

Research Paper

Patterns of livelihood diversification in farming systems of the Eastern Gangetic Plains

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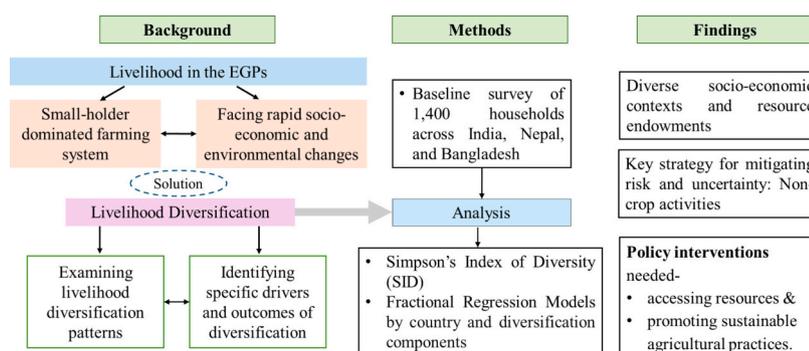
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HIGHLIGHTS

- Smallholders face socio-economic and environmental challenges, necessitating diversification for resilience in the EGP.
- Elucidates livelihood diversification patterns in the EGP, identifying drivers of diversification by type and location.
- Diversification levels vary geographically; key drivers are resource access, gender, education, market access, and support.
- Findings guide policymakers to support resilience and sustainability in smallholder farming through tailored interventions.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: The Eastern Gangetic Plains (EGP) is a region characterized by smallholder-dominated farming systems, facing rapid socio-economic and environmental changes. Livelihood diversification away from traditional agriculture is increasingly seen as a strategy to enhance resilience, income stability, and food security among these smallholders. However, comprehensive understanding of diversification patterns and their drivers within the EGP remains limited.

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OBJECTIVE: This study aims to elucidate the patterns of livelihood diversification in farming systems across the EGP, and identify the key factors driving diversification.

METHODS: Utilizing data from the *Rupantar* project involving a baseline survey of 1400 households across India, Nepal, and Bangladesh, and a subsequent analysis employing the Simpson's Index of Diversity (SID) to quantify diversification levels. Multivariate regression models were used to explore the determinants of diversification, while disaggregating the analysis by country and diversification components (crop plot, crop non-plot, and non-crop non-plot).

RESULTS AND CONCLUSION: The study revealed moderate levels of diversification across the EGP, with significant geographical and contextual variability. Key drivers of diversification included access to resources, gender, education, market access, and institutional support, with notable differences across countries and diversification types. Specifically, non-ownership of irrigation pumps, female household headship, and engagement in off-farm and non-farm activities emerged as significant predictors of higher diversification levels. **SIGNIFICANCE:** This study contributes to a nuanced understanding of livelihood diversification in the EGP, highlighting the complexity of diversification patterns and the multifaceted nature of its determinants and impacts. By identifying specific drivers of diversification, the findings provide valuable insights for policymakers, development practitioners, and researchers aiming to support rural livelihoods in the region. Emphasizing the role of gender, resource access, and institutional support, the study underscores the importance of tailored interventions to enhance the resilience and sustainability of smallholder farming systems in the face of changing environmental and socio-economic conditions.

1. Introduction

The Eastern Gangetic Plains (EGP) of South Asia is one of the most densely populated parts of the globe, with a population of over 400 million people (Pyne et al., 2023) and a high incidence of rural poverty. It remains an agriculture-based economy (Hoq et al., 2022), where tens of millions of smallholder farmers rely on a diverse set of livelihood options for both subsistence and income. Brown et al. (2020) describe the historical trajectory of farming systems and agrarian socioeconomic structures, which has differentiated states and nations out of what was originally one Bengali region. Food insecurity (including famine) have featured for centuries in this region, shaping modern jurisdictions, and remaining deeply ingrained on the psyche of farmers and policymakers. The region is characterized by relatively low productivity, poor infrastructure (although this is changing), restricted capacity for private investment, and sensitivity to climate challenges (Aggarwal et al., 2004). Low profitability of traditional rice-wheat systems means many families have members working away from their home region to earn remittances; this puts pressure on households due to labour shortages and the additional costs of hiring labour if that is required (Gathala et al., 2021), and also has social implications. Outmigration also increases gendered vulnerability related to distribution of labour and resources, and is further exacerbated by climate change (Sugden et al., 2014). In the EGP, the large-scale private sector is noticeably absent, and most farmers rely on the small scale private sector to purchase inputs and sell their surplus to market (Jackson et al., 2018). The EGP today has varying degrees of transition from more traditional, agrarian socioeconomic structures, through to integration into the global economy (Brown et al., 2020). These settings make understanding livelihood strategies in different locations critical to enable sustainable development.

