



Survey-Based Assessment of Fluvial Geomorphological Dynamics and Livelihood Vulnerability Along the Ganga River Corridor in Prayagraj city, Uttar Pradesh

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Abstract

This study examines how fluvial geomorphological dynamics influence the livelihood vulnerability of river-dependent communities residing along the Ganga floodplain in Prayagraj, Uttar Pradesh. It investigates the socio-economic and environmental consequences of recurring floods, riverbank erosion, sediment accumulation, channel migration, and environmental degradation on households whose livelihoods are closely linked to the river. These communities rely on a range of activities, including agriculture, fishing, tourism, wage labour, and other informal occupations. A household survey was carried out using a proportionate stratified random sampling approach across 33 riparian wards, covering 384 households. The findings suggest that repeated flood events, increasing environmental pollution, the erosion of traditional river-based livelihoods, and rising socio-economic insecurity have significantly affected both livelihood stability and the sustainability of settlements within the floodplain. To understand the extent of vulnerability and the strategies adopted by communities to cope with these challenges, the study employed several statistical techniques, including descriptive statistics, coefficient of variation, Z-score analysis, vulnerability categorisation, and principal component analysis. The analysis identifies flood exposure, poverty, and health-related concerns as the major factors contributing to livelihood vulnerability. In response to these challenges, many households have adopted livelihood diversification and seasonal migration as key adaptation strategies to reduce risks and improve their resilience. The study emphasizes the importance of integrated floodplain management, stronger measures to control river pollution, sustainable urban planning, and community-centred resilience-building initiatives. Such interventions are vital for enhancing environmental sustainability, strengthening the adaptive capacity of local communities, and promoting long-term socio-economic stability for people living along the Ganga floodplain in Prayagraj.

Keywords

Fluvial Geomorphology, Livelihood Vulnerability, Riverbank Erosion, Floodplain Communities, Resilience and Adaptation Strategies.



1. Introduction

Fluvial geomorphology is the study of how flowing water shapes the Earth's surface through processes such as erosion, transportation, and deposition. Rivers are dynamic systems that constantly adjust their form and behaviour in response to changes in water discharge, sediment load, channel slope, and human activities (Gregory & Walling, 1973; Schumm, 1977). As one of the world's largest alluvial rivers, the River Ganga displays a wide range of geomorphological features, including meandering channels, active floodplains, channel migration, bank erosion, and sediment deposition. These processes not only influence the physical landscape but also have profound implications for the livelihoods and well-being of communities living along the river corridor (Sinha & Friend, 1994).

The Ganga's riparian zone supports millions of people who depend on agriculture, fisheries, livestock rearing, and other river-based activities for their survival. At the same time, the river's dynamic nature creates recurring hazards such as flooding, riverbank erosion, channel shifting, and sedimentation. These hazards often damage agricultural land, settlements, and infrastructure, thereby threatening livelihood security and increasing vulnerability among riverine populations (Singh, 2014). As a result, understanding the relationship between fluvial processes and livelihood vulnerability has become increasingly important for sustainable river management and regional development.

The foundations of fluvial geomorphology were laid by Gregory and Walling (1973), who highlighted the role of hydrological processes and drainage basin characteristics in shaping river systems. Schumm (1977) further demonstrated that channel instability and river metamorphosis are major drivers of landscape evolution and floodplain development. Earlier, Leopold and Wolman (1957) showed that river channel patterns are determined by the interaction of discharge, sediment load, and channel slope, while Leopold, Wolman, and Miller (1964) emphasized that fluvial processes operate across a range of spatial and temporal scales. Building on these ideas, Knighton (1998) argued that rivers are constantly adjusting to changing environmental conditions, making them inherently dynamic and ever-evolving systems.

Over time, fluvial geomorphology has developed into a multidisciplinary field that explores the interactions between river processes, environmental change, and human activities. According to Bridge (2003), river channels continuously modify their morphology in response to changes in hydrological and sediment regimes, making them highly sensitive to both natural and human-induced disturbances. This perspective has become particularly relevant in densely populated and rapidly urbanizing river basins, where human interventions increasingly influence river behaviour.

Urbanization is now recognized as one of the major drivers of geomorphic change in river systems. The expansion of built-up areas alters natural drainage patterns, increases surface runoff, reduces groundwater recharge, and often accelerates channel instability, thereby increasing the likelihood of floods and environmental degradation (Gregory, 2006). Chin (2006) observed that urban rivers frequently experience channel incision, bank erosion, and altered sediment transport due to intensive human modifications. Such changes not only transform river morphology but also expose urban populations to greater environmental risks.



Within the Ganga Basin, channel migration, sediment transport, and floodplain evolution have played a crucial role in shaping the geomorphology of the Indo-Gangetic Plains (Sinha & Friend, 1994). Their work demonstrated the sensitivity of the basin to fluctuations in water flow and sediment dynamics. Subsequent studies have shown that human interventions, including embankments, barrages, urban expansion, and land-use changes, have accelerated geomorphic transformations throughout the river system (Chakraborty, 2002).

The Farakka region represents one of the most significant examples of human-induced changes in the Ganga's morphology. The construction of the Farakka Barrage altered flow patterns, sediment deposition, and bank stability, leading to substantial adjustments in channel morphology (Chakraborty, 2002). Research has indicated that changes in flow regulation and sediment transport have intensified bank erosion and channel migration in several stretches of the river, producing far-reaching environmental and socio-economic consequences (Thakur et al., 2011).

Among the various geomorphic hazards associated with the Ganga, riverbank erosion remains one of the most serious. Using Remote Sensing and GIS techniques, Thakur et al. (2011) documented significant channel migration and erosion upstream of the Farakka Barrage, resulting in extensive losses of agricultural land and increased vulnerability of nearby settlements. Similar trends have been observed elsewhere in the Ganga floodplain, where recurring erosion events contribute to displacement, loss of productive land, and declining livelihood opportunities (Singh, 2014).

The impacts of fluvial hazards extend beyond physical changes to the landscape. Structural measures such as dams, embankments, and channelization often disrupt natural river processes and generate unintended ecological and geomorphic consequences (Pinter, 2005). Wohl (2014) argued that such modifications can reduce ecological resilience, degrade aquatic habitats, interrupt sediment connectivity, and diminish the ecosystem services provided by floodplains and riparian environments. Consequently, environmental degradation can further increase the vulnerability of communities that depend on river ecosystems for their livelihoods.

The socio-economic consequences of fluvial hazards have received considerable attention in recent years. Flooding, bank erosion, and channel shifting frequently damage agricultural land, transportation networks, public infrastructure, and settlements, resulting in substantial economic losses (Singh, 2014). Recurrent flood and erosion events often force households to relocate, leading to displacement, landlessness, unemployment, and long-term livelihood insecurity. Douglas et al. (2008) noted that flooding in urban river landscapes can disrupt economic activities, damage critical infrastructure, and create serious public health challenges. These impacts are often most severe among marginalized communities with limited resources and restricted access to institutional support.

Scholars have increasingly emphasized that vulnerability to fluvial hazards is shaped not only by physical exposure but also by social, economic, and political conditions. Blaikie et al. (1994) argued that vulnerability emerges from the interaction between environmental hazards and the social structures that influence people's ability to cope and adapt. Similarly, Adger (2006) highlighted that socio-economic inequalities often make poorer and marginalized populations disproportionately vulnerable to environmental risks and disasters.



To better understand these complex relationships, recent studies have adopted vulnerability assessment frameworks that integrate physical and social dimensions of risk. Cutter, Boruff, and Shirley (2003) developed the Social Vulnerability Index (SoVI), which measures community susceptibility to environmental hazards using socio-economic indicators. Turner et al. (2003) proposed a coupled human–environment framework that links environmental processes with social vulnerability in the context of sustainability. More recently, Sultana (2024) emphasized that livelihood vulnerability in riverbank environments is determined by a combination of physical exposure, socio-economic conditions, adaptive capacity, and institutional support. These approaches underscore the importance of examining geomorphological processes alongside social and economic factors.

Despite substantial progress in understanding the geomorphology of the Ganga and the hazards associated with it, much of the existing research has treated physical and socio-economic dimensions separately. Relatively few studies have explored the direct linkages between fluvial geomorphic processes and livelihood vulnerability within a single analytical framework (Sultana, 2024). Furthermore, limited attention has been given to how channel dynamics, bank erosion, floodplain transformation, and urban expansion collectively contribute to environmental, social, and economic vulnerabilities in riverine landscapes. Therefore, an integrated investigation of channel dynamics, bank erosion, floodplain changes, and their effects on livelihood systems is essential for developing sustainable river management strategies, reducing disaster risks, and strengthening the resilience of communities living along the River Ganga (Wohl, 2014; Sultana, 2024).

2. Study Area Profile

The present study was conducted in the Ganga floodplain region of Prayagraj, located in the southern part of Uttar Pradesh, India. The city occupies a unique geographical position at the confluence of the Rivers Ganga and Yamuna, popularly known as the Sangam, which holds immense religious, cultural, and historical importance. The study covers 33 riparian wards and riverbank settlements, including Daraganj, Arail, Shivkuti, Rajapur, Jhunsi, and Phaphamau, where a large section of the population depends directly or indirectly on river-based activities such as agriculture, fishing, boating, tourism, and daily wage labour for their livelihoods.

The geomorphological setting of the region is highly dynamic, as it is continuously shaped by fluvial processes such as flooding, riverbank erosion, sediment deposition, and channel migration. These processes play a significant role in influencing both the physical landscape and the livelihoods of communities living along the riverbanks. In recent decades, rapid urban growth, increasing encroachment on floodplain areas, and the discharge of untreated domestic and industrial waste into the river system have further intensified environmental pressures within the region. Such changes have contributed to the degradation of riverine ecosystems and heightened the vulnerability of local communities to flood-related hazards.

Seasonal monsoon floods are a recurring feature of the area and often result in damage to agricultural land, settlements, infrastructure, and public utilities. These flood events not only threaten livelihood security but also affect public health, disrupt economic activities, and reduce the overall resilience of river-dependent households. Communities residing in low-lying floodplain areas are particularly vulnerable due to their greater exposure to flooding and limited adaptive resources.

Owing to its unique combination of active fluvial processes, expanding urbanization, environmental challenges, and dependence on river-based livelihoods, Prayagraj provides an ideal setting for examining the relationship between fluvial geomorphology and livelihood vulnerability. The study area offers important insights into how river dynamics interact with socio-economic and environmental factors, thereby influencing the resilience of local communities. Understanding these interactions is essential for developing sustainable floodplain management strategies and promoting a balance between urban development, ecological conservation, and community well-being in a rapidly changing riverine landscape.

3. Research Objectives

The present study aims to examine the impact of fluvial geomorphological processes, such as flooding, riverbank erosion, sediment deposition, and channel instability, on the livelihoods and socio-economic conditions of river-dependent communities in the Ganga riparian wards of Prayagraj City. These processes significantly influence livelihood security, settlement stability, and access to essential resources.

The study also seeks to assess the environmental and socio-economic vulnerabilities associated with poverty, migration, public health challenges, and the decline of traditional river-based occupations within the Ganga floodplain region. Furthermore, it aims to evaluate the adaptation and resilience strategies adopted by households in response to environmental stress, recurring flood hazards, and livelihood instability. The findings will contribute to a better understanding of the relationship between fluvial processes and community vulnerability in an urban riverine environment.

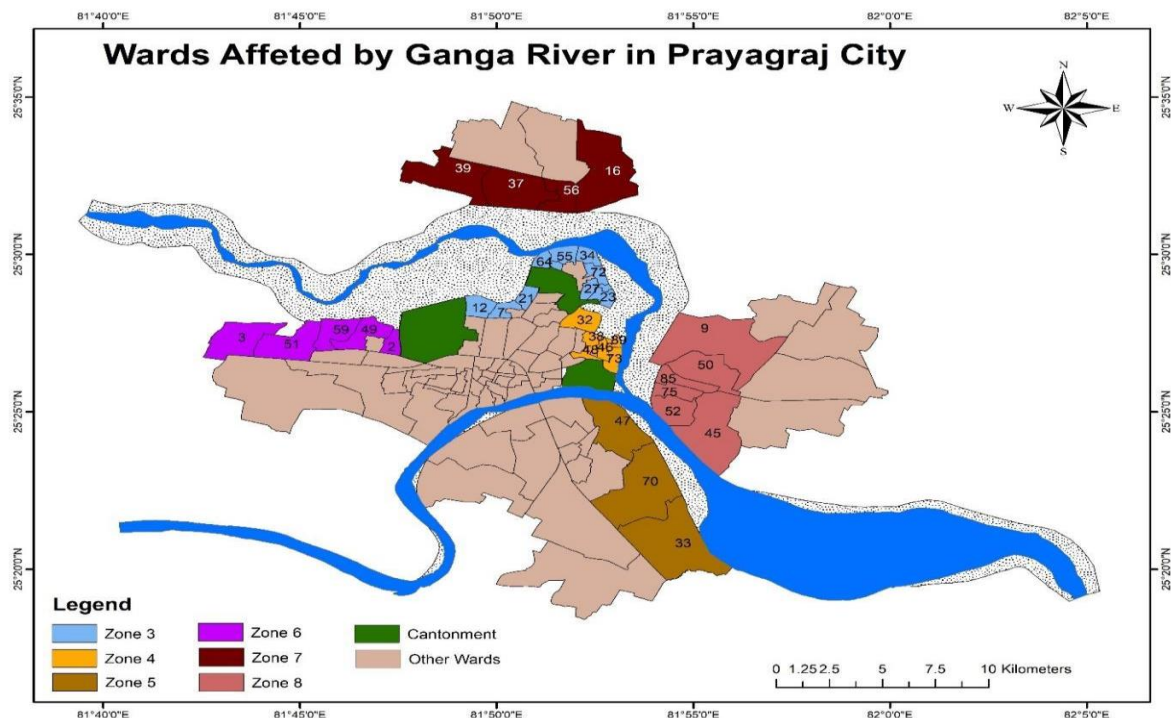


Figure 1: Wards affected by the Ganga River in Prayagraj City



4. Research Methodology

This study is based on primary data collected to assess the socio-economic and environmental impacts of fluvial changes on communities dependent on the River Ganga in Prayagraj. To ensure adequate representation of the study population, a proportionate stratified random sampling method was adopted for conducting household surveys across 33 riparian wards located along the river. The selected wards comprised a total of 106,380 households. The sample size was determined scientifically using the sample size estimation methods proposed by Yamane (1967) and Cochran (1977), considering a 95% confidence level and a 5% margin of error. Based on these calculations, 384 households were selected and surveyed proportionately from the identified wards (Cochran, 1977; Yamane, 1967).

The questionnaire-based household survey provided comprehensive information on various aspects of community life, including occupational structure, income levels, flood-related impacts, migration trends, environmental conditions, public health concerns, and local adaptation measures. Respondents represented a wide range of river-dependent groups, such as farming households, fishing communities, tourism-related workers, sand mining labourers, daily wage earners, and families involved in informal economic activities. To evaluate the socio-economic and environmental status of these communities, statistical tools such as descriptive statistics, coefficient of variation, Z-score analysis, and vulnerability classification were employed (Kothari, 2004; Singh & Singh, 2014).

In addition to the socio-economic survey, the study incorporated fluvial geomorphological analysis and environmental risk assessment to explore the complex relationship between river dynamics, urban expansion, and livelihood vulnerability within the Ganga floodplain of Prayagraj. Key geomorphological processes, including flooding, riverbank erosion, sediment deposition, and channel migration, were examined to understand their effects on settlement patterns, resource availability, and environmental risks faced by communities residing in the floodplain region (Knighton, 1998; Gregory & Walling, 1973).

4. Results and Discussion

4.1. River-Dependent Communities

The River Ganga has long served as the backbone of livelihood activities in Prayagraj, supporting thousands of people residing along its banks, floodplains, sand bars, and low-lying peri-urban areas. The livelihoods of these communities are closely intertwined with the river's seasonal flow regime, fertile floodplain soils, fisheries resources, sand extraction activities, and the thriving religious and tourism-based economy. However, over time, significant changes in the river's fluvial morphology—including channel migration, bank erosion, sand bar development, floodplain inundation, and sediment redistribution—have increasingly affected the livelihood security and socio-economic well-being of river-dependent populations.

To examine these impacts, a socio-economic and environmental household survey was undertaken across the Ganga riparian wards of Prayagraj. Given the variation in population size among the wards, a proportionate stratified random sampling technique was adopted to ensure adequate representation



of households from each ward. The study area comprised 33 riparian wards with a total household population of 106,380.

The required sample size was determined using the sample size estimation approaches proposed by Yamane (1967) and Cochran (1977). Considering a 95 percent confidence level, a 5 percent margin of error, and a 50 percent response distribution, the scientifically acceptable sample size for the survey was estimated to be approximately 384 households. The sample households were then distributed proportionately across the selected wards according to their share in the total household population.

The sample size for the household survey was calculated using the Yamane–Cochran adjusted formula:

$$n = \frac{N}{1 + N(e)^2}$$

Where, N= Total household population; e= margin of error and: n= required number of sample household

For the present study:

$$N = 106380e = 0.05$$

calculating the values, Recommended total sample size ≈ 384 households

The sample may then be distributed proportionately across wards as follows:

Table 1: Ward Wise Sample Households Surveyed

Zone	Ward Name	Total Households	Sample Households
6	Mundera	3606	13
6	Neem Sarai	3310	12
6	Bamrauli Uparhar	3311	12
6	Sulem Sarai	3268	12
6	Transport Nagar	3355	12
3	Mehdauri	3121	11
3	Ashok Nagar	2944	11
3	Rajapur	3251	12
3	Teliyarganj	2995	11
3	Shivkuti	3403	12
3	Govindpur	2901	10



3	Myorabad	3365	12
3	Salori	3055	11
3	Sadiyabad	3022	11
4	Allenganj	2914	10
4	Baghambari Housing Scheme	3313	12
4	Alopibagh	2948	11
4	Pura Padain	3173	11
4	Daraganj	3500	13
4	Bakshi Khurd	3485	13
5	Arail	3600	13
5	Mawaiya	3167	11
5	Lavayan	3520	13
8	Katka	3573	13
8	Sonauti	3152	11
8	Jhunsi Azad Nagar	2904	10
8	Jhunsi Kohana	3156	11
8	Haveliya	3147	11
8	Chhatnag	2704	10
7	Malak Harhar	3541	13
7	Shantipuram	2870	10
7	Phaphamau	3185	11
7	Bahmalpur	3621	13

The objective of the household survey was to assess the impacts of fluvial changes on river-dependent communities and to understand their effects on occupational structure, household income, population displacement, migration trends, public health conditions, and adaptation strategies adopted to cope with environmental and socio-economic challenges.

