Changing Nature of Agriculture and Rural Livelihoods Due to Flood Induced Sand Deposition: A Micro Level Study of Guptipara Char Mouza in the Lower Bhagirathi Floodplain, West Bengal, India

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Abstract: Floodplains represent highly productive yet environmentally vulnerable landscapes because of their dynamic geomorphic processes and recurring hydrological disturbances. The present micro-level study investigates the changing nature of agriculture and rural livelihoods under the influence of recurrent flooding and flood-induced sand deposition in Guptipara Char Mouza of the lower Bhagirathi floodplain, West Bengal, India. The study analyses spatio-temporal flood characteristics, sand-splay deposition, land-use transformation, agricultural change, socio-economic vulnerability, and livelihood adaptation between the agricultural years 1999–2000, 2012–2013, and 2025–2026. Both primary and secondary data sources were used. Household surveys, farmer perception analysis, plot-wise land-use surveys, GPS-based field investigation, and satellite image interpretation using Google Earth Pro imagery (2015 and 2025) formed the major methodological basis of the study. Several agricultural indices, including Cropping Intensity, Gibbs–Martin Crop Diversification Index, Overall Yield Index (Shafi, 1972), Enyedi Crop Productivity Index, and Volume of Change in Crop Cultivation Index, were applied to measure agricultural transformation. The results reveal that the floods of 2000, 2007, and 2015 caused severe inundation and extensive sand-splay deposition across the study area. The flood of 2000 affected almost the entire mouza, whereas the flood extent gradually declined in later years due to partial embankment strengthening and local adaptation measures. Sand deposition significantly reduced soil fertility, altered soil texture, and negatively affected traditional crop cultivation, particularly Boro paddy. Consequently, agricultural diversification increased gradually, while orchard farming, especially mango cultivation, emerged as a major adaptive strategy in sand-affected areas. Land-use and land-cover analysis indicates a decline in traditional agricultural land and a rapid increase in orchard area and settlement expansion between 2015 and 2025. Occupational diversification also increased substantially as households shifted from cultivation toward agricultural labour, business, transportation, textile work, service activities, and seasonal migration. The study demonstrates that recurrent flood hazards and geomorphic disturbances have fundamentally transformed the agricultural economy and livelihood structure of the lower Bhagirathi floodplain. Sustainable floodplain management therefore requires integrated river management, scientific sediment-control measures, climate-resilient agricultural planning, community-based adaptation strategies, and improved rural livelihood support systems.

Keywords: *Sand-Splay Deposition; Rural Livelihood; Crop Diversification; Agricultural Transformation; Bhagirathi Floodplain; Farmer Perception Study.*

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I. INTRODUCTION

Floodplains constitute one of the most productive yet environmentally vulnerable landscapes in the world because of their dynamic geomorphic processes, fertile alluvial soils, and continuous interaction between river systems and human settlements [1,2]. Riverine floodplains support dense agricultural populations due to the availability of fertile sediments, irrigation potential, and favourable hydrological conditions; however, these same regions frequently experience

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recurrent flooding, erosion, channel shifting, and sediment deposition that adversely affect agricultural productivity and rural livelihoods [3,4]. In developing countries, particularly within South Asia, floodplain communities remain highly dependent on agriculture, making them increasingly vulnerable to hydro-geomorphic hazards and climate-induced environmental changes [5,6]. Repeated flood events not only damage standing crops and infrastructure but also create long-term ecological disturbances through sand casting, waterlogging, riverbank erosion, and degradation of soil fertility [7,8].

The lower Gangetic floodplain of eastern India represents one of the most hazard-prone riverine environments where seasonal flooding is a recurring phenomenon [9]. The Bhagirathi-Hooghly river system, an important distributary of the River Ganga, plays a crucial role in shaping the geomorphology, hydrology, economy, and settlement structure of southern West Bengal [10]. The lower Bhagirathi floodplain experiences annual monsoonal flooding caused by intense rainfall, upstream water discharge, river-bed siltation, embankment breaching, and synchronization of tributary flow systems [11,12]. Although floodwaters often contribute nutrient-rich sediments that enhance agricultural fertility, severe floods frequently deposit coarse sandy sediments over agricultural land, thereby reducing productivity and altering the ecological condition of the floodplain landscape [13,14].

Flood-induced sand deposition, commonly referred to as sand-splay or sand casting, has emerged as one of the most serious environmental problems in many parts of the Gangetic floodplain [15]. During high-intensity flood events, rivers transport large volumes of sediment that spread across adjoining low-lying agricultural land after embankment breaches or overbank flooding [16]. These coarse-textured deposits reduce soil moisture retention capacity, alter soil texture, decrease nutrient availability, and make cultivation increasingly difficult for local farmers [17,18]. In several flood-prone districts of West Bengal and Bihar, extensive sand deposition has transformed fertile agricultural land into temporarily barren surfaces, resulting in reduced crop productivity and increasing socio-economic vulnerability among agrarian communities [19,20].

The relationship between floods and agricultural transformation has become increasingly significant under contemporary climate variability and environmental change [21]. Climate change has intensified the frequency and magnitude of extreme rainfall events, resulting in increasing flood hazards in many tropical river basins [22]. Rural agricultural communities depending primarily on climate-sensitive livelihoods are therefore facing severe challenges associated with declining crop productivity, land degradation, irrigation uncertainty, and occupational instability [23,24]. Consequently, many floodplain farmers are gradually shifting toward diversified livelihood systems including horticulture, orchard farming, wage labour, transportation, service activities, and seasonal migration as adaptive responses to recurring environmental stress [25,26].

In eastern India, particularly within the lower Bhagirathi floodplain region of West Bengal, recurrent flooding has substantially altered agricultural practices and rural socio-economic conditions over the last few decades [27]. Several studies have highlighted the geomorphic instability, riverbank erosion, and flood vulnerability of the Bhagirathi-Hooghly river system [28,29]. However, micro-level investigations focusing on flood-induced sand deposition and changing agricultural livelihoods at mouza level remain limited. Most previous studies have concentrated primarily on regional flood hazard mapping or riverbank erosion assessment, whereas the localized impacts of flooding on agricultural transformation, cropping characteristics, productivity, and rural livelihood adaptation have received comparatively less attention [30].

The present study therefore attempts to analyze the changing nature of agriculture and rural livelihoods due to flood-induced sand deposition in Guptipara Char Mouza. The study adopts a micro-level approach to examine the spatio-temporal characteristics of flood occurrence, sand-splay deposition, land-use change, agricultural transformation, and socio-economic adaptation between the agricultural years 1999–2000, 2012–2013, and 2025–2026. Particular emphasis has been given to understanding the effects of recurrent flooding on cropping intensity, crop diversification, irrigation practices, agricultural productivity, land degradation, occupational restructuring, and household vulnerability. The study further evaluates how local farmers have adapted their agricultural and livelihood strategies in response to increasing environmental uncertainty.

Several agricultural and geographical indices have been used to quantify the changing agricultural scenario of the study area. Cropping intensity has been calculated using the ratio between gross cropped area and net sown area. Crop diversification has been measured through the Gibbs–Martin Crop Diversification Index [31], while overall agricultural performance has been evaluated using the Overall Yield Index proposed by Shafi [32]. Crop productivity variations have been analyzed using the Enyedi Crop Productivity Index [33], and the Volume of Change in Crop Cultivation Index developed by Singh and Dhillon [34] has been applied to examine changes in crop composition over time. In addition, plot-wise land-use and land-cover survey, farmer perception analysis, GPS-based field investigation, and Google satellite image interpretation have been incorporated to understand the changing floodplain landscape and livelihood dynamics.

The significance of the study lies in its ability to provide an integrated understanding of flood-induced environmental transformation and rural adaptation at a micro-spatial level. The findings are expected to contribute toward sustainable floodplain management, climate-resilient agricultural planning, and rural livelihood policy formulation in the lower Gangetic floodplain region. The study also highlights the importance of integrating geomorphological processes, agricultural transformation, and socio-economic vulnerability within a unified framework for understanding floodplain environmental change in eastern India.

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II. STUDY AREA

The present micro-level study was conducted in Guptipara Char Mouza under Balagarh Community Development Block in the lower floodplain region of the Bhagirathi River of Hooghly district, West Bengal, India (Fig. 1). The study area is situated within an active fluvial environment that experiences recurrent flooding, channel instability, and flood-induced sand deposition during the monsoon season. The mouza lies between 23°12′14.04″ N to 23°13′17.87″ N latitude and 88°26′16.74″ E to 88°27′23.02″ E longitude, covering an area of approximately 163.19 hectares. The area belongs to J.L. No. 10 and represents a typical riverine floodplain environment of the lower Bhagirathi basin [35,36]. The mouza is bounded by Chhenra Char Mouza in the north-east, Sabek Char Mouza in the east, Guptipara Mouza and Char Krishna Bati Mouza in the south, and Char Sultanpur Mouza in the west.

The physiography of the area is characterized by a flat and monotonous alluvial plain with an average elevation of nearly 16 metres above mean sea level. The entire geomorphic structure has developed through continuous deposition of recent alluvium by the Bhagirathi-Hugli river system. The soils are predominantly sandy loam to loamy in nature, although field survey identified several locations where thick layers of coarse sand have covered the original fertile topsoil due to repeated flood-induced sand-splay processes. The climate of the study area is tropical monsoon type characterized by hot humid summers, monsoonal rainfall, and mild winters. Most rainfall occurs during June to September, which often coincides with flood occurrences in the Bhagirathi floodplain. According to farmers’ perceptions collected during the 2026 field survey, the frequency of intense rainfall events and flood-related crop damage has increased in recent years, affecting agricultural sustainability and livelihood security.

Agriculture remains the principal economic activity of the mouza. The major crops cultivated are Aman paddy, Boro paddy, jute, mustard, vegetables, pulses, and sweet potato. However, recent field observations indicate a gradual decline in traditional paddy cultivation due to declining soil quality, rising production costs, irregular flooding, and sand deposition. Simultaneously, orchard farming, particularly mango cultivation, has expanded considerably in sand-affected areas because it requires comparatively lower irrigation and provides relatively stable economic returns.