Although cereals continue to dominate South Asian agriculture, there is evidence that the share of high value crops is also increasing (Kumar et al., 2024; Singh et al., 2022). Farming households often produce a variable range of crop (cereals and non-cereals), livestock and fisheries products depending on agro-ecological, socio-economic and institutional settings. They also often have access to sources of off- and non-farm income through wage labour, employment and remittances. These varying combinations of income and food streams combine to make a livelihood strategy. Chambers and Conway (1992; pp6) describe livelihoods as: "the capabilities, assets (stores, resources, claims and access) and activities required for a means of living."

Employing diversified livelihood strategies is a common way for smallholders to reduce risk and cope with uncertainty, particularly in unfavourable environments (Ellis, 2000a, 2000b; Hoq et al., 2022; Waha

et al., 2018). Adapting the livelihood strategy can help households mitigate or adapt to climate change (Hoq et al., 2022), secure non-farm income (Sarker et al., 2020) and maintain food security. Drivers of diversification can include risk minimisation, sustainability or increased production and profitability depending on the intention of the farmer (Sen et al., 2017). Many factors influence livelihood diversification and have been explored across the region, including gender, education, farm size, organisational participation, training experience and ICT use (Sarker et al., 2020).

Across South Asia, cereals continue to dominate cropping patterns – for example Bangladesh (78 %), India (45 %), Nepal (70 %), but changes are evident across time and space (Singh et al., 2022). In particular, over the last three decades Bangladesh has seen increased citrus, fruit and root crops; India citrus, fruit, fibre and tree nuts; and Nepal tree nuts, sugar and root crops (Singh et al., 2022). West Bengal has moderate levels of crop diversification (Kumar et al., 2024), but with huge inter-district variation. For Bangladesh, Production Diversity Score varies across districts and showed around five different crop and animal products produced at the smallholder level (Khandoker et al., 2022). In Nepal, over 50 % of households had diversified outside the farm (Rahut et al., 2014).

1.1. Different patterns of diversification have varying effects

Depending on the starting conditions, the same broad measure of diversification can result in very different environmental (states of biodiversity, ecosystem services (Hufnagel et al., 2020)), profitability and nutrition impacts. Diversification towards more remunerative fruits, plantations and vegetables can enhance the income security and risk bearing ability of households (Sharma, 2011; Feliciano 2019; Anuja et al., 2020). In a study in Bihar, (Sen et al., 2017) found that diversification only within field crops (e.g. cereals, oilseeds, pulses, sugarcane, fibre crops) actually reduced farm income, but diversification that included high value enterprises such as horticulture, livestock and other ancillary enterprises improved farm income. A higher Simpson Diversity Index for cash crops has a positive impact on food production (Mukherji et al., 2021). Households in China with more diverse agricultural activities benefited from both more profitable and environmentally sustainable production from a food-energy-water perspective, due to changes to agricultural inputs in those systems (Peng et al., 2022). In South America, households with higher rural livelihood diversification (i.e. different kinds of activities) were less vulnerable to climate change (Beltrán-Tolosa et al., 2022). Households in Bangladesh that included a combination of agricultural activities as well as non-farm activities had the highest reduction in rates of poverty during the period 2000–2008,

compared to households who only focused on agriculture or those that only had non-farm income (Salam, 2020). Diversification from traditional arable farming to commercial enterprises like dairying, poultry farming, bee keeping, and floriculture resulted in a marked increase in farm income from 6 to 138 % (Kalaiselvi, 2012).

Most households in the EGP rear livestock (dairy cows, goat, buffalo, pig and poultry) (Brown et al., 2023). Including livestock into a livelihood portfolio has benefits for income (Herrero et al., 2013) and nutrition (Hossain et al., 2021) but also in being able to integrate production and consumption activities by using waste products from one as inputs to another. Integrated crop-livestock systems have multiple benefits including increased economic returns, improved income stability, reduced inputs, improved human nutrition and environmental benefits such as increased carbon accumulation and biodiversity and a reduction in GHG emissions (Sekaran et al., 2021). Improving the integrated farming system, in particular by better supporting the livestock component, