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# Agro ecological variability, technology adoption, and livelihoods in the Sundarbans delta: evidence from a baseline study

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This research investigates the socio-economic profile, land resources, cropping patterns, livelihood strategies, and technology adoption of farming households in two contrasting agro-ecological settings: saline and lowsaline areas of the Sundarbans delta in West Bengal. The two blocks under study were Hasnabad (North 24 Parganas) and Basanti (South 24 Parganas). A baseline survey of 400 farmers, equally divided between the two blocks, was conducted using stratified random sampling to capture differences in salinity, water availability, and agricultural intensity. Data was gathered over an entire agricultural year through a structured questionnaire covering demographics, landholding, crop management, allied enterprises, institutional access, and production constraints. Results indicate clear contrasts between the two blocks. Farmers in Hasnabad are relatively older, have larger households, and maintain higher cropping intensity (243.4%) through rotations such as rice–mustard–jute, achieving greater *kharif* rice yields (4110.9 kg per hectare) than Basanti (138.9%, 3484.6 kg per hectare). Basanti shows more rice monocropping, lower fertilizer application, higher migration rates, and greater female participation in farming, albeit with lower individual labor intensity. Both regions face *rabi* season irrigation shortages, while Hasnabad additionally struggles with high soil salinity and Basanti with inadequate market infrastructure. Recommended measures include the introduction of salt-tolerant and hybrid high-yielding varieties, diversification in monocropping and saline areas, land shaping for water harvesting, improved vegetable seed delivery, targeted fisheries training, and site-specific integrated nutrient management with essential micronutrients. Policy priorities should differ by location: Hasnabad requires salinity control, expanded irrigation, and adoption of climate-resilient practices, whereas Basanti needs better irrigation, stronger market linkages, and a shift toward high-value diversified crops.

KEYWORDS

**Asian mega delta, baseline survey, farming systems, livelihoods, rural development, socio-economic profile, Sundarbans**

# 1 Introduction

The Ganges-Brahmaputra-Meghna (GBM) delta is one of the largest Asian mega deltas, alongside the Yangtze, Pearl, Chao Phraya, and Mekong deltas, collectively spanning over 215,000 $km^2$ and supporting more than 400 million people, which accounts for approximately 80% of the global deltaic population (Tatem, 2017; Chan et al., 2024). These deltas have formed through continuous sediment deposition where rivers meet oceans, resulting in diverse deltaic forms such as, fan-shaped, lobate, or bird's foot deltas. The Sundarbans mangrove ecosystem, a significant part of the GBM delta, covers around 100,000 $km^2$ shared between Bangladesh (60%) and India (40%) (Gopal and Chauhan, 2006; Abul et al., 2024). The Indian Sundarbans lies within West Bengal and comprises about 2,400 $km^2$, constituting the most extensive contiguous tidal halophytic mangrove forest globally. This ecosystem supports high biodiversity, with around 350 plant species, 250 fish species, 300 bird species, and numerous other fauna (Gopal and Chauhan, 2006).

Agriculture is the primary livelihood in the Sundarbans, with approximately 315,000 hectares of cultivable land (Department of Sundarbans Affairs, 2018). Rice cultivation dominates, covering 98% of the cultivated area, mainly during the monsoon season from June to November. Cropping patterns often include rice-rice, rice-vegetable, and rice-fallow rotations, with minor areas for oilseeds and pulses (Indian Council of Agricultural Research–National Rice Research Institute, 2022). However, agriculture here is rainfed primarily (about 80%) due to limited irrigation infrastructure, leading to fallow fields during dry months, compounded by soil salinity and waterlogging challenges (Bhattacharyya et al., 2021; Saha, 2015). Soil salinity is a critical abiotic stress restricting agricultural productivity in the Sundarbans. Salinity results from seawater intrusion due to tidal floods, storm surges and upward capillary rise of salts from shallow brackish groundwater with levels peaking in the dry summer months due to evaporation (Biswas et al., 2017a; Mandal et al., 2023). It limits nutrient availability, causes osmotic stress that hampers root development and water uptake, and leads to toxic ion accumulation in plants, thereby reducing crop yield (Pan et al., 2021; Zhang et al., 2022). Waterlogging and poor drainage lead to hypoxia, further affecting root respiration and plant health (Pan et al., 2021). Rice productivity remains low at around 2.5 tons per hectare due to these constraints (Palombi and Sessa, 2013; Mandal et al., 2023; Sarangi et al., 2016). The region frequently suffers from tropical cyclones, such as Aila (in 2009), Bulbul (in 2019), Amphan (in 2020), and Remal and Dana (in 2024), which cause saline water inundation and destruction of crops and agricultural lands (Palombi and Sessa, 2013; Biswas et al., 2017a). These disasters severely threaten the resilience of local farmers and rural livelihoods.

Socioeconomic vulnerabilities exacerbate these environmental challenges. Over 40% of households in the Indian Sundarbans live below the poverty line, with many relying on subsistence agriculture, fishing, and forest-based activities that are highly susceptible to climate shocks and seasonal unemployment during lean agricultural periods (Ghosh et al., 2014; Majumder, 2023). Education and healthcare access are limited, and migration to urban centers for employment is common as a coping strategy (Ghosh et al., 2014; Majumder, 2023). Adaptation efforts by local communities include cultivating salt-tolerant and climate-resilient rice varieties, rainwater harvesting, and agroforestry practices. However, adoption rates remain limited due to infrastructural and institutional challenges (Jana et al., 2013; Billah et al., 2021). Enhancing irrigation infrastructure, community awareness, and climate-smart agricultural practices are vital for building resilience (Jana et al., 2013). Mangrove forests themselves provide critical ecosystem services by protecting agricultural lands and settlements from storm surges and coastal erosion but are under threat due to deforestation for shrimp farming, aquaculture expansion, and illegal extraction (Guha et al., 2006; Zero Carbon Analytics, 2022). Climate change, including sea level rise and altered rainfall patterns, intensifies these stresses, further threatening biodiversity, agricultural productivity, and livelihoods (Ghimire and Vikas, 2012).

Recognizing these challenges, the Consultative Group of International Agricultural Research (CGIAR) launched the Food Systems of the Asian Mega-Deltas for Climate and Livelihood Resilience (AMD) Initiative. This program aims to develop resilient, inclusive, and productive agricultural systems in Asian mega-deltas by implementing locally relevant and scalable interventions. A bottom-up approach was adopted through a detailed farmer survey in the Sundarbans delta of West Bengal to document agricultural practices, constraints, and livelihood conditions. By actively involving local farmers, the study captured insights into cropping systems, input use, resource access, and adaptive strategies against salinity, tidal inundation, and variable rainfall. The findings provide essential baseline information to understand regional vulnerabilities and resilience patterns. This evidence supports the formulation of context-specific interventions aimed at improving agricultural sustainability, building climate resilience, and enhancing the socio-economic well-being of farming communities in the ecologically fragile Sundarbans delta.

# 2 Materials and methods

## 2.1 Study area

The present study was undertaken in two districts of the Sundarbans delta *viz.*, North 24 Parganas and South 24 Parganas located in the southern part of West Bengal, India. Within these districts, the Hasnabad block (North 24 Parganas) and Basanti block (South 24 Parganas) were purposively selected to represent contrasting agro-ecological conditions. The study location is depicted in Figure 1. According to the latest district statistics, North 24 Parganas has an estimated population of approximately 1.0 billion, while South 24 Parganas hosts about 0.8 billion inhabitants.