4.2. Nature of River-Dependent Livelihoods



The livelihoods of people living along the Ganga floodplain in Prayagraj are closely connected to the river and its resources. Fertile soils, water availability, fish resources, sand deposits, and the religious importance of the Sangam create a range of livelihood opportunities. However, the survey indicates that not all households depend directly on the river, as many have shifted towards wage labour and other occupations.

Table 2: Survey Profile of River-Dependent Households

Category	Number of Households	Percentage
Agriculture-dependent households	58	15
Fishing-dependent households	38	10
Boatmen and tourism-related households	27	7
Sand mining/labour households	15	4
Wage labour and informal work	134	35
Other occupations	112	29
Total	384	100%

As shown in Table 2, the largest share of households (**35%**) is engaged in wage labour and informal work, while **29%** depend on other occupations. Traditional river-based livelihoods account for about **36%** of the surveyed households, including agriculture (**15%**), fishing (**10%**), boating and tourism (**7%**), and sand mining (**4%**).

Agriculture-Based Livelihoods

Agriculture remains an important source of income for many families because the floodplain soils are highly fertile and suitable for crops such as wheat, paddy, vegetables, and pulses. Among the **58 agricultural households**, more than half (**51%**) reported that their farmland had been affected by floods, sand deposition, or riverbank erosion during the last decade. This highlights both the benefits and challenges of farming in the floodplain.

Fishing Communities



Fishing continues to be a traditional occupation for some households. Of the **38 fishing households** surveyed, nearly two-thirds (**64%**) reported a decline in fish catches. Respondents linked this decline to pollution, siltation, reduced water flow during the lean season, and disturbances to fish habitats.

Boat Transport and Tourism

The religious significance of Prayagraj, particularly the Sangam, provides livelihood opportunities for boatmen and other tourism-related workers. The **27 households** engaged in this sector earn higher incomes during events such as Magh Mela and Kumbh Mela. However, their earnings are seasonal and often decrease during floods when boating activities are restricted for safety reasons.

Sand Mining and Labour

Sand mining supports a small number of households (**4%**) and provides employment mainly to economically weaker sections of society. While it offers an important source of income, excessive extraction can negatively affect riverbanks and the overall river environment.

Overall, the findings suggest that livelihoods in the Ganga floodplain are becoming more diverse. Although agriculture, fishing, boating, and sand mining continue to support many households, a larger proportion of families now depend on wage labour and other occupations. Even so, changes in the river environment—such as floods, erosion, pollution, and siltation—continue to influence the livelihoods and well-being of river-dependent communities.

4.3 Flood and Erosion-Induced Livelihood Disruptions

The livelihoods of people living along the Ganga floodplain in Prayagraj are strongly influenced by the river's dynamic nature. Flooding and riverbank erosion are the two most common fluvial processes affecting local communities. While floods usually cause temporary disruptions to farming, fishing, transport, and daily wage activities, riverbank erosion often leads to permanent loss of agricultural land and property. As a result, these processes have significant social and economic consequences for households dependent on river resources.

Table 3: Impact of Fluvial Change on Agricultural Households

Type of Impact	Percentage of Agricultural Households Affected
Seasonal crop damage due to floods	48.8%



Sand deposition on agricultural land	51.2%
Partial land loss due to erosion	45.0%
Decline in soil productivity	34.0%
Temporary loss of access to fields	53.7%

The survey findings show that agricultural households face several challenges linked to river processes. More than half of the respondents (**53.7%**) reported temporary difficulty in accessing their fields during or after floods. Similarly, **51.2%** experienced sand deposition on farmland, which often reduces the suitability of land for cultivation. Nearly half (**48.8%**) suffered crop damage due to flooding, while **45%** reported partial loss of land caused by riverbank erosion. A further **34%** observed a decline in soil productivity, indicating that the impacts of flooding can continue even after floodwaters recede.

Overall, **67% of surveyed households** stated that floods had affected their livelihoods at least once during the previous five years. Among them, **41%** experienced moderate economic losses, whereas **19%** reported severe losses. This suggests that flood-related impacts are widespread and recurrent in the riverine areas of Prayagraj.

Table 4: Flood-Related Livelihood Losses in the Last 10 Years

Type of Loss	Percentage of Households Reporting Loss
Crop damage	53.0%
Loss of wage work during flood period	65.0%
Damage to house or temporary shelter	61.0%



Loss of fishing days	41.5%
Damage to boats, nets, and equipment	36.0%
Loss of livestock/fodder	46.0%
Debt taken after flood	41.5%

The effects of floods extend far beyond damage to crops and farmland. As shown in Table 4, the most common impact reported by households was the **loss of wage employment during flood periods (65%)**, reflecting the disruption of daily economic activities. **Damage to houses and temporary shelters (61%)** and **crop losses (53%)** were also widely reported. In addition, floods affected fishing activities, livestock resources, and household equipment. Importantly, **41.5%** of households had to take loans or borrow money after flood events, highlighting the financial difficulties faced during recovery.

Agricultural Land Loss and Crop Damage

Riverbank erosion remains a major concern for farming communities. As the river gradually shifts its course, portions of agricultural land are lost along the banks, reducing the area available for cultivation. Even when the loss is small each year, its cumulative effect can significantly affect household livelihoods.

Floods also damage standing crops, particularly paddy, vegetables, and fodder crops grown in low-lying areas of the floodplain. Prolonged waterlogging and the deposition of sand often lower agricultural productivity and increase cultivation costs. The findings indicate that floods and erosion not only cause immediate physical damage but also create longer-term challenges such as income loss, indebtedness, and livelihood insecurity for river-dependent households.

4.4. Socio-Economic Vulnerability

The impacts of floods and riverbank erosion are not experienced equally by all households. Vulnerability is often influenced by social and economic conditions such as income level, housing quality, land ownership, and access to basic services. Households with limited resources often find it more difficult to recover from flood-related losses and environmental changes.

The survey revealed that a significant proportion of households faced economic insecurity. About **58.8%** reported seasonal unemployment, while **40.5%** lacked secure land ownership. Poor housing



conditions and limited access to sanitation further increased the vulnerability of many families living in riverine areas.