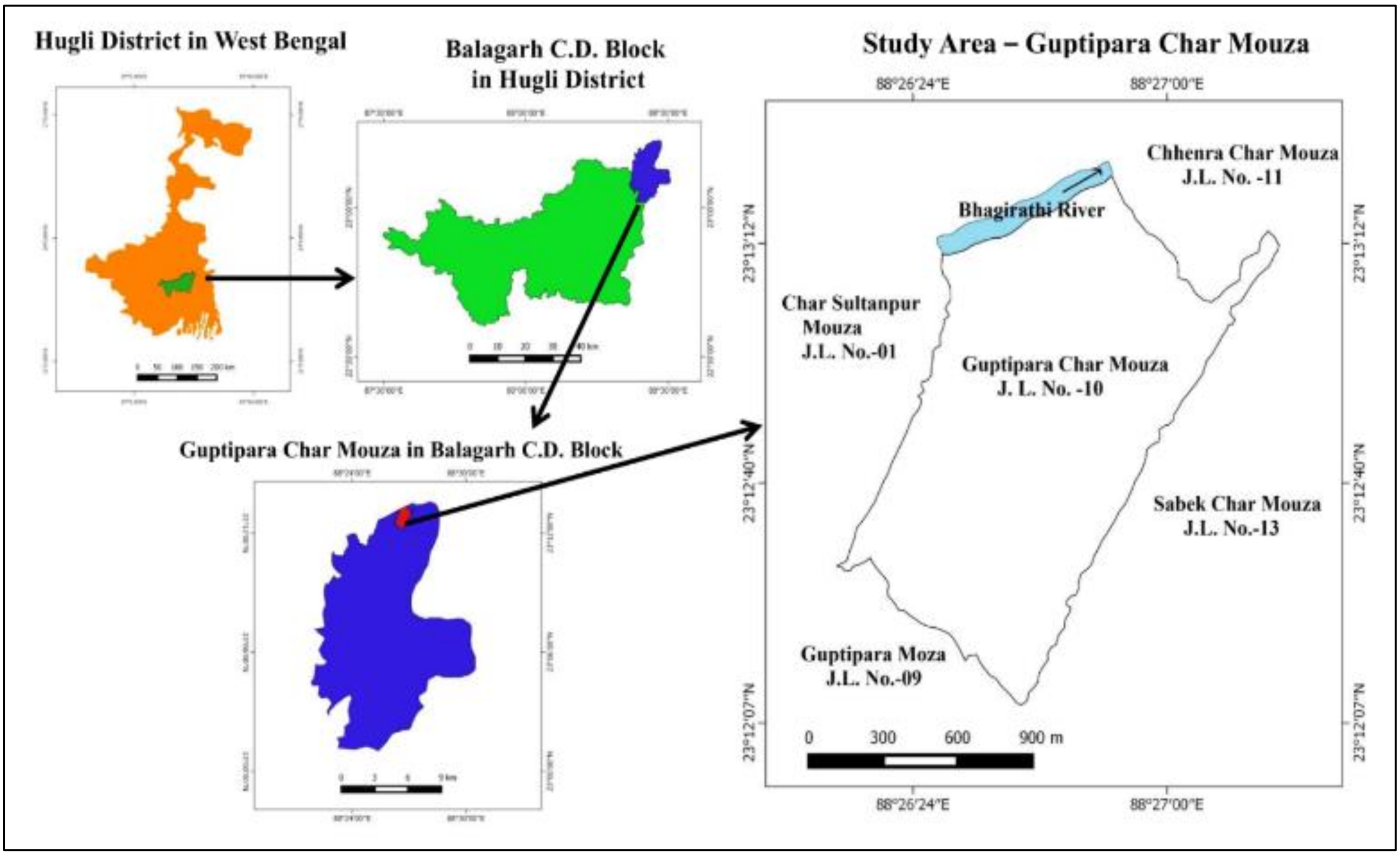

Fig 1 Location Map of Study Area.
Source: West Bengal Administrative Atlas, 2011 and Balagarh BL-LRO Office, Hooghly, West Bengal

III. DATABASE AND METHODOLOGY

➢ *Database*

The present study is based on both primary and secondary data sources to assess the changing nature of agriculture and rural livelihoods under recurrent flood and sand-splay conditions in Guptipara Char Mouza of the lower Bhagirathi floodplain. A mixed-method approach was adopted to integrate spatial, socio-economic, agricultural, and environmental datasets for comprehensive analysis.

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Primary data were collected through intensive field surveys conducted during January–April 2026. Household-level socio-economic surveys were carried out using a structured questionnaire among selected farming households of the mouza. Information regarding cropping pattern, occupational structure, flood experiences, sand deposition, agricultural productivity, irrigation practices, income level, adaptation strategies, and livelihood transformation was collected directly from farmers through interview and participatory observation methods.

Farmer perception surveys were particularly important in understanding long-term environmental changes and local adaptation mechanisms associated with recurrent flooding and sand-splay deposition. In addition, GPS-based plot-wise land-use and land-cover surveys were conducted to identify changes in agricultural land, orchard development, settlement expansion, fallow land, and sand-covered areas.