The Hasnabad block is characterized by freshwater availability predominantly during the monsoon season, sourced from the Ichamati River and its distributaries. In the dry season, the area experiences brackish water intrusion due to tidal backflow from the Bay of Bengal. Local farmers typically follow triple-cropping sequences, such as rice-mustard-jute, and rice-vegetables-jute. Freshwater availability in Basanti is limited to the rainy season (June–October), while tidal inflow during the dry season renders irrigation water saline. Farmers here generally adopt double-cropping systems including rice-rice, rice-vegetables, and rice-pulses. The agro-hydrological contrasts between the two sites were a decisive factor in their selection, as they enabled the study to capture farming practices

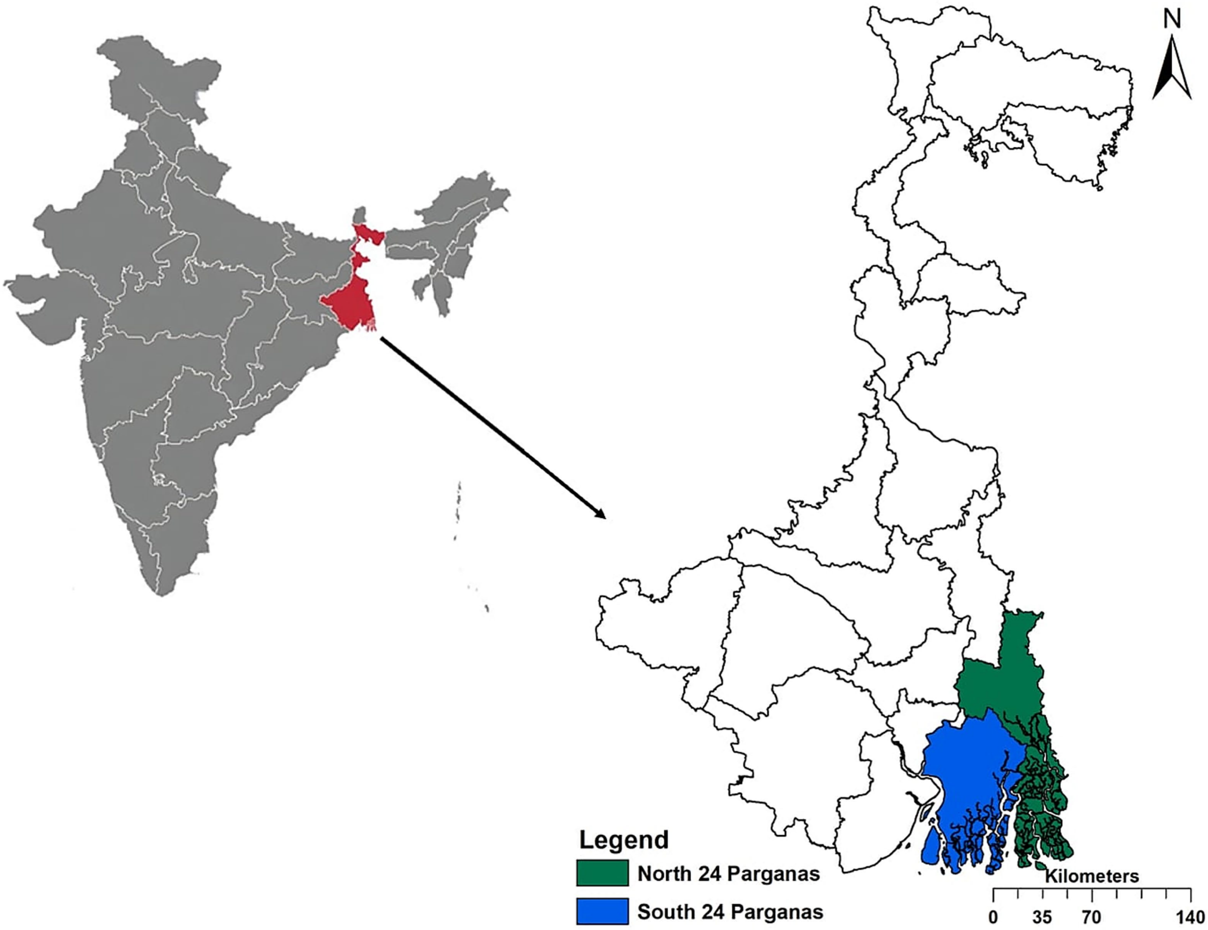


FIGURE 1
The study-area-location-map.

and constraints across diverse salinity and water availability regimes within the delta.

The Basanti and Hasnabad areas, experience a tropical subtropical climate characterized by significant monsoonal rainfall and high humidity. The annual average rainfall in Basanti is around 1,650 mm, typical of the alluvial and deltaic plains of South 24 Parganas, with approximately 74% of this rainfall occurring during the monsoon season from June to September. During this period, temperatures generally range between 26 °C to 33 °C with high humidity levels. Hasnabad, situated in North 24 Parganas and adjacent to Basanti, receives a slightly higher average annual rainfall estimated between 1800 and 1900 mm. The major portion of rainfall also falls between June and September, with average monthly rainfall in August reaching about 435 mm. Temperatures in Hasnabad during the peak monsoon months usually range from 26 °C to 31 °C, accompanied by similarly high humidity.

## 2.2 Survey design

A baseline household survey was implemented, covering a total of 400 farmers, with 200 respondents surveyed in each of the two study blocks. The selection employed a stratified random sampling strategy, wherein villages within each block were first identified to reflect key agro-ecological conditions, and households engaged in paddy-based cropping systems were then randomly sampled from updated farmer lists. A structured questionnaire, a Baseline Survey Questionnaire (attached as Supplementary material), formed the primary data collection tool. The survey instrument was carefully designed to capture a broad spectrum of socio-economic, biophysical, and farm management variables relevant to the study objectives. The structured questionnaire comprised seven major modules:

- Household demographics: information on the socio-demographic profile of the respondents, including age, gender, educational attainment, migration status, and occupational composition of household members.
- Landholding and tenure: data on the extent of cultivated land, ownership or lease arrangements, land classifications, and prevailing soil health conditions.
- Cropping systems and management practices: details of seasonal cropping patterns, crop varieties, input usage, pest and weed management practices, irrigation sources, and cost of cultivation.
- Harvest and post-harvest management: records of yield levels, value addition processes, storage infrastructure, and marketing channels used by farmers.

- Abiotic stresses and coping strategies: farmer-reported experiences of salinity intrusion, flooding, cyclonic events, and drought, along with the adoption of climate resilient agricultural practices.
- Allied agricultural activities: engagement in livestock rearing, poultry farming, and fisheries, including their contribution to household income.
- Extension and support services: access to government schemes, farmer training programs, and technology dissemination channels.

The questionnaire was designed to align with the research objectives, ensuring a systematic comparison of farming practices, resource access, and adaptive strategies across the two study blocks. This structure also served to generate a comprehensive baseline dataset to support future monitoring and evaluation of agricultural development interventions in the Sundarbans delta.

## 2.3 Data collection

The survey was conducted through face-to-face interviews conducted in the local language by trained enumerators. a two-day training programme that covered the objectives of the research, a detailed review of questionnaire content, mock interview exercises, and ethical guidelines, including protocols for obtaining informed consent and ensuring respondent confidentiality was organized for enumerators. Data collection was conducted across one full cropping year to account for both *kharif* and *rabi* season production activities. Respondents were encouraged to refer to farm records to improve the accuracy of recall-based responses. Ethical considerations were strictly adhered to throughout the study. Participation was voluntary, informed consent was obtained verbally, and all responses were anonymized in compliance with institutional ethics protocols.

## 2.4 Data processing and analysis

Upon completion of fieldwork, all questionnaires were systematically checked for completeness and logical consistency. Data entry was performed using a predefined coding framework. The data processing steps included two steps *viz*., identification and correction of missing, inconsistent, or outlier values (Cleaning) and transformation of categorical responses into numerical codes for analytical purposes (Coding). Subsequent descriptive statistical analyses including frequency distributions, means, and percentages; and graphical outputs (bar charts, pie diagrams, histograms) and tabulated summaries were generated using Microsoft Excel and SPSS software (Verma, 2012; George and Mallery, 2018). These analytical outputs were used to describe patterns in household structure, landholding distribution, crop management practices, productivity, and market participation in the two study blocks.

# 3 Results

## 3.1 Demographic and household profile

The socio-economic characteristics of farmers in Hasnabad and Basanti blocks show notable variations. In Hasnabad, the average age of farmers is 49.4 years, ranging from 23 to 79 years, with a standard deviation of 13.2, while in Basanti, the average age is lower at 42.2 years, ranging from 21 to 74 years, with a standard deviation of 11.9 (Table 1). Operational landholding averages 0.5 ha in Hasnabad (ranging from no land to 2.0 ha) and 0.4 ha in Basanti (0.1–2.4 ha) (Table 1). The percentage of males and females involved in the whole survey was 87.0 and 13% overall. A survey of 200 farmers each in the Hasnabad and Basanti blocks shows that male farmers dominate all age groups, especially in Hasnabad, where almost no women are involved in farming (Figure 2a). In Basanti, however, female participation is higher, particularly among younger farmers (up to 33% in the 20–30 age group), though it declines with age.

Overall, while men remain the majority in agriculture, there are signs of increasing involvement of women in farming among the younger generation, particularly in Basanti. The majority of farmers in Hasnabad and Basanti have low levels of education, with most completing only primary education or having no formal schooling. Very few farmers progress to upper secondary, diploma, or university entrance, indicating limited access to higher education in these regions. The primary occupation of respondents of both the blocks is farming, labour being secondary occupation (Figure 2b).

### 3.1.1 Migration pattern

The comparative analysis of socio-economic indicators between Hasnabad and Basanti reveals distinct differences in household composition and male migration. The average family size is larger, with 6.8 members (including males, females, and children) compared to 5.2 members in Basanti (Figure 2). Similarly, the average number of males per household is slightly higher in Hasnabad (2.47) than in Basanti (2.14), and the average number of females per household is also greater in Hasnabad (2.24) compared to Basanti (1.75). Male migration is more prevalent in Hasnabad, with an average of 1.4 migrating males per household, whereas in Basanti, the figure stands at 1.2. This

TABLE 1 Socio-economic characteristics of farmers.

| Particulars | Hasnabad | | | | Basanti | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Min. | Max. | Mean | SD | Min. | Max. |
| Age (years) | 49.4 | 13.2 | 23.0 | 79.0 | 42.2 | 11.9 | 21.0 | 74.0 |
| Family size (no.) | 5.8 | 2.8 | 1.0 | 20.0 | 4.8 | 2.2 | 2.0 | 19.0 |
| Operational landholding (ha) | 0.5 | 0.3 | 0.0 | 2.0 | 0.4 | 0.3 | 0.1 | 2.4 |

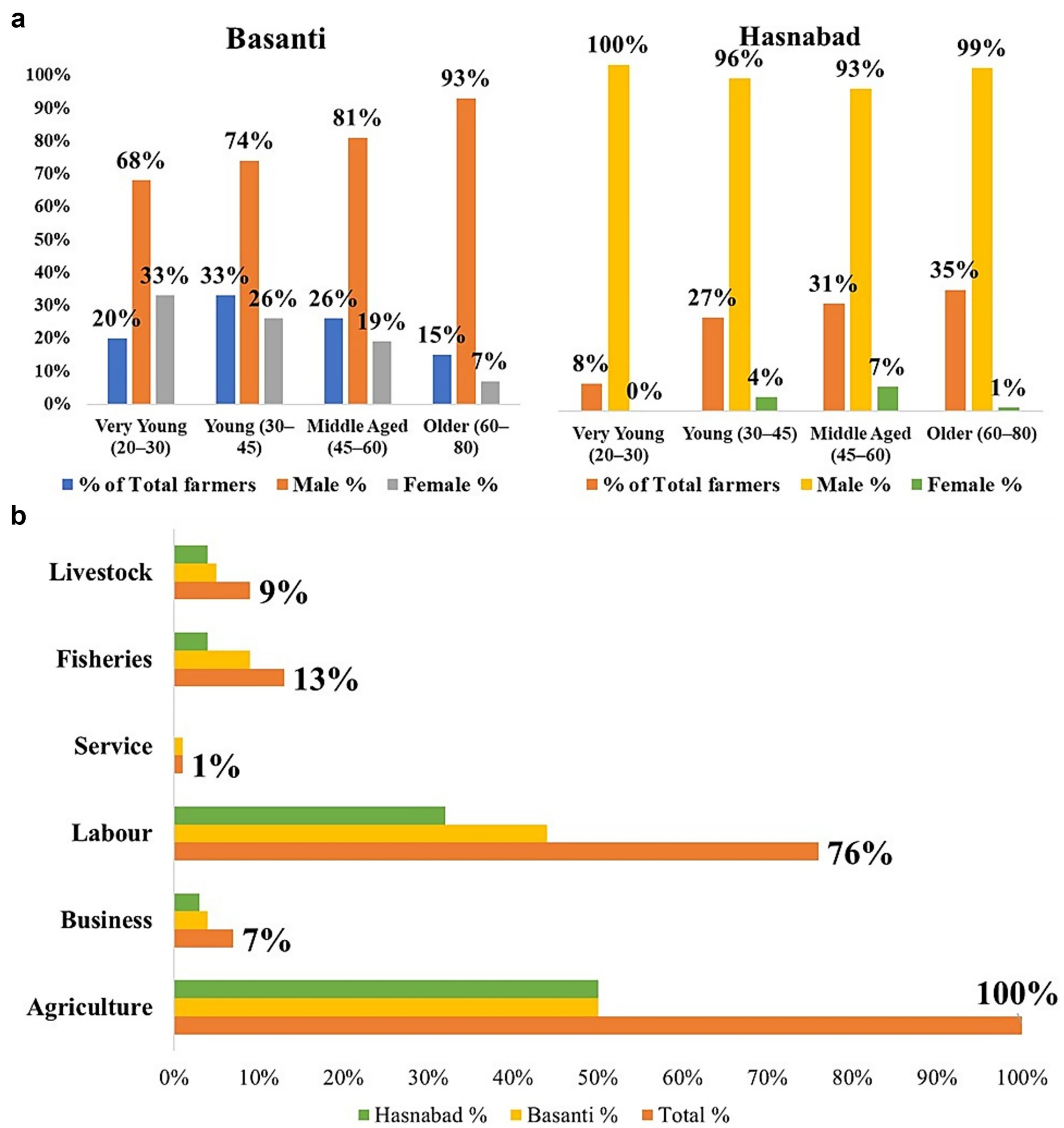


FIGURE 2
**(a,b)** Information about the gender and occupation of farmers of both the block.

indicates that Hasnabad households tend to be larger, with higher numbers of both male and female members, and also experience slightly higher male migration rates than Basanti. The overall percentage of migration among the respondents was 5.1% of households in Hasnabad, while 33.2% of households in Basanti reported migration.

## 3.2 Land holding and utilization

### 3.2.1 Land type classification (in acre)

The land type classification in the surveyed area highlights the predominance of medium and low lying fields, characterized by higher waterlogging depths (Table 2). In Basanti block, only 0.6 acres (1.3%) fall under high land with no waterlogging, and 3.7 acres (8.0%) are upland areas with shallow waterlogging of less than 15 cm. The majority, 28.0 acres (60.7%), are medium land with waterlogging depths of 15–30 cm, while 12.4 acres (26.9%) are low land areas experiencing deep waterlogging exceeding 30 cm. In Hasnabad block, 9.6 acres (2.7%) are high land without waterlogging, and 11.1 acres (3.1%) are upland areas with less than 15 cm waterlogging. The bulk of cultivated land (294.9 acres, i.e., 81.2%) falls under medium land with 15–30 cm waterlogging depth, while 87.8 acres (24.1%) are low land with more than 30 cm waterlogging. Overall, across both blocks, only 2.2% of land is high land (no waterlogging) and 3.2% is upland (<15 cm waterlogging), whereas medium land with 15–30 cm waterlogging accounts for 70.0% of the area, and low land with >30 cm waterlogging covers 21.7%. This indicates that most agricultural land is subject to seasonal water accumulation, which has

TABLE 2 Classification of land (in acre) based on type of land and depth of waterlogging.

| Blocks | High land (no waterlogging) | Upland area (depth of waterlogging <15 cm) | Medium land area (depth of waterlogging 15 to 30 cm) | Low land area (depth of waterlogging >30 cm) |
|---|---|---|---|---|
| Basanti | 0.6 | 3.7 | 28.0 | 12.4 |
| Hasnabad | 9.6 | 11.1 | 294.9 | 87.8 |
| Total | 10.2 | 14.8 | 322.9 | 100.2 |

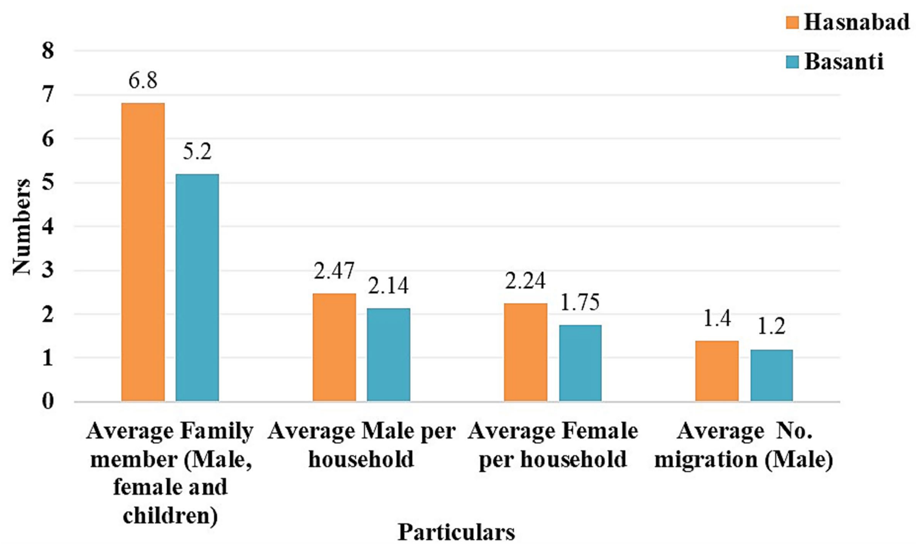


FIGURE 3
Family and migration statistics of the two blocks.

significant implications for crop choice, drainage management, and productivity Figure 3.

The pie charts illustrate the distribution of agricultural land types in Hasnabad and Basanti blocks based on the depth of waterlogging (Figures 4, 5). In Hasnabad, the majority of land (73%) falls under medium land with a waterlogging depth of 15–30 cm, followed by low land (>30 cm waterlogging) at 22%. High land without waterlogging accounts for only 3%, while upland areas with shallow waterlogging (<15 cm) are negligible at 2%. In Basanti, medium land also dominates, covering 63% of the total area, followed by low land with deep waterlogging (>30 cm) at 28%. Upland areas (<15 cm waterlogging) constitute 8%, and high land with no waterlogging is minimal at 1%. Overall, both blocks are predominantly characterized by medium and low land types, indicating that most cultivated areas experience moderate to high seasonal waterlogging, which has direct implications for crop selection and water management practices.

### 3.2.2 Saline area

The distribution of saline areas shows a significant disparity between the two blocks. Hasnabad has a considerably larger saline affected area, measuring 147.5 acres, compared to only 30.8 acres in Basanti (Figure 6). This indicates that soil salinity is a more prominent issue in Hasnabad, which could potentially limit crop choice, reduce productivity, and necessitate the adoption of salinity management practices. In contrast, the relatively smaller saline area in Basanti suggests a lesser degree of soil salinity constraints, allowing for a wider range of crop cultivation options practices.

## 3.3 Cropping patterns and practices

### 3.3.1 Major crops and seasons

In Hasnabad block, rice is universally cultivated in the *kharif* season, with 100% of the surveyed farmers (200 farmers) growing the crop. In the *rabi* season, 97.5% of the farmers who cultivated crops (188 out of 195) grew mustard, while the remaining 2.5% grew vegetables. During the summer season, only 81% of the farmers (162 out of 200) engaged in cultivation, with 94.4% of them (153 farmers) growing jute and the remaining 5.6% cultivating sesame. The major cropping system in Hasnabad is predominantly rice–mustard–jute, reflecting a strong reliance on oilseed and fibre crops after the *kharif* rice harvest.

In Basanti block, rice dominates the *kharif* season, with 100% of the surveyed farmers (200 respondents) cultivating the crop. In the *rabi* season, 39% of farmers (78 respondents) grow pulses, including *khesari*, 34.5% (69 farmers) cultivate vegetables such as chilli, potato, brinjal, bitter gourd, and ridge gourd, while 26.5% (53 respondents) grow rice. The major cropping system observed is a rice-based sequence, with *kharif* rice followed by *rabi* pulses, vegetables, or rice. Yet, 26.5% farmers follow rice monocropping which require crop

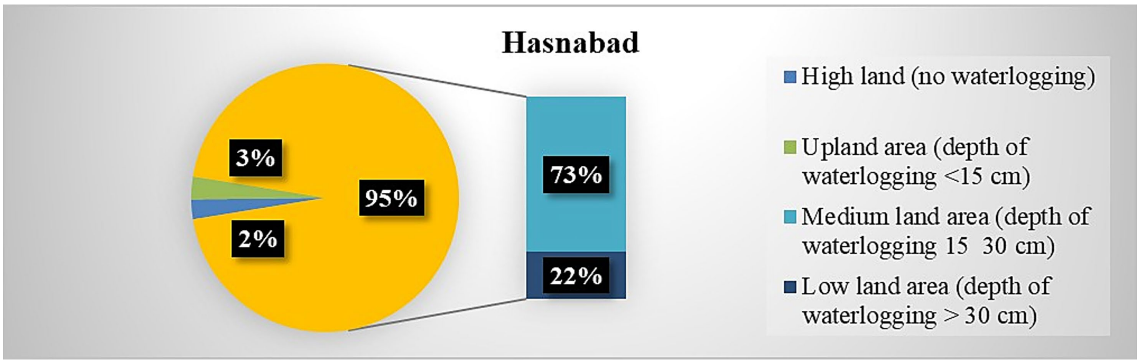


FIGURE 4
Land type classification in Hasnabad block.

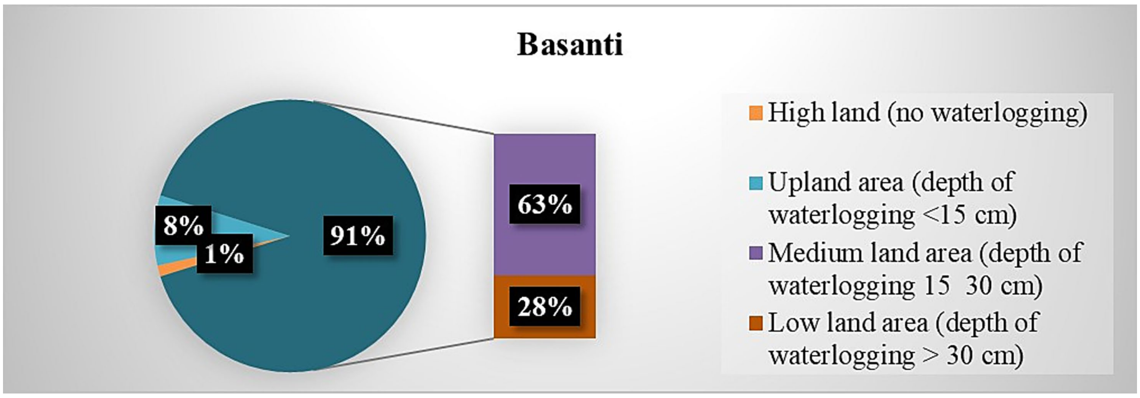


FIGURE 5
Land type classification in Basanti block.

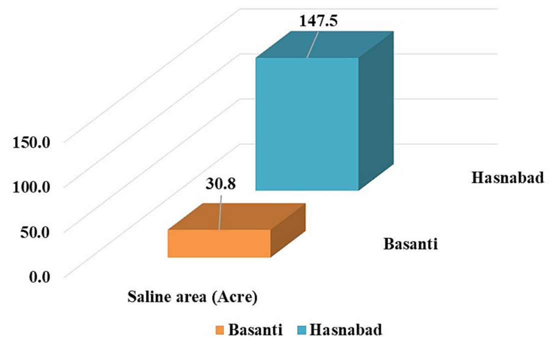


FIGURE 6
Block wise distribution of saline areas (acre).

diversification. In summer, none of the respondent had grown any crop.

### 3.3.2 Cropping intensity

The block-wise analysis of cropping area reveals notable differences between Hasnabad and Basanti. In Hasnabad, the cultivated area was 232.0 acres during *kharif*, 189.9 acres in *rabi*, and 142.8 acres in the summer season, resulting in a high cropping intensity of 243.4% (Table 3). In contrast, Basanti recorded 191.9 acres in *kharif*, 74.7 acres in *rabi*, and no cultivation in summer, leading to a much lower cropping intensity of 138.9%. The higher cropping intensity in Hasnabad indicates more intensive use of agricultural land across multiple seasons, while the absence of summer crops in Basanti suggests seasonal cultivation limitations, possibly due to factors such as water availability or soil conditions.