Table 5: Socio-Economic Vulnerability Indicators

Indicator	Survey Result
Households earning below ₹10,000 per month	17.0%
Households without secure land ownership	40.5%
Households living in kutcha/semi-pucca houses	31.7%
Households with seasonal unemployment	58.8%
Households taking loans after flood events	31.0%
Households reporting poor access to sanitation	53.7%
Women reporting increased burden during floods	70.7%

The data suggest that environmental hazards often interact with existing social and economic disadvantages. For example, households with unstable incomes, insecure housing, and limited savings are less able to cope with the impacts of floods and erosion. In contrast, households with secure land ownership, better housing, and regular income sources are generally more resilient to such disturbances.

Gender Dimensions of Vulnerability



Women often experience the effects of floods differently from men. During flood events, their household responsibilities tend to increase as they manage water collection, food preparation, childcare, and the protection of household belongings. Access to sanitation also becomes more difficult, particularly when families are displaced or living in temporary shelters.

The survey findings highlight this additional burden, with **70.7% of women respondents** reporting that flood conditions increased their workload and responsibilities. Many women also reported concerns related to privacy, safety, and sanitation during periods of displacement. These findings demonstrate that the impacts of riverine hazards extend beyond economic losses and have important social and gender dimensions that need to be considered in vulnerability assessments and disaster management planning.

The results indicate that vulnerability in Prayagraj's riverine communities is shaped by a combination of environmental exposure and socio-economic conditions. Factors such as insecure land tenure, seasonal unemployment, inadequate housing, poor sanitation, and gender-based responsibilities increase the risks faced by households during floods and erosion events. Therefore, efforts to reduce vulnerability should address both physical hazards and underlying social inequalities.

4.6. Migration and Settlement Transformation

Changes in the course and behaviour of the river have a noticeable impact on both migration and settlement patterns in Prayagraj. Flooding, riverbank erosion, and the decline of traditional river-based livelihoods often force households to look for alternative ways of sustaining their income. For many families, migration becomes an important response to environmental and economic challenges.

The survey shows that mobility is a common coping mechanism among riverine households. Many families send one or more members to nearby towns and cities for seasonal work, particularly in construction, transport, vending, and other informal sectors. Temporary relocation is also common during flood periods when homes and agricultural lands become inaccessible.

Table 6: Migration Pattern among Surveyed Households

Migration Type	Percentage of Households
Seasonal migration for wage labour	53.7%
Temporary relocation during floods	65.9%



Permanent relocation due to erosion	26.0%
Rural-to-urban movement	27.0%
No migration reported	31.0%

The data indicate that **temporary relocation during floods (65.9%)** is the most frequently reported form of movement among surveyed households. More than half (**53.7%**) reported seasonal migration for employment, while **27%** had experienced rural-to-urban migration in search of better livelihood opportunities. In addition, **26%** of households reported permanent relocation due to riverbank erosion. However, nearly one-third (**31%**) of respondents reported no migration, suggesting that many families continue to remain connected to their traditional settlements despite recurring environmental risks.

These findings highlight that migration is not simply a response to environmental hazards but also a strategy for maintaining household income and reducing livelihood insecurity. At the same time, strong social ties, cultural attachment to the river, and dependence on river-related occupations often discourage permanent migration.

Settlement Transformation

The recurring effects of floods and erosion have gradually altered settlement patterns across the floodplain. Many households have adapted by constructing houses on relatively higher ground or relocating to areas that are perceived as less vulnerable to flooding. Others have moved closer to roads, embankments, or the outskirts of urban areas where access to services and employment opportunities is better.

Field observations suggest that these movements have contributed to the expansion of informal settlements in safer and more accessible locations. Such areas often attract displaced households and economically weaker groups seeking affordable housing. As a result, new settlements have emerged along transport routes and elevated land patches, leading to unplanned urban growth and increased pressure on local infrastructure and public services.

The findings reveal that fluvial instability influences not only livelihoods but also the movement and settlement decisions of local communities. Seasonal migration and temporary relocation have become common adaptation strategies, while riverbank erosion continues to cause displacement in some areas. Over time, these responses have reshaped settlement patterns and contributed to the growth of informal residential areas, reflecting the close relationship between environmental change and human adaptation in the Ganga floodplain.



4.7. Health and Social Impacts of Floods

Floods and environmental changes in the riverine areas of Prayagraj affect not only livelihoods but also the health and well-being of local communities. During flood events, drinking water sources are often contaminated, sanitation facilities become difficult to use, and stagnant water creates favourable conditions for the spread of diseases. These conditions increase health risks, particularly among children, elderly people, and economically vulnerable households.

The survey found that **57% of households** experienced health-related problems during or immediately after flood events, indicating that floods have significant public health consequences in the study area.

Table 7: Health Problems Reported During Flood Period

Health Issue	Percentage of Households Reporting
Diarrhea/Stomach infection	38%
Fever	44%
Skin infection	29%
Mosquito-related illness	33%
Drinking water contamination	51%
Sanitation difficulty	52%
Psychological stress due to flood/erosion	47%

The survey results show that **sanitation difficulties (52%)** and **drinking water contamination (51%)** were the most commonly reported problems during flood periods. Among health issues, **fever (44%)** was reported most frequently, followed by **diarrhea and stomach infections (38%)**,



mosquito-related illnesses (33%), and skin infections (29%). These findings suggest that flood events create conditions that increase exposure to water-borne and vector-borne diseases.

Beyond physical health impacts, floods and riverbank erosion also affect the mental and emotional well-being of affected households. Nearly **47%** of respondents reported experiencing psychological stress associated with floods and erosion. Households living close to unstable riverbanks often face uncertainty about the safety of their homes, the loss of agricultural land, and the possibility of future displacement. Repeated exposure to such risks can create anxiety and insecurity, particularly among families that depend heavily on river-based livelihoods.

The findings indicate that the impacts of floods extend beyond economic losses and physical damage. Problems related to safe drinking water, sanitation, disease outbreaks, and psychological stress significantly affect the quality of life of riverine communities. Therefore, improving health services, sanitation infrastructure, clean water access, and disaster preparedness measures is essential for reducing the overall vulnerability of households living in the Ganga floodplain.

