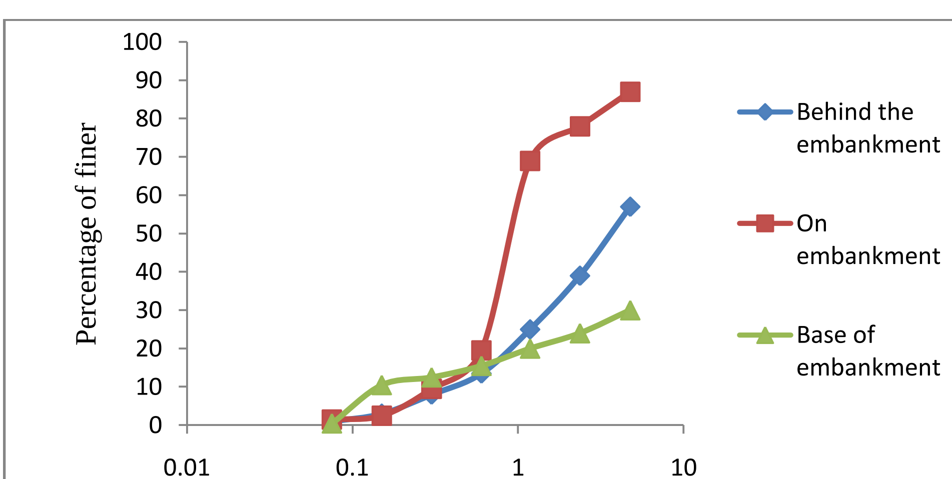

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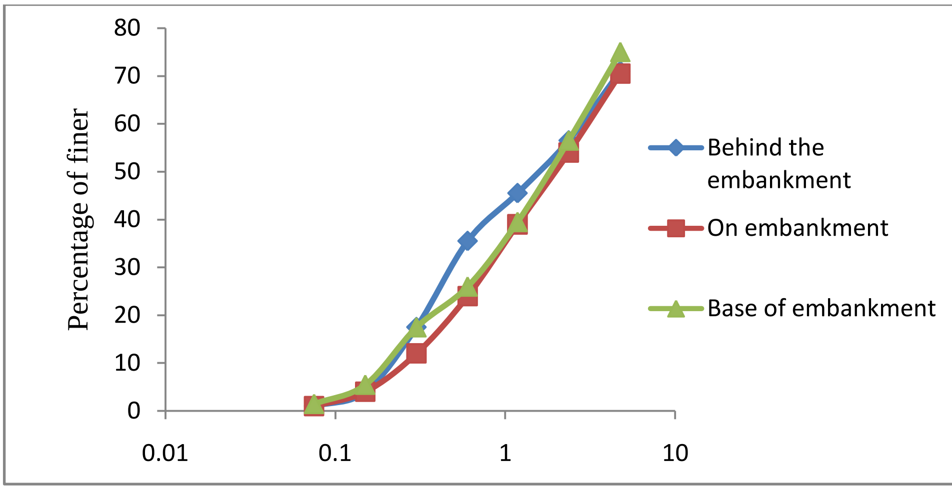

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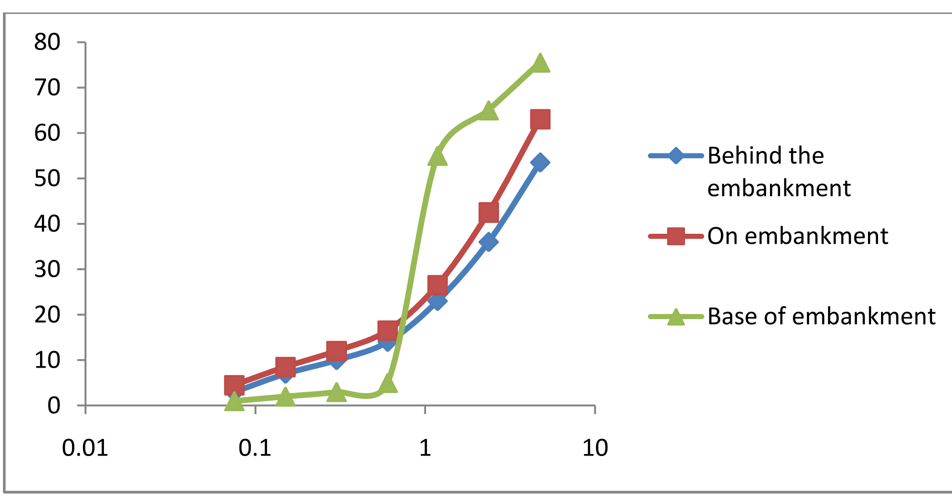
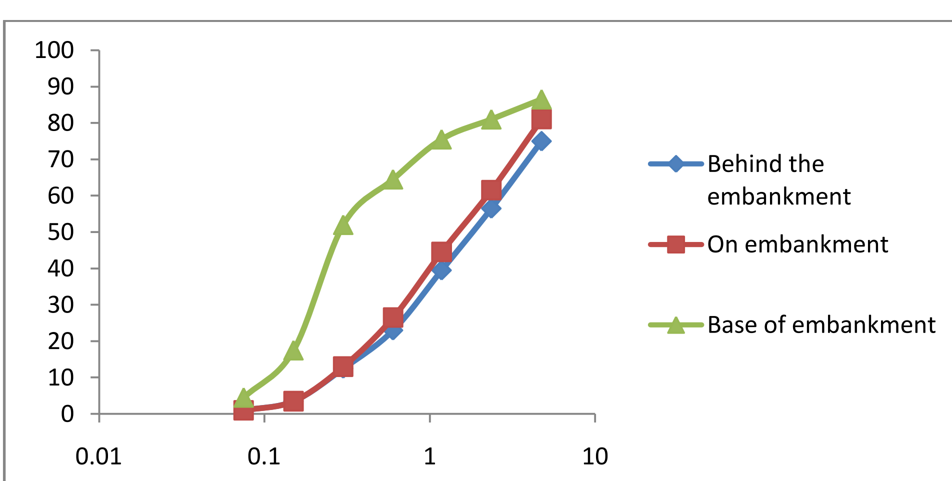