Secondary data were collected from multiple governmental and institutional sources including the Population Census of India, District Census Handbook of Hugli District, Office of the Assistant Director of Agriculture, Government of West Bengal, and the Irrigation and Waterways Department.

Satellite-based land-use and land-cover information was generated using multi-temporal Google Earth Pro satellite imagery for the years 2015 and 2025. Visual image interpretation and field verification techniques were jointly used to improve the accuracy of land-use classification.

➢ *Sampling Design and Household Survey*

A purposive sampling technique was adopted considering the flood-prone and sand-affected characteristics of the mouza. A total of 67 households were surveyed during the field investigation in 2026. The selected households represented different socio-economic categories including marginal farmers, small farmers, agricultural labourers, and households engaged in non-farm occupations.

➢ *Methodological Framework*

The study followed an integrated methodological framework combining spatial analysis, statistical analysis, agricultural indices, and socio-economic assessment. Both qualitative and quantitative methods were used to evaluate the changing agricultural scenario and rural livelihood vulnerability. Several agricultural and geographical indices were applied to measure changes in agricultural characteristics and productivity. Cropping intensity was calculated using the ratio between gross cropped area and net sown area:

Cropping Intensity = (Gross Cropped Area / Net Sown Area) × 100

Crop diversification was measured using the Gibbs–Martin Crop Diversification Index:

$$CDI = 1 - (\sum x^2 / (\sum x)^2)$$

Where x = percentage of area under individual crops.

The Overall Yield Index after Shafi (1972) was used to evaluate relative agricultural performance:

$$OYI = Ye / Yr$$

Where Ye = estimated yield and Yr = regional average yield.

Crop productivity analysis was performed using the Enyedi Crop Productivity Index, while the volume of change in crop cultivation was measured following the method developed by Singh and Dhillon (1984).

IV. RESULTS

➢ *Spatio-Temporal Characteristics of Flooding*

The analysis of flood occurrences in Guptipara Char Mouza demonstrates that flooding remains one of the most significant environmental hazards affecting the lower Bhagirathi floodplain. Historical records, field observations, and farmer perceptions indicate that severe floods occurred in 2000, 2007, and 2015, causing extensive inundation, agricultural damage, and sand-splay deposition. The magnitude and spatial extent of flooding varied considerably across different years depending on monsoonal rainfall intensity, river discharge, embankment conditions, and upstream hydrological controls.

The flood of 2000 was the most catastrophic event (Table 1 & Fig.2), affecting the entire mouza area. The floodwaters spread rapidly across low-lying agricultural fields due to excessive rainfall and overflow of the Bhagirathi River. In comparison, the floods of 2007 and 2015 affected relatively smaller areas, although substantial agricultural losses and livelihood disruptions were still recorded.

Table 1 Flood-Affected Area in Different Flooding Years

Flooding Year	Flood-Affected Area (Ha)	Flood-Affected Area (%)	Non-Flooded Area (Ha)	Non-Flooded Area (%)
2000	163.19	100.00	0.00	0.00
2007	148.75	91.14	14.44	8.86
2015	138.03	84.58	25.16	15.42

Source: Field Survey (2026) and Author's Calculation.

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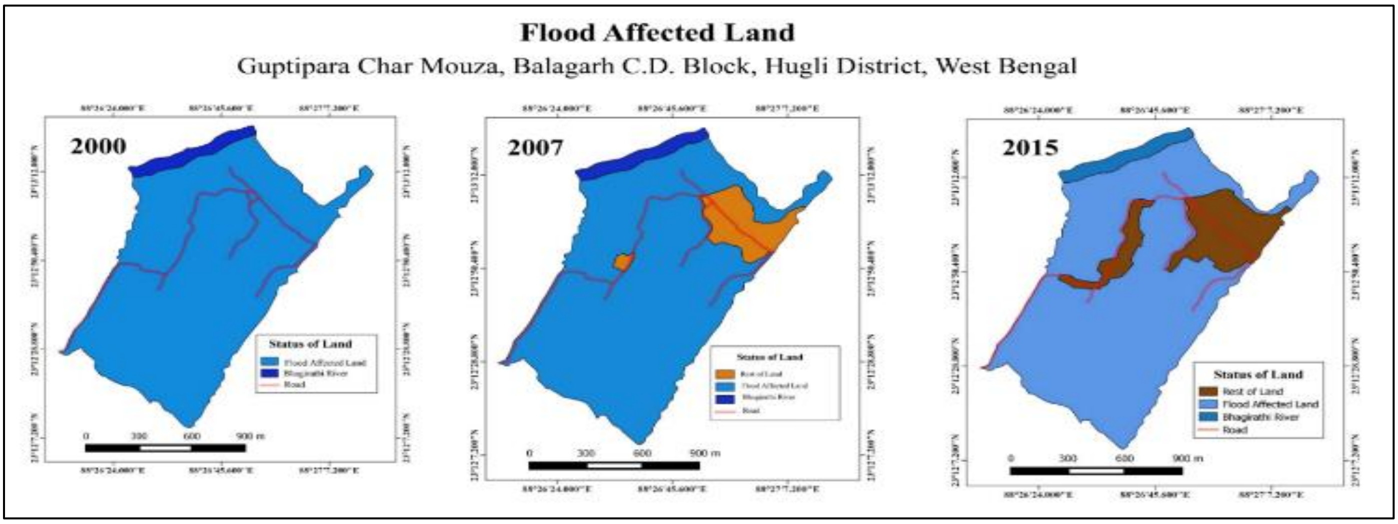