4.8. Adaptation and Resilience Strategies

Adaptation and Coping Strategies

Communities living along the Ganga floodplain in Prayagraj have developed a range of strategies to cope with floods, riverbank erosion, and livelihood uncertainty. These strategies include both traditional knowledge and practical measures adopted at the household level. In many villages, people rely on local observations of river levels, mobile communication, and community networks to anticipate flood events and take precautionary measures. Neighbours often support one another by helping to move household belongings, livestock, and vulnerable family members to safer locations during emergencies.

One of the most common responses to environmental and economic uncertainty is livelihood diversification. Many households combine farming, fishing, wage labour, small-scale trade, boating, and other informal activities to reduce dependence on a single source of income and improve their resilience to shocks.

Table 8: Adaptation Strategies Adopted by Households

Adaptation Strategy	Percentage of Households
Seasonal migration for work	36%
Livelihood diversification	49%



Raising house plinth	42%
Temporary relocation during floods	60%
Borrowing from relatives/moneylenders	31%
Crop diversification	26%
Use of local flood warning knowledge	60%
Government relief support received	34%

The survey results indicate that **temporary relocation during floods (60%)** and the **use of local flood warning knowledge (60%)** are the most widely adopted adaptation measures. Nearly half of the households (**49%**) reported diversifying their livelihoods, while **42%** had raised the plinth level of their houses to reduce flood damage. Seasonal migration for employment (**36%**) also serves as an important coping strategy for many families.

Some households rely on financial support from relatives, friends, or moneylenders during difficult periods, with **31%** reporting borrowing as a coping mechanism. In agriculture, **26%** of households adopted crop diversification to reduce the risk of complete crop failure during adverse conditions.

The findings suggest that adaptation in the study area is largely driven by household initiatives and community support systems. Although government assistance plays a role, only **34%** of households reported receiving relief or compensation. This indicates that formal institutional support remains limited, and many families continue to depend primarily on their own resources, local knowledge, and social networks to cope with the challenges posed by floods and riverbank erosion.

The survey highlights the resilience of riverine communities in adapting to environmental risks. Strategies such as livelihood diversification, temporary relocation, improved housing structures, seasonal migration, and the use of local flood knowledge help households reduce their vulnerability. However, the relatively low level of government support suggests a need for stronger institutional interventions to complement community-based adaptation efforts and enhance long-term resilience.



4.9 Comprehensive Risk Interpretation and Statistical Assessment of River-Dependent Households in Prayagraj

The findings from the household survey provide a comprehensive picture of the challenges faced by river-dependent communities in Prayagraj. The results suggest that these communities are exposed to multiple environmental and socio-economic risks arising from recurrent floods, riverbank erosion, declining river-based livelihoods, health concerns, and limited institutional support. The interaction of these factors increases household vulnerability and affects long-term livelihood security.

To better understand the overall risk profile of the study area, a set of key indicators was compiled covering livelihood dependence, socio-economic conditions, flood impacts, health issues, migration, and adaptation strategies. These indicators help illustrate the extent to which riverine households are affected by environmental change and their capacity to respond to it.

Table 9: Consolidated Socio-Economic and Livelihood Indicators of River-Dependent Households in Prayagraj

Indicator	Percentage (%)
Agriculture-dependent households	15%
Fishing-dependent households	10%
Tourism-related households	7%
Sand mining/labour households	4%
Flood-affected households	67%
Low-income households	58%



Seasonal migration for work	36%
Health problems during floods	57%
Livelihood diversification	49%
Government relief support received	34%

Taken together, the indicators reveal that river-dependent households in Prayagraj face a combination of environmental exposure and socio-economic vulnerability. Frequent flooding, health risks, low income levels, and dependence on climate-sensitive livelihoods contribute to livelihood insecurity. At the same time, adaptation measures such as livelihood diversification and seasonal migration demonstrate the resilience of local communities. Strengthening institutional support, improving disaster preparedness, and promoting sustainable livelihood opportunities could help reduce vulnerability and enhance the long-term resilience of riverine populations.

4.10. Descriptive Statistical Analysis

Descriptive statistics were used to summarize the major socio-economic and environmental indicators of river-dependent households in Prayagraj. These measures help explain the overall pattern of vulnerability by identifying the average condition of households, the spread of values, and the extent of variation among different indicators.

Table 10: Descriptive Statistics of Socio-Economic Indicators

Statistical Measure	Value	Interpretation
Number of Variables	10	Ten key indicators were selected to represent livelihood dependence, socio-economic conditions, flood impacts, health issues, and adaptation strategies



		among river-dependent households.
Mean	33.70	The mean value suggests that, on average, around one-third of households are affected by the socio-economic and environmental conditions represented by the selected indicators. This points to a moderate to high level of vulnerability within the study area.
Median	35.00	The median indicates that half of the indicators have values below 35% and half above 35%. Its closeness to the mean suggests that the data are fairly balanced, although some higher values influence the overall average.
Standard Deviation	23.44	The relatively high standard deviation reflects substantial variation among the indicators. This suggests that vulnerability is not evenly distributed, with some issues affecting a large proportion of households while others are comparatively less significant.



Minimum Value	4	The lowest value relates to households engaged in sand mining and associated labour activities, indicating that only a small section of the population depends on this occupation.
Maximum Value	67	The highest value corresponds to flood-affected households, highlighting the widespread impact of flooding on riverine communities in Prayagraj.
Range	63	The large difference between the minimum and maximum values demonstrates considerable diversity among the indicators and reflects varying levels of exposure and vulnerability across households.

The descriptive statistics reveal significant differences in the socio-economic conditions and environmental challenges faced by river-dependent households. The mean value (33.70%) indicates that many of the identified issues affect a substantial proportion of the surveyed population. The median value (35%), which is very close to the mean, suggests that the distribution of indicators is relatively balanced and not heavily skewed.

However, the standard deviation of 23.44 points to considerable variation among the indicators. Certain issues, such as flood exposure, low-income status, and health impacts, affect a large share of households, whereas activities like sand mining involve only a small proportion of the population. This uneven distribution highlights the diverse nature of vulnerability within riverine communities.

The minimum value (4%) and maximum value (67%) further illustrate the contrast between different indicators. The resulting range of 63 percentage points demonstrates the wide gap between the least

and most significant factors affecting households. Overall, these findings suggest that vulnerability in Prayagraj’s river-dependent communities is shaped by a complex combination of environmental risks, livelihood dependence, and socio-economic inequalities, with flooding emerging as the most widespread challenge.