**TABLE 3** Block wise cropping area in different seasons and the cropping intensities.

| Blocks | *Kharif* (acre) | *Rabi* (acre) | Summer (acre) | Cropping intensity (%) |
|---|---|---|---|---|
| Hasnabad | 232.0 | 189.9 | 142.8 | 243.4 |
| Basanti | 191.9 | 74.7 | 0.0 | 138.9 |

### 3.3.3 Rice varietal information

Despite the availability of newer high yielding and stress tolerant rice varieties, farmers in Hasnabad and Basanti continue to rely on several traditional cultivars. In Hasnabad, Gotra, Jaya, and Pratikhya remain popular among cultivators, while in Basanti, Bangabondhu, Jamuna, and Santashi are still widely grown (Figure 7).

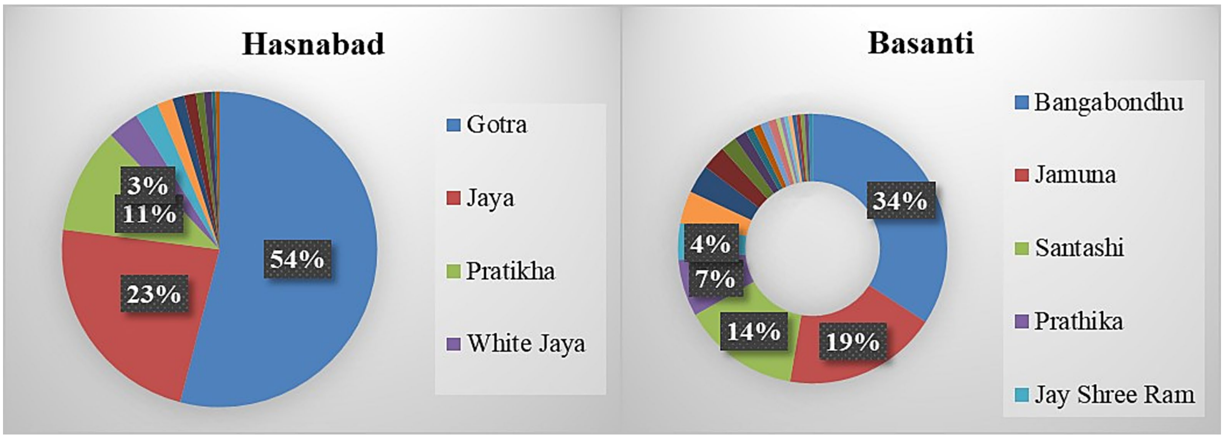


FIGURE 7
Rice varietal usage in two blocks.

### 3.3.4 Average rice yield in *kharif*

In the *kharif* season, the average rice yield in Hasnabad block is 4110.93 kg/ha, which is notably higher than the 3484.61 kg/ha recorded in Basanti block (Figure 8). This difference of 626.32 kg/ha suggests that Hasnabad enjoys more favorable production conditions, possibly due to better soil fertility, improved irrigation availability, or superior crop management practices. Conversely, the lower yield in Basanti may be linked to constraints such as saline patches, limited water resources, or other abiotic stresses that hinder optimal crop performance.

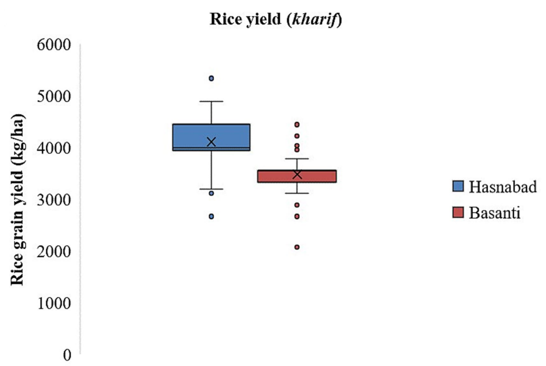


FIGURE 8
The average grain yield in *Kharif*.

### 3.3.5 Average fertilizer used NPK

In the *kharif* season, the average nutrient application in rice crops shows a clear difference between Hasnabad and Basanti blocks (Figure 9). Farmers in Hasnabad applied 94.2 kg/ha of nitrogen, 58.6 kg/ha of phosphorus, and 49.5 kg/ha of potassium, indicating a relatively balanced and higher input use. In contrast, Basanti recorded much lower application rates, with 51.8 kg/ha of nitrogen, 24.2 kg/ha of phosphorus, and 24.5 kg/ha of potassium.

The substantially higher nutrient use in Hasnabad could be a contributing factor to its higher rice yields, while the lower rates in Basanti may reflect resource constraints, limited input availability, or differing management practices that could be affecting crop productivity.

## 3.4 Livelihood diversification

The average annual income of farmers in Hasnabad stood at ₹1,11,119, marginally lower than Basanti's ₹1,12,343 (Table 4). Yet, Hasnabad offered better employment opportunities with 302 workdays as against 258 in Basanti. Field crops remained the dominant sector, involving 194 farmers in Hasnabad and 168 in Basanti, with higher returns observed in Hasnabad (₹33,515) compared to Basanti (₹18,754). Vegetable cultivation was another important contributor, where 24 farmers in Hasnabad earned an average of ₹29,292, while 42 farmers in Basanti managed ₹20,487. Orchard based income was exclusive to Hasnabad, averaging ₹35,000 annually. In contrast, livestock rearing played a more significant role in Basanti, engaging 108 farmers with average yearly earnings of ₹20,564, against 68 farmers in Hasnabad who earned ₹12,424.

Income from local services were considerably higher in Hasnabad (₹1,42,000) than in Basanti (₹80,000), whereas outside service opportunities were recorded only in Basanti with an average of ₹60,000. Men's wage employment within the locality was substantial in both regions, involving 155 farmers in Hasnabad earning ₹57,000 on average and 161 farmers in Basanti with ₹52,377. Wage work outside the locality was more prevalent in Basanti, where 80 farmers earned an average of ₹62,621, compared to just 7 farmers in Hasnabad, though they reported a much higher return of ₹1,30,714. Women's participation in wage work remained limited, with only 2 women in Hasnabad (₹25,000) and 8 in Basanti (₹18,571). Aquaculture held greater significance in Basanti, engaging 115 farmers with an average income of ₹19,882, compared to 104 farmers in Hasnabad earning ₹15,826. Business related income was higher in Hasnabad (₹74,789) than in Basanti (₹70,000). Additionally, other income sources were reported by 13 farmers in Hasnabad averaging ₹62,384, while only 2 farmers in Basanti reported higher earnings of ₹80,000 (Figure 3; Table 5).

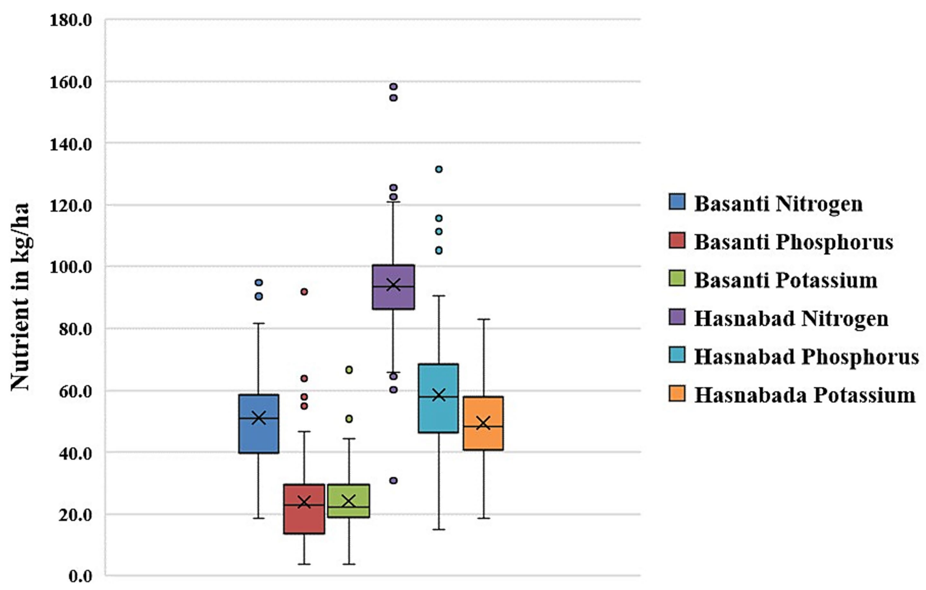


FIGURE 9
Amount of nutrient used in rice (kg/ha) in both the blocks.