Fig 2 Flood Affected Land in the Study Area During Flooding Years 2000, 2007& 2015
Source: Field Survey (2026)

The results indicate a gradual reduction in flood-affected area between 2000 and 2015. Nevertheless, more than 84% of the mouza remained vulnerable to flood inundation during major flood years, demonstrating the persistent environmental sensitivity of the floodplain landscape. The spatial pattern of flood expansion revealed that riverbank-adjacent agricultural lands and low-elevation basins were most severely affected. Similar floodplain behaviour has been observed in other parts of the Ganga–Bhagirathi system where recurrent flooding alters geomorphology, agricultural productivity, and rural livelihoods (Sinha & Jain, 1998; Rudra, 2018; Thakkar et al., 2017).

- *Sand-Splay Deposition and Land Degradation*

One of the most significant post-flood environmental impacts in the study area is sand-splay deposition. Floodwaters transported coarse sandy sediments from the river channel and deposited them over fertile agricultural land, thereby reducing soil fertility and moisture retention capacity. Field investigation revealed that severe sand deposition occurred after the 2000 flood (Table2), particularly near riverbank zones and lower topographic surfaces.

Table 2 Sand-Splay Deposition after Major Flood Event

Thickness of Sand Deposit (Feet)	Area (Ha)	Area (%)
> 4 ft	36.99	22.67
2.6 – 4.0 ft	31.40	19.24
1.1 – 2.5 ft	46.96	28.78
< 1 ft	47.83	29.31
Total	163.19	100.00

Source: Field Observation and Farmer Survey (2026).

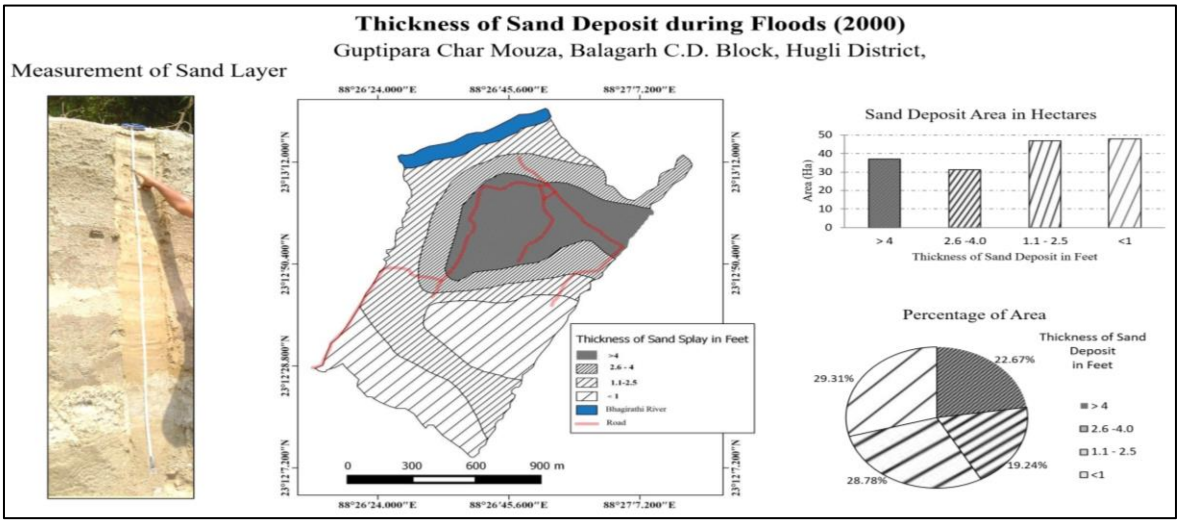

Fig 3 Thickness of Sand Deposit in the Study Area During Flooding Year 2000
Source: Field Survey (2026)

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The data demonstrate that nearly 42% of the total area experienced moderate to severe sand deposition exceeding 2.5 feet thickness. Such sedimentation substantially altered the agricultural landscape and reduced crop productivity. Similar impacts of flood-induced sand casting on fertile alluvial lands have also been documented in the middle and lower Gangetic plains (Ghosh & Kar, 2018; Chakraborty et al., 2020). The accumulation of sandy sediments transformed productive cropland into temporarily barren surfaces. Farmers reported declining soil moisture retention, lower organic matter content, and increasing irrigation requirements following major flood events.

- *Demographic and Socio-Economic Transformation*

The demographic and socio-economic structure of the study area changed significantly between 2000 and 2026 due to recurring floods, declining agricultural stability, and livelihood diversification (Table 3).