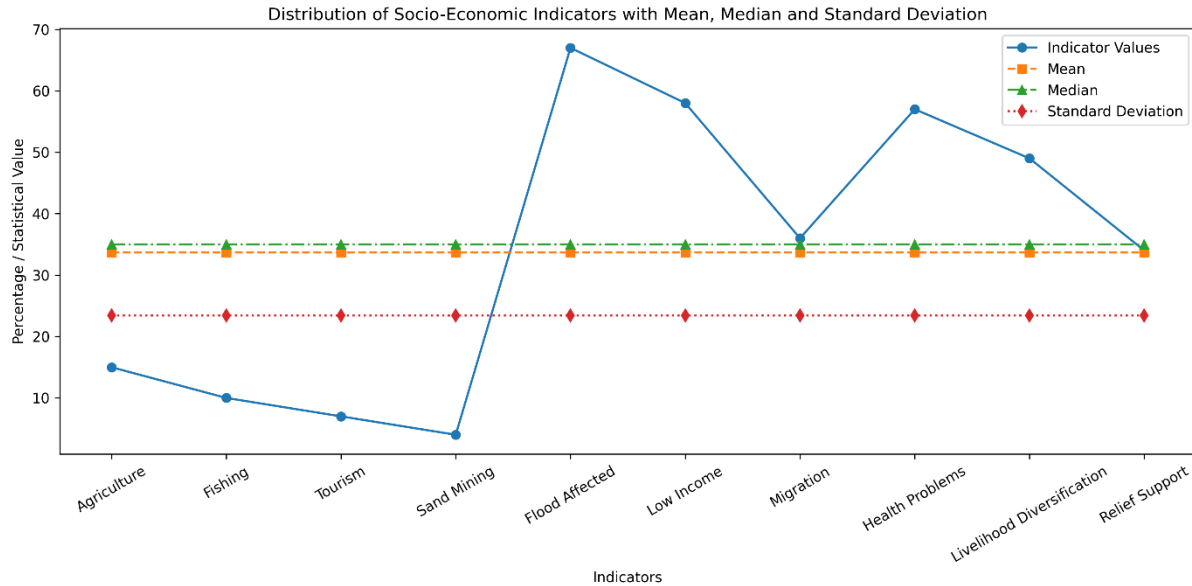


Figure 2: Distribution of Socio-economic Indicators with Mean, Median and Standard Deviation

Coefficient of Variation (CV) Analysis

The coefficient of variation (CV) was used to assess the relative variability among the socio-economic and environmental indicators. Using the calculated mean (**33.70**) and standard deviation (**23.44**), the CV was found to be **69.56%**.

A CV value of nearly **70%** indicates a high degree of variation among the indicators. This suggests that vulnerability is not evenly distributed across river-dependent households in Prayagraj. While some issues, such as flooding, poverty, and health problems, affect a large proportion of households, others, including sand mining, tourism, and fishing, involve a much smaller share of the population. The high CV therefore reflects the diverse livelihood conditions and unequal levels of environmental risk within the Ganga floodplain.

Z-Score Analysis

Z-score analysis was applied to determine how far each indicator deviates from the average value. Positive z-scores indicate indicators that are more prominent than the average, while negative z-scores represent less dominant conditions.

Table 11: Z-Score Analysis of Key Indicators



Indicator	Value (%)	Z-Score	Interpretation
Flood-affected households	67	+1.42	Extremely high vulnerability
Low-income households	58	+1.04	High economic stress
Health problems during floods	57	+0.99	High health risk
Livelihood diversification	49	+0.65	Important adaptation strategy
Seasonal migration	36	+0.10	Moderate livelihood instability
Government relief support	34	+0.01	Near average level
Agriculture dependence	15	-0.80	Reduced occupational dependence
Fishing dependence	10	-1.01	Declining traditional livelihood



Tourism-related households	7	-1.14	Limited livelihood contribution
Sand mining/labour	4	-1.27	Least common occupation

Interpretation of Z-Score Results

The indicators with positive z-scores highlight the major challenges faced by river-dependent communities. **Flood-affected households (Z = +1.42)** show the highest deviation from the mean, confirming that flooding is the most significant source of vulnerability in the study area. Similarly, **low-income households (Z = +1.04)** and **health problems during floods (Z = +0.99)** reflect widespread economic hardship and public health concerns. **Livelihood diversification (Z = +0.65)** stands out as an important coping mechanism adopted by households to manage environmental and economic uncertainties.

In contrast, indicators with negative z-scores represent activities that are less prominent within the local economy. **Sand mining (Z = -1.27)** and **tourism-related livelihoods (Z = -1.14)** account for only a small share of households. Likewise, **fishing (Z = -1.01)** and **agriculture (Z = -0.80)** show lower representation, reflecting the gradual decline of traditional river-based occupations due to environmental pressures, changing livelihood patterns, and urban expansion.

The CV and Z-score analyses together indicate that flood exposure, poverty, and health risks are the most critical concerns affecting river-dependent households in Prayagraj. At the same time, the decline in traditional occupations and the growing importance of livelihood diversification highlight how communities are adapting to changing environmental and socio-economic conditions. These findings emphasize the uneven nature of vulnerability across the Ganga floodplain and the need for targeted interventions to strengthen resilience among the most affected households.

4.11 Vulnerability Classification

To better understand the level of risk faced by river-dependent households, the selected indicators were classified into three categories based on their percentage values.

Table 12: Vulnerability Classification

Vulnerability Level	Percentage Range
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High Vulnerability	Above 50%
Moderate Vulnerability	25–50%
Low Vulnerability	Below 25%

High Vulnerability Indicators (>50%)

Table 13: High Vulnerability Indicators

Indicator	Percentage	Interpretation
Flood-affected households	67%	Indicates widespread exposure to flood hazards
Low-income households	58%	Reflects significant economic insecurity
Health problems during floods	57%	Highlights major health risks during flood periods

The indicators in this category represent the most critical challenges faced by river-dependent communities in Prayagraj. The high percentage of flood-affected households confirms that flooding remains the dominant environmental hazard in the floodplain. At the same time, the large proportion of low-income households and flood-related health problems demonstrates that environmental risks are closely linked with economic hardship and public health concerns. Together, these factors contribute to a high level of overall vulnerability.