TABLE 4 Source of income generation and average annual income per annum of farmers.

| Sector | Hasnabad | | Basanti | |
|---|---|---|---|---|
| | No. of farmers | Average income (₹) | No. of farmers | Average income (₹) |
| Field crops (paddy + pulses + oilseed) | 194 | 33,515 | 168 | 18,754 |
| Vegetables | 24 | 29,292 | 42 | 20,487 |
| Orchards | 2 | 35,000 | 0 | 0 |
| Livestock | 68 | 12,424 | 108 | 20,564 |
| Service (within locality) | 3 | 142,000 | 2 | 80,000 |
| Service (outside locality) | 0 | 0 | 2 | 60,000 |
| Men wage (within locality) | 155 | 57,000 | 161 | 52,377 |
| Men wage (outside locality) | 7 | 130,714 | 80 | 62,621 |
| Women wage (within locality) | 2 | 25,000 | 8 | 18,571 |
| Women wage (outside locality) | 0 | 0 | 0 | 0 |
| Aquaculture | 104 | 15,826 | 115 | 19,882 |
| Business | 19 | 74,789 | 2 | 70,000 |
| Others | 13 | 62,384 | 2 | 80,000 |
| Avg. total income per year | | 111,119 | | 112,343 |
| Avg. employment in days | | 302 | | 258 |

## 3.5 Innovation, knowledge, and institutional linkages

### 3.5.1 Hasnabad

The survey conducted in Hasnabad block among 200 respondents reveals very low adoption of several improved agricultural practices and technologies (Figure 10). None of the farmers reported using stress tolerant crop varieties, Integrated Pest Management (IPM) practices, machines for land levelling, direct seeding of rice, fertilizer application based on soil or crop needs, manure or biofertilizers, zero tillage, or alley cropping. Only 14 farmers (7%) practiced alternate wetting and drying (AWD) for irrigation, indicating limited awareness or feasibility of water saving irrigation methods. Incorporation of crop residues into the soil was practiced by just 3 farmers (1.5%) and mulching by only 4 farmers (2%), reflecting minimal residue management and soil conservation measures. A positive finding is that seed treatment before sowing had a high adoption rate, with 181 farmers (90.5%) following the practice, suggesting awareness of its benefits in disease and pest

TABLE 5 Women's participation in agriculture and allied sectors.

| Agriculture | Hasnabad | | | | Basanti | | | |
|---|---|---|---|---|---|---|---|---|
| | Average | SD | Min. | Max. | Average | SD | Min. | Max. |
| No. of days in work | 85.2 | 52.9 | 30 | 250 | 19.2 | 8.0 | 10 | 60 |
| Hours/day | 4.1 | 0.82 | 2 | 5 | 8.2 | 11.8 | 2 | 56 |
| Total no. of household | 23 | | | | 170 | | | |
| **Poultry** | | | | | | | | |
| No. of days in work | 279.5 | 57.0 | 100 | 365 | 292.7 | 43.0 | 30 | 320 |
| Hours/day | 6.7 | 7.3 | 0.5 | 23 | 1.8 | 2.4 | 0.5 | 12 |
| Total no. of household | 29 | | | | 98 | | | |
| **Livestock** | | | | | | | | |
| No. of days in work | 291.8 | 53.0 | 100 | 365 | 300.7 | 16.6 | 200 | 350 |
| Hours/day | 4.9 | 5.5 | 1 | 23 | 3.1 | 3.3 | 1 | 12 |
| Total no. of household | 49 | | | | 138 | | | |
| **Fisheries** | | | | | | | | |
| No. of days in work | 223.6 | 69.2 | 100 | 300 | 191.7 | 33.2 | 30 | 280 |
| Hours/day | 6.6 | 6.2 | 1 | 23 | 1.5 | 2.0 | 0.5 | 12 |
| Total no. of household | 91 | | | | 115 | | | |

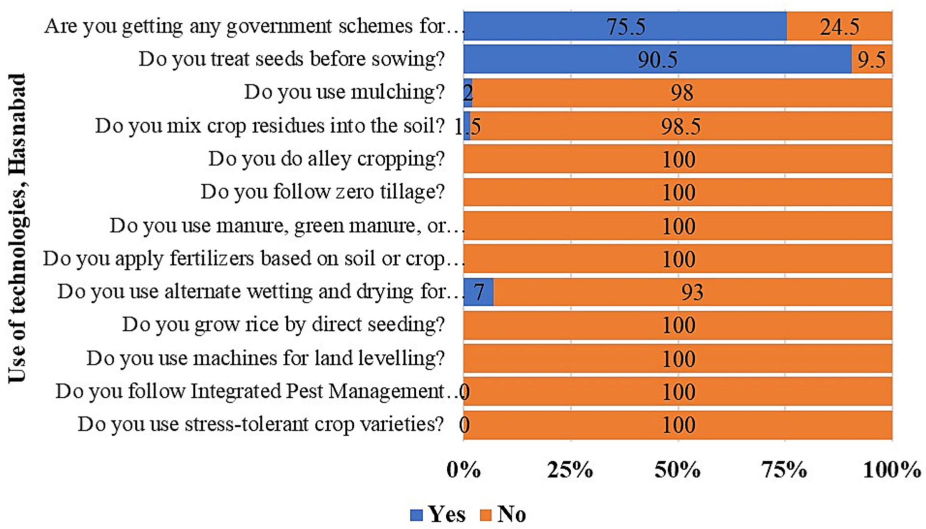


FIGURE 10
Usage of technologies among respondents in Hasnabad (% of responses).

prevention. Additionally, 151 farmers (75.5%) reported receiving benefits from government schemes for farming, livestock, fishery, insurance, or Direct Benefit Transfer (DBT), highlighting significant coverage of institutional support in the area.

The overall results suggest that while seed treatment and government assistance have relatively high penetration, most other improved agronomic practices remain absent in Hasnabad. The lack of adoption of modern techniques such as stress-tolerant varieties, IPM, and resource conserving technologies may be linked to poor irrigation access, salinity issues, lack of awareness, or inadequate extension support. Strengthening farmer training, demonstration programs, and access to inputs could enhance the adoption of climate resilient and resource efficient practices in the block.

### 3.5.2 Basanti

The survey results from Basanti block, conducted among 200 respondents, show a mixed pattern of adoption of agricultural practices (Figure 11). A large proportion of farmers (196 respondents, 98%) reported growing rice by direct seeding, suggesting a strong shift from traditional transplanting methods, likely influenced by labor and water constraints. Seed treatment before sowing also showed very high adoption, with 199 farmers (99.5%) following the practice, and mulching was adopted by 131 farmers (65.5%), indicating significant awareness of its role in moisture conservation and weed suppression. However, the adoption of other improved practices was minimal. Only 2 farmers (1%) used stress-tolerant crop varieties, and 4 farmers (2%) practiced Integrated Pest Management (IPM) or zero tillage. The use

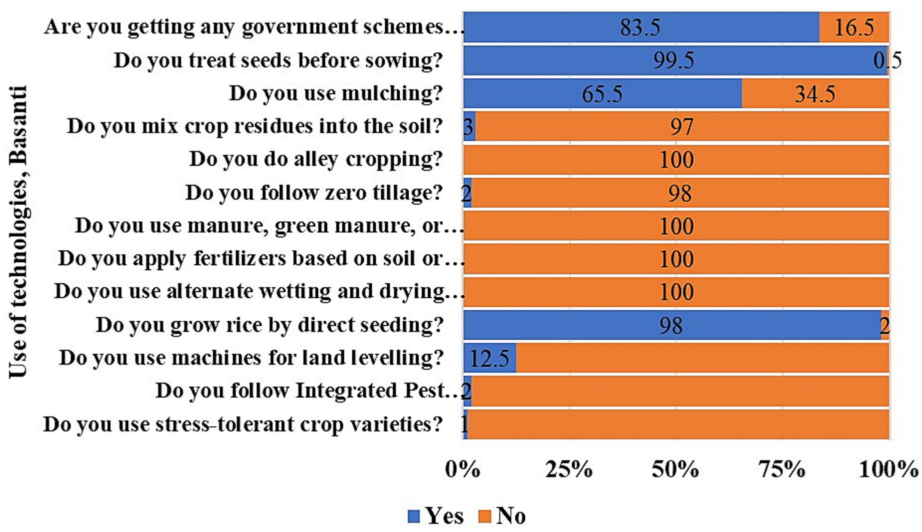


FIGURE 11
Usage of technologies among respondents in Basanti (% of responses).

of machines for land levelling was reported by 25 farmers (12.5%), indicating moderate mechanization in land preparation. Practices such as alternate wetting and drying, fertilizer application based on soil or crop needs, use of manure or biofertilizers, and alley cropping were completely absent. Incorporation of crop residues into the soil was done by only 6 farmers (3%). Institutional support was relatively high, with 167 farmers (83.5%) receiving benefits from government schemes for farming, livestock, fishery, insurance, or DBT, which suggest good outreach of policy interventions.