Sakai



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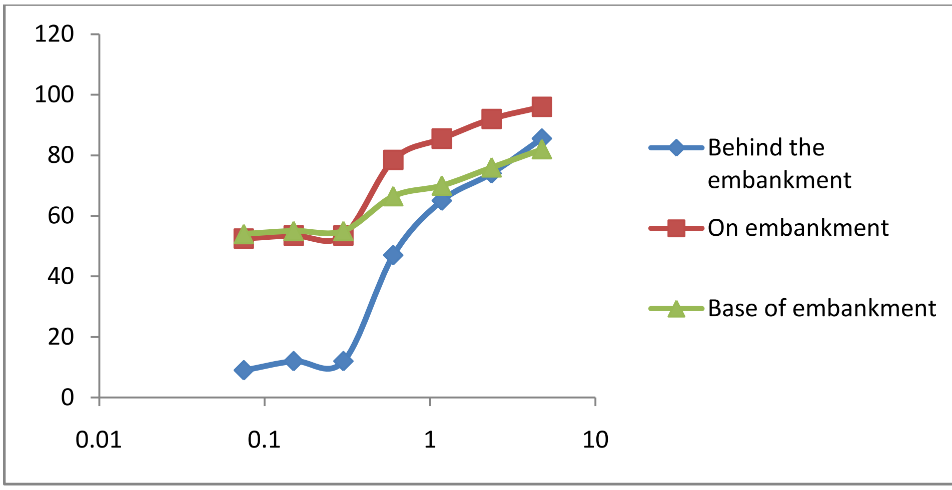

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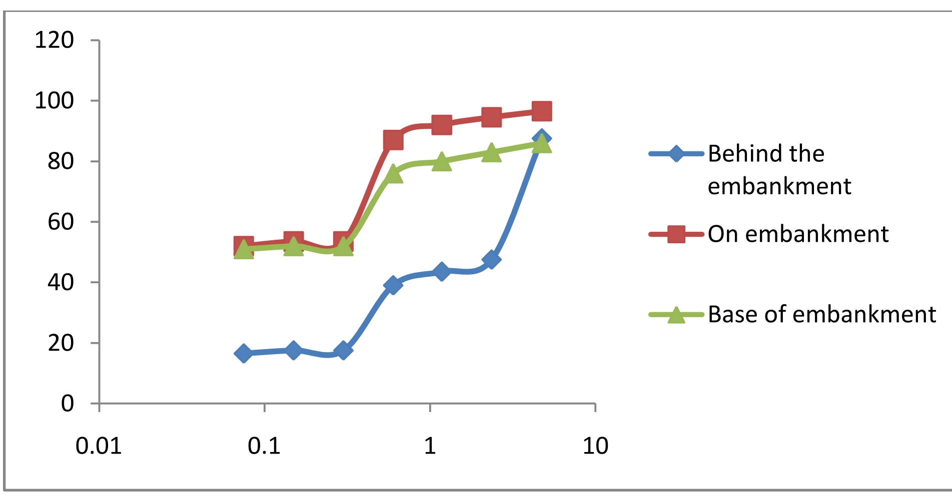

Kheyarbani right

Appendix J: Field photograph

Data collection from Irrigation office Katwa

Data collection from stakeholders

Gauge station in Bhedia

Gauge reading in Budra gauging station

Channel restoration and sand mining

Sand mining

ASSESSMENT OF FLOOD VULNERABILITY OF LOWER AJAY BASIN AND ITS SUSTAINABLE MANAGEMENT SOLUTION

By Kartick Chandra Mondal

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DR. SUTAPA SAHA
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DEPARTMENT OF GEOGRAPHY
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