Moderate Vulnerability Indicators (25–50%)

Table 14: Moderate Vulnerability Indicators



Indicator	Percentage	Interpretation
Livelihood diversification	49%	Adoption of multiple income sources
Seasonal migration	36%	Movement in search of employment opportunities
Government relief support	34%	Moderate access to institutional assistance

These indicators reflect how households respond to environmental and economic challenges. Nearly half of the surveyed households reported diversifying their livelihoods, while seasonal migration has become a common strategy for coping with limited local employment opportunities. The moderate level of government support suggests that although institutional assistance is available, many households still rely primarily on their own resources and community networks during difficult periods.

Low Vulnerability Indicators (<25%)

Table 15: Low Vulnerability Indicators

Indicator	Percentage	Interpretation
Agriculture-dependent households	15%	Limited dependence on farming as a primary livelihood
Fishing-dependent households	10%	Reduced reliance on traditional fishing activities



Tourism-related households	7%	Small contribution of tourism-based livelihoods
Sand mining/labour households	4%	Lowest level of occupational dependence

These indicators represent activities that involve a relatively small proportion of households. The low percentages suggest that traditional river-based occupations such as agriculture and fishing are no longer the dominant sources of livelihood for most families. Urbanization, changing economic opportunities, environmental degradation, and livelihood diversification have gradually reduced dependence on these occupations. Tourism and sand mining also contribute only a limited share to the local livelihood structure.

Overall Interpretation

The vulnerability classification highlights that the most serious concerns for river-dependent households are related to flood exposure, poverty, and health risks, all of which fall within the high-vulnerability category. Moderate-level indicators show how households are adapting through migration and livelihood diversification, while low-level indicators reflect the declining importance of traditional river-based occupations. Overall, the results suggest that vulnerability in Prayagraj's riverine communities is driven more by environmental hazards and socio-economic insecurity than by direct dependence on river-based livelihoods alone.

6.12 Risk Assessment of River-Dependent Households

The level of risk faced by river-dependent communities in Prayagraj is shaped by the combined effects of environmental hazards and socio-economic vulnerability. This relationship can be expressed as:

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability}$$

Environmental Risk Assessment

Flooding is the most significant environmental hazard affecting households in the Ganga floodplain. Its impacts are intensified by riverbank erosion, floodplain encroachment, drainage problems, sediment deposition, and seasonal changes in river flow. These factors not only damage homes, infrastructure, and agricultural land but also disrupt livelihoods and daily life.

Environmental risks are further increased by the discharge of untreated sewage into the Ganga, which contributes to water pollution and health hazards. During floods, contaminated water often spreads



across settlements, increasing the risk of water-borne diseases and creating serious sanitation challenges for local communities.

Socio-Economic Risk Assessment

Socio-economic vulnerability remains high among many river-dependent households. Factors such as low income, seasonal unemployment, informal work, and limited financial resources reduce the ability of families to cope with environmental shocks. Repeated flood events often lead to income loss, debt, and livelihood insecurity, particularly among economically weaker households.

In response to these challenges, many families adopt seasonal migration as a coping strategy. While migration helps supplement household income, it also reflects the limited livelihood opportunities available within the local area.

Livelihood Transition and Occupational Risk

Traditional river-based occupations such as agriculture and fishing have become less reliable over time. Urban expansion, pollution, environmental degradation, changing land use, and declining fish resources have reduced the viability of these activities. As a result, many households are increasingly diversifying their livelihoods and seeking alternative sources of income outside the traditional river economy.

The findings suggest that risk in Prayagraj's riverine communities is driven by both environmental and socio-economic factors. Floods, pollution, and riverbank erosion remain major environmental concerns, while poverty, unstable employment, and declining traditional livelihoods increase household vulnerability. Consequently, many families are adapting through livelihood diversification and migration, highlighting both the challenges they face and their efforts to build resilience in a changing floodplain environment.

6.13 Fluvial Geomorphological Interpretation and Policy Implications

The Ganga floodplain in Prayagraj represents a dynamic socio-ecological system where natural fluvial processes and human activities interact continuously. Processes such as channel migration, sediment deposition, riverbank erosion, seasonal flooding, and fluctuations in river discharge shape the physical landscape and influence settlement patterns, land use, livelihoods, and environmental conditions. However, rapid urbanisation, floodplain encroachment, and the discharge of untreated sewage have increased environmental degradation and intensified the vulnerability of river-dependent communities.

According to Forman and Godron (1986), ecological corridors perform important functions as habitats, movement pathways, ecological filters, and resource sources. In urban areas, rivers provide additional benefits by supporting transportation, fisheries, tourism, recreation, groundwater recharge, flood regulation, and climate moderation. Therefore, the Ganga serves not only as a geomorphological feature but also as a critical resource for economic activities, environmental sustainability, and human well-being in Prayagraj.



The findings highlight the need for integrated floodplain management and sustainable riverfront development. Measures such as restricting encroachment, improving sewage treatment facilities, strengthening healthcare and sanitation infrastructure, and promoting livelihood rehabilitation programmes are essential for reducing vulnerability. Community-based disaster management and environmentally sensitive urban planning should also be encouraged to enhance resilience against recurring floods and environmental change.

Conclusion

The study reveals that river-dependent communities in the Ganga floodplain of Prayagraj face increasing environmental and socio-economic challenges due to recurrent flooding, riverbank erosion, pollution, and rapid urban growth. Among these factors, flooding emerged as the most significant hazard, affecting livelihoods, settlements, public health, and overall socio-economic security.

Traditional river-based occupations, particularly agriculture and fishing, are gradually declining as a result of environmental degradation, pollution, and changing economic conditions. Consequently, many households have adopted livelihood diversification and seasonal migration as important coping and adaptation strategies.

The statistical analysis further indicates that poverty, health risks, seasonal unemployment, and limited institutional support significantly increase household vulnerability. Despite these challenges, local communities continue to rely largely on indigenous knowledge, social networks, and household-level adaptation measures to manage environmental risks.

The study concludes that improving resilience in the Ganga floodplain requires a combination of integrated floodplain management, effective pollution control, sustainable urban planning, improved healthcare and sanitation services, and stronger livelihood support programmes. Greater community participation in disaster management and inclusive development planning will be essential for promoting long-term environmental sustainability and socio-economic well-being in Prayagraj's riverine communities.

Annexure: Survey Questionnaire

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