There is a clear difference in the adoption of agricultural practices. In Hasnabad, adoption of most improved practices was negligible, with the only notable exceptions being seed treatment which was followed by 90.5% of farmers and access to government schemes which reached 75.5% of respondents. Practices such as stress tolerant varieties, Integrated Pest Management, direct seeding, use of manure or biofertilizers, and resource conserving methods were almost entirely absent. In contrast, Basanti showed relatively higher adoption of certain techniques, particularly direct seeding of rice practiced by 98% of farmers, seed treatment by 99.5%, and mulching by 65.5%, along with moderate use of machines for land levelling by 12.5% of respondents. However, both blocks had extremely low uptake of climate resilient practices like stress tolerant varieties, alternate wetting and drying, zero tillage, and soil test-based fertilizer application, as well as limited use of organic soil amendments. Access to government schemes was slightly higher in Basanti at 83.5% compared to Hasnabad. The differences suggest that while Basanti farmers have adopted some modern practices, particularly in crop establishment and soil moisture management, Hasnabad lags behind in overall technology adoption. In both blocks there is a clear need for targeted extension programs, demonstrations, and improved input delivery systems to promote sustainable and climate resilient practices.

## 3.6 Challenges and opportunities

The survey results highlight the key constraints faced by farmers in the Hasnabad and Basanti blocks in undertaking *rabi* crop cultivation. In Hasnabad, the foremost problem reported by the majority of respondents was the lack of irrigation facilities, with 194 farmers indicating that the absence of assured water supply during the *rabi* season severely hampers crop establishment and growth (Figure 12). The second most significant issue was soil salinity, cited by 185 respondents, which affects soil health, reduces germination, and limits the choice of crops suitable for cultivation. The third major constraint was the non-availability of quality seeds, reported by 90 farmers, reflecting a gap in timely seed supply and access to improved varieties.

In Basanti, the leading problem was again the lack of irrigation facilities, mentioned by 199 respondents, highlighting the critical dependence on water for successful *rabi* crop production (Figure 13). The second major constraint was the non-availability of quality seeds, reported by 191 farmers, which mirrors the challenge seen in Hasnabad, indicating systemic seed supply issues in the region. The third problem identified was poor marketing facilities, with 182 respondents expressing concerns over inadequate infrastructure and market access, leading to reduced profitability and discouraging farmers from investing in *rabi* crops.

Overall findings underscore that water scarcity, seed supply issues, and location specific constraints like salinity in Hasnabad and poor marketing in Basanti are the primary barriers to enhancing *rabi* crop production. Addressing these challenges through improved irrigation infrastructure, timely seed distribution, soil management interventions, and better market linkages could significantly boost productivity and farmer incomes in both blocks.

## 4 Discussion

This comparative study of Hasnabad and Basanti blocks highlights substantial differences in demographic makeup, land characteristics, cropping patterns, livelihood strategies, technology adoption, and production constraints. Linking these findings with locally relevant recommendations reveals promising approaches for enhancing agricultural productivity and sustainability in the coastal saline and waterlogged environments of the Sundarbans delta.

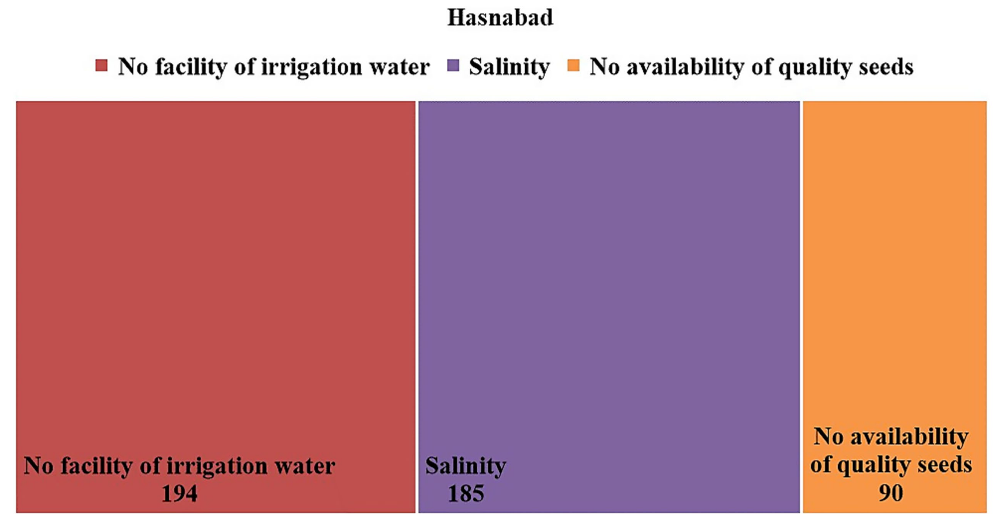


FIGURE 12
Top three problems to take *rabi* crops in Hasnabad block.

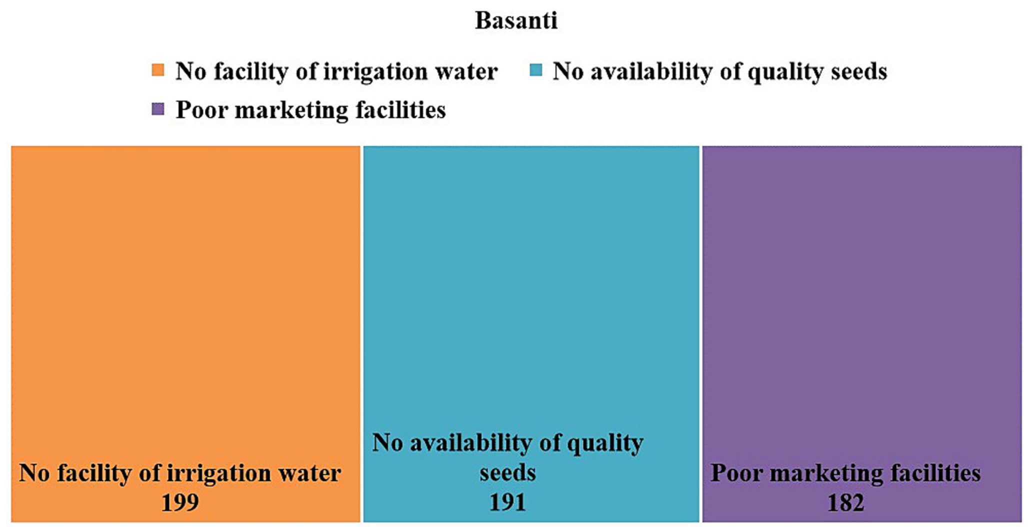


FIGURE 13
Top three problems to take *rabi* crops in Basanti block.