Table 3 Demographic Characteristics of Guptipara Char Mouza

Indicators	**2000**	**2013**	**2026**
Total Households	42	54	67
Total Population	176	212	251
Literacy Rate (%)	61.80	79.29	87.60
Female Literacy (%)	54.10	76.40	84.90
Sex Ratio	796	827	887

Source: Census Data and Field Survey (2026).

The literacy rate increased substantially during the study period, particularly among women. Improved educational access and increasing social awareness contributed to this transformation. However, despite improvements in literacy, the local economy remained highly vulnerable to environmental shocks.

- *Occupational Structure and Livelihood Diversification*

The occupational structure underwent substantial transformation due to flood-induced agricultural uncertainty and sand deposition. Traditional dependence on cultivation gradually declined, while non-farm activities increased (Table 4).

Table 4 Changing Occupational Structure (% of Workers)

Occupation Category	**2000**	**2013**	**2026**
Cultivators	68.56	53.40	39.60
Agricultural Labourers	15.42	22.80	24.50
Service Sector	2.60	5.60	11.80
Business Activities	4.64	7.20	12.40
Textile/Industrial Work	1.78	8.40	7.30
Others	7.00	2.60	4.40

Source: Household Survey (2026).

The percentage of cultivators declined sharply from 68.56% in 2000 to 39.60% in 2026. Recurrent flooding and declining agricultural productivity forced households to adopt alternative occupations including transport services, business, construction work, and migration-based labour activities. Similar livelihood diversification trends in flood-prone rural areas have been reported by Ellis (2000) and Adger (2006).

- *Monthly Household Income Structure*

Changes in occupational diversification influenced household income patterns. The proportion of extremely low-income households gradually declined over time, although economic vulnerability remained significant (Table 5).

Table 5 Monthly Household Income Categories

Income Category	**2000 (%)**	**2013 (%)**	**2026 (%)**
Below ₹5000	76.00	54.00	38.80
₹5000–10000	18.00	32.00	41.80
Above ₹10000	6.00	14.00	19.40

Source: Household Survey (2026).

The increase in middle-income households reflects gradual occupational diversification and expansion of orchard-based agriculture. Nevertheless, economic instability remained high because agricultural earnings continued to fluctuate with flood severity and land degradation.

- *Land Use and Land Cover Change (2015–2025)*

Satellite image interpretation using Google Earth imagery revealed significant land-use transformation between 2015 and 2025 (Table 6 & Fig. 4).

Table 6 Land Use and Land Cover Change (2015–2025)

Land Use Category	2015 (Ha)	2025 (Ha)	Change (%)
Agricultural Land	118.60	96.20	-18.89
Sand-Covered Area	21.50	14.30	-33.49
Mango Orchard	4.80	18.60	+287.50
Settlement Area	9.40	17.80	+89.36
Water Bodies	8.89	16.29	+83.24

Source: Google Earth Pro Imagery (2015 & 2025) and Plot-Wise Survey 2026.

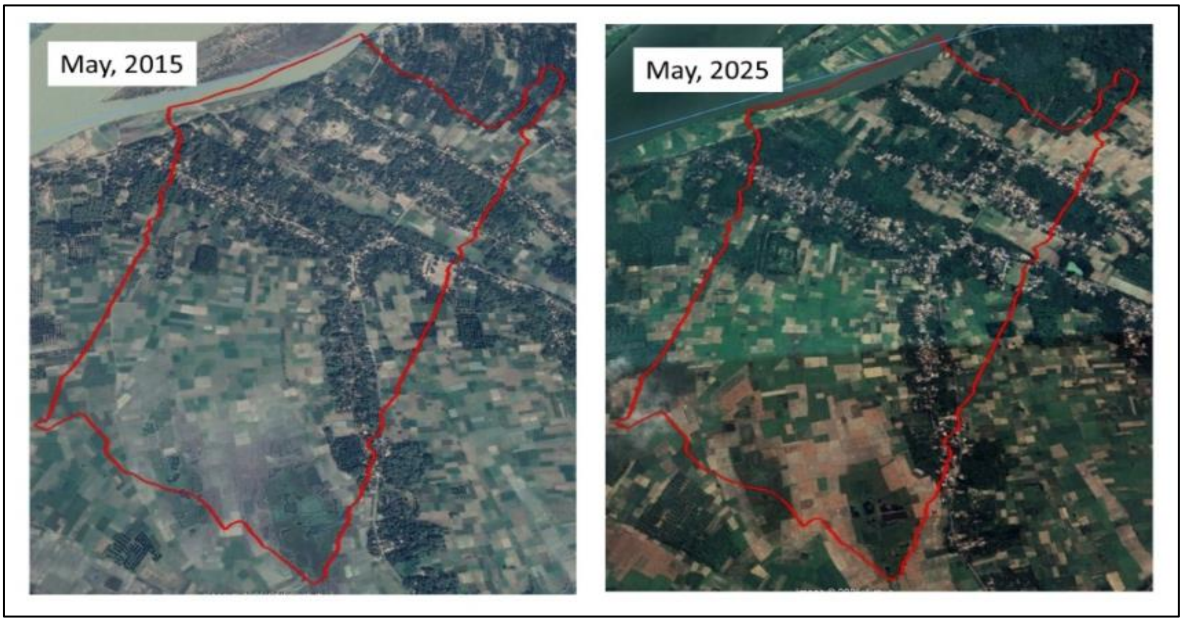

Fig 4 Visual Land use Land Cover (LULC) Imagery of Guptipara Char Mouza (2015 & 2025)
Source: Google Earth Pro Imagery, 2015 & 2025

The results indicate a considerable reduction in traditional agricultural land alongside a rapid increase in orchard farming and settlement expansion. Mango orchards emerged as an adaptive land-use strategy because orchard cultivation is comparatively resilient to sandy soils and irregular flood conditions.

➢ *Changing Cropping Intensity*

Flood and sand deposition significantly influenced cropping intensity in the study area.

Table 7 Changing Cropping Intensity

Agricultural Year	Net Cropped Area (Ha)	Gross Cropped Area (Ha)	Cropping Intensity (%)
1999–2000	122	299.5	245
2012–2013	118	223	189
2025–2026	120	261	218

Source: Department of Agriculture and Field Survey.

Cropping intensity (Table 7) declined sharply after severe flood events because of sand deposition and declining soil productivity. However, partial recovery occurred by 2025–2026 through reclamation measures, irrigation expansion, and adoption of modern agricultural practices.

➢ *Changing Cropping Pattern*

The cropping pattern (Table 8) changed significantly between 1999–2000 and 2025–2026.

Table 8 Changing Cropping Pattern (% of Gross Cropped Area)

Crops	1999–2000	2012–2013	2025–2026
Boro Paddy	44.40	39.63	38.31
Jute	20.03	18.91	19.16
Vegetables	8.34	8.10	11.50
Sweet Potato	3.34	2.25	2.68
Mango Orchard	0.16	1.35	1.91

Source: Field Survey and Agricultural Records.

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The area under Boro paddy gradually declined due to increasing flood vulnerability and irrigation uncertainty. Conversely, mango orchard cultivation expanded rapidly as a climate-adaptive agricultural strategy.

➤ *Crop Diversification Analysis*

Crop diversification increased significantly during the study period due to environmental instability and adaptive agricultural strategies. The Crop Diversification Index (CDI) was calculated using the Gibbs-Martin method (1962).

Table 9 Crop Diversification Index

Agricultural Year	Crop Diversification Index
1999–2000	0.69
2012–2013	0.76
2025–2026	0.78

Source: Calculated by Author using Gibbs-Martin Method (1962).

The increasing CDI value (Table 9) indicates that farmers gradually diversified cropping practices to reduce agricultural risk and economic uncertainty associated with flood hazards.

➤ *Overall Yield Analysis*

The Overall Yield Index proposed by Shafi (1972) was used to evaluate changes in agricultural performance (Table 10).

Table 10. Overall Yield Index

Agricultural Year	Overall Yield Index
1999–2000	1.14
2012–2013	1.23
2025–2026	1.30

Source: Calculated from Agricultural Production Data.

Despite repeated flood hazards, the overall yield index improved gradually due to mechanization, irrigation development, fertilizer use, and crop diversification.

➤ *Crop Productivity Analysis*

Crop productivity was analyzed using the Enyedi Crop Productivity Index (1964). The results (Table 11) indicate declining productivity for traditional cereal crops and increasing productivity for orchard crops.

Table 11 Crop Productivity Index (Enyedi, 1964)

Crop	1999–2000	2012–2013	2025–2026
Boro Paddy	0.32	0.65	0.36
Jute	0.63	0.65	0.42
Vegetables	1.14	0.97	0.76
Mango	1.04	1.92	6.52

Source: Calculated by Author.

The exceptionally high productivity index of mango indicates that orchard farming emerged as one of the most successful adaptive agricultural strategies in the flood-affected environment.

➤ *Volume of Change in Crop Cultivation*

The volume of change in crop cultivation was calculated following the method of Singh and Dhillon (1984). The analysis (Table 12) demonstrates substantial changes in crop composition and agricultural land utilization.

Table 12 Volume of Change in Crop Cultivation

Crop	Change in Percentage Points (2025–2026 over 2012–2013)
Boro Paddy	-1.32
Jute	+0.25
Vegetables	+3.40
Mango	+0.56
Mustard	+1.13

Source: Calculated by Author.

The results show declining dominance of Boro paddy and increasing importance of vegetables, mustard, and orchard cultivation.

V. DISCUSSION

The lower Bhagirathi floodplain of Guptipara Char Mouza represents a highly dynamic fluvial landscape where recurrent flooding, channel instability, and sand-splay deposition have significantly altered the agricultural environment and rural livelihood structure during the last two decades [37,38]. The comparative analysis between the agricultural years 1999–2000, 2012–2013, and 2025–2026 clearly demonstrates that repeated flood events have transformed both the ecological and socio-economic foundations of the floodplain community.

The flood events of 2000, 2007, and 2015 revealed considerable temporal variation in flood magnitude and spatial extension within the study area. The flood of 2000 affected nearly the entire mouza, while the subsequent floods of 2007 and 2015 showed relatively lower inundation extent due to partial embankment reinforcement and localized flood-control interventions. Nevertheless, the persistence of annual flooding continues to produce severe environmental stress within the lower floodplain ecosystem [39].

One of the most important findings of the study is the increasing impact of sand-splay deposition on agricultural land degradation. Field investigation and plot-wise land-use survey indicate that coarse sand deposition after major flood events reduced soil fertility, moisture-retention capacity, and crop suitability in extensive portions of agricultural land [40,41]. Similar sand-casting processes have been widely reported from the Kosi floodplain, Brahmaputra valley, and lower Ganga floodplain where post-flood sedimentation creates long-term agricultural disruption [42].

The study further reveals a substantial transformation in cropping pattern and agricultural intensity during the study period. Boro paddy remained the dominant crop; however, its cultivation gradually declined due to repeated flood damage, unstable irrigation conditions, and increasing sand deposition. At the same time, orchard farming, particularly mango cultivation, increased significantly as an adaptive response to environmental instability [43].

The calculated agricultural indices also demonstrate important structural transformations within the farming system. Cropping intensity declined sharply after the flood of 2000 due to large-scale inundation and land degradation, although it gradually recovered through technological adaptation, increased irrigation coverage, and reclamation of sand-covered fields. The application of the Gibbs–Martin Crop Diversification Index indicates increasing crop diversification between 1999–2000 and 2025–2026. This diversification reflects farmers' adaptive strategy to reduce dependence on a single crop under environmentally uncertain conditions [44].

Similarly, the Overall Yield Index proposed by Shafi (1972) indicates gradual improvement in aggregate productivity despite the declining performance of several traditional crops. However, the Enyedi Crop Productivity Index demonstrates that productivity changes were uneven across crop categories. Traditional food crops exhibited declining productivity trends, while mango and sweet potato showed relatively higher productivity growth.

The socio-economic analysis demonstrates that recurrent flooding has substantially altered rural livelihood patterns in the study area. The proportion of cultivators declined significantly between 2000 and 2026, while engagement in agricultural labour, business, transportation, textile work, and service activities increased. Occupational diversification emerged primarily as a livelihood adaptation mechanism against agricultural uncertainty [45].

The household income analysis further highlights persistent socio-economic vulnerability among flood-affected communities. Although the proportion of middle-income households increased gradually, a considerable percentage of households remained within the low-income category even in 2026. Economic vulnerability persists because agricultural production remains highly unstable and flood-sensitive.

The findings of the study demonstrate that recurrent flood and sand-splay processes have fundamentally transformed the agricultural landscape, ecological condition, and livelihood structure of the lower Bhagirathi floodplain.

VI. CONCLUSION

The present study clearly demonstrates that recurrent flooding and flood-induced sand-splay deposition have significantly transformed the agricultural landscape and rural livelihood structure of Guptipara Char Mouza over the last two and a half decades. Comparative analysis between the agricultural years 1999–2000, 2012–2013, and 2025–2026 reveals substantial changes in flood extent, land-use pattern, cropping intensity, crop productivity, irrigation practices, and occupational structure. The flood events of 2000, 2007, and 2015 caused severe environmental degradation through prolonged inundation and large-scale sand deposition, which reduced soil fertility, altered soil texture, and negatively affected traditional crop cultivation.

The study further indicates that the socio-economic vulnerability of rural households remains high despite gradual adaptation and livelihood diversification. Repeated crop loss, unstable agricultural income, inadequate irrigation facilities, and declining land productivity have forced many households to shift toward alternative occupations including business, transportation, service activities, textile work, and seasonal labour migration. Sustainable management of the lower Bhagirathi floodplain therefore requires integrated floodplain planning, scientific river management, effective sediment-control measures, community-based disaster preparedness, and promotion of climate-resilient agriculture.

FUTURE SCOPE OF THE STUDY

The present micro-level study provides important insights into the interaction between flood hazards, sand-splay deposition, agricultural transformation, and livelihood adaptation in the lower Bhagirathi floodplain. However, future research may further improve the understanding of floodplain dynamics through advanced geospatial and interdisciplinary approaches.

Future studies should incorporate high-resolution satellite imagery, drone-based mapping, and GIS-based hydrodynamic modelling for detailed assessment of flood inundation, sediment deposition, and river-channel migration. Long-term climatic analysis using rainfall variability and discharge data would help to understand the influence of climate change on flood frequency and agricultural vulnerability. Detailed soil-quality assessment, groundwater analysis, and sediment-characterization studies are also required to evaluate the long-term ecological consequences of repeated sand deposition. In addition, socio-economic studies focusing on gender dimensions, migration patterns, rural health vulnerability, and livelihood resilience may provide a broader understanding of adaptation strategies in flood-prone communities.

Future research should also evaluate the effectiveness of government flood-control measures, crop-insurance schemes, climate-resilient agricultural technologies, and community-based adaptation programmers. Comparative studies across multiple floodplain mouzas of the lower Gangetic basin would help to establish broader regional patterns of agricultural transformation and environmental vulnerability.

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