## 4.1 Socio-economic and demographic profile

Farmers in Hasnabad are on average older at 49.4 years, compared to 42.2 years in Basanti. Age influences physical capacity, openness to innovation, and willingness to take risks. Hasnabad households are also larger, averaging 5.8 members versus 4.8 in Basanti, offering more on-farm labor but higher consumption demands. Although Hasnabad has a slightly higher average number of migrating men per household, migration is far more widespread in Basanti, where about one third of households have at least one member working away. This is linked to lower cropping intensity and fewer local job opportunities. Migration can also relate to diversification in cropping systems or shifts in labor availability influencing intensity. The result in current investigation is strongly supported by the findings of Liu et al. (2016) and Banerjee et al. (2023). Liu et al. (2016) examined migration's impact on agricultural restructuring in Jiangxi Province, China, finding labor outflows push households toward less labor-intensive grain farming over capital-intensive options like livestock, mirroring age and labor shifts affecting cropping in Indian contexts. This supports how older farmers and migration reduce innovation and intensity, as households prioritize subsistence over diversification. Educational levels are low in both blocks, with most farmers having only primary schooling or none, underscoring the importance of practical, easy to understand training at the field level.

## 4.2 Land types, waterlogging, and salinity

In both locations, most farmland is medium or low lying and prone to seasonal waterlogging, limiting crop options. Hasnabad faces a more serious salinity challenge, with 147.5 acres affected compared to 30.8 acres in Basanti. Managing salt stress is, therefore, a higher priority in Hasnabad. Introducing and scaling up stress-tolerant and hybrid high yielding varieties suited for saline and submerged conditions could help maintain production despite poor soil and water quality (Liu et al., 2016; Sackey et al., 2025). Sackey et al. (2025) advocate GWAS (Genome-Wide Association Study)-identified tolerant accessions for submerged saline fields, boosting yields 20%–30%.

## 4.3 Cropping patterns and diversification needs

Rice is the dominant crop in the *kharif* season in both areas, yet Hasnabad records much higher cropping intensity (243.4%) due to year round rotations such as rice–mustard–jute. In Basanti, cropping intensity is lower (138.9%), largely due to limited summer cultivation and heavy reliance on rice monocropping in the *rabi* season by over 25% of farmers. Cropping intensity measures total cropped area relative to net sown area across seasons, dropping when summer cultivation is limited by waterlogging or salinity, forcing reliance on single rice crops in *kharif* and minimal *rabi* options beyond rice monocropping (Saha D. et al., 2024). In saline, monocropped areas, diversified multiple cropping systems with salt-tolerant crops are essential to improve soil health, reduce risk, and increase returns (Ashilenje et al., 2022; Atta et al., 2023). For waterlogged plots, land shaping methods like farm pond, deep furrow and high ridge, and paddy–fish cultivation can improve drainage, reduce salinity, broaden income sources, and increase resilience (Burman et al., 2013; Velmurugan et al., 2015; Mandal et al., 2019).

A central aim of this research is to design an improved package of practices for potato cultivation in coastal saline soils, especially in the Sundarbans where land often remains fallow after *kharif* rice due to unsuitable soil conditions and water scarcity in dry season water. Transforming these idle lands through suitable technologies could add significant income (Velmurugan et al., 2015; Mandal et al., 2019; Sarangi et al., 2018; Sarangi et al., 2021). For farmers already cultivating vegetables in the second season, the provision of quality seeds of improved varieties, along with technical guidance, would raise productivity and profitability.

## 4.4 Livelihood diversification

Basanti recorded a marginally higher average annual income, driven largely by livestock, aquaculture, and wage migration, as its proximity to Kolkata allows farmers to easily access daily wage opportunities. In contrast, Hasnabad demonstrated advantages in services, business, orchards, and better returns from field crops, coupled with longer employment days. These variations highlight distinct livelihood strategies, with Hasnabad's diversified portfolio ensuring greater resilience, while Basanti's reliance on wage work and livestock reflects dependence on external and supplementary income sources. Soil salinity, frequent extreme weather events have led to increased local reliance on mangrove based nonfarm livelihoods, emphasizing the need for conservation of natural ecosystem services (Sarkar et al., 2024).

## 4.5 Women's role in agriculture and allied activities

Women are active contributors in both blocks but with different patterns. In Hasnabad, fewer households have women in farming, but those who do participate work for more days annually. In Basanti, more households involve women, yet the number of days worked per person is lower and concentrated in seasonal peak periods. Women in Hasnabad also invest more daily hours in poultry, livestock, and fisheries, reflecting more intensive roles. Expanding women-focused training and enterprise support can strengthen their contribution to household income (Ge et al., 2022; Bhattacharya et al., 2024; Saha A. et al., 2024; Begum et al., 2025).

## 4.6 Technology adoption and nutrient management

Modern practices such as direct seeding, mulching, and seed treatment are more common in Basanti, while Hasnabad shows limited uptake beyond seed treatment. The use of climate resilient techniques, Integrated pest management, and precision input application remains low in both blocks. Fertilizer application is typically unbalanced, and micronutrients such as zinc and boron have not been used at all in rice farming. Introducing site-specific, soil test-based Integrated Nutrient Management (INM) including micro nutrients is essential to boost yields, safeguard soil fertility, and optimize resource use (Arif et al., 2012; Paramesh et al., 2023; Dwivedi et al., 2024).

## 4.7 Major constraints and targeted interventions

The major limitations include lack of irrigation in the *rabi* season (both areas), severe soil salinity in Hasnabad, weak market infrastructure in Basanti, and poor seed availability in both blocks. Recommended measures include expanding irrigation capacity for dry season crops, promoting salt-tolerant high yielding varieties, introducing multiple cropping and crop diversification in saline areas, applying land shaping in waterlogged areas, distributing improved vegetable seeds, offering focused fisheries training, implementing soil test-based nutrient management with micronutrients, and upgrading Basanti's market facilities to improve farmer returns (Mitran et al., 2014; Biswas et al., 2017b).

## 4.8 Policy priorities and development pathways

Interventions must align with the unique conditions of each block. In Hasnabad, priorities should include salinity control, irrigation development, and the promotion of climate resilient, water efficient practices. In Basanti, efforts should focus on strengthening irrigation, improving market connectivity, and moving from rice monocropping toward more diverse and higher value cropping systems. Across both blocks, coordinated policy support, enhanced extension services, better access to inputs, and inclusive programme for women's empowerment will be crucial for achieving resilient and profitable farming systems (Mandal et al., 2023).

## 5 Conclusion

The overall agricultural cropping system in the Hasnabad and Basanti block of Sundarbans suffers from salinity stress, poor crop management practices, and limited market linkages, leading to lower agricultural productivity and migration of men for better livelihood. In submerged saline areas, adoption of stress-tolerant and hybrid high-yielding varieties is vital, while monocropping saline lands requires multiple cropping and diversification with salt-tolerant crops. Land shaping, including farm pond, deep furrow and, high ridge, and paddy–fish cultivation, offers solutions for submerged zones. This research suggested developing improved potato cultivation practices for coastal saline soils of the Sundarbans delta to address high salinity and poor irrigation quality. Improved vegetable seeds should be promoted for second season crops. Training on improved packages of practices for suitable crops will help in better decision making and fetch higher return from the crops. Fishing being an important source of income can contribute to enhancing the livelihood of the farmers. Awareness, training and support on improved fisheries practices are some of the key measures for better returns from fisheries. Crop diversification with suitable crops offers alternatives and means to improve the farming income. Balanced, soil test based integrated nutrient management with micronutrients like zinc and boron is essential for sustainable productivity. Instead of following blanket-approach on nutrient management, site-specific approach which considers the plot variabilities ensure sustainable nutrient use and promotes climate-smart approach. Use of digital advisories can significantly improve information access and bring timely and guided advisories to the farmers' doorsteps. Focusing on inclusive development by providing training and involving women farmers makes them contribute efficiently. Overall, improved agricultural productivity in the region will ensure higher returns and lower distress driven migration from the affected areas.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

## Ethics statement

Ethical approval was not required for the studies involving humans because International Rice Research Institute has internal evaluation and ethics clearance process for the studies which involves extensive household interviews and detailed personal data collections. However, this study is a mixed method study relying on participatory interaction, case study and secondary literature reviews and market analysis and does not involve any sensitive and extensive human data and information to be processed through that committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

PB: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. SG: Funding acquisition, Validation, Writing – review & editing. GP: Data curation, Formal analysis, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. DB: Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. RC: Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing. TL: Investigation, Methodology, Supervision, Writing – review & editing. UM: Methodology, Supervision, Validation, Writing – review & editing.

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## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial hips that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2026.1743073/full#supplementary-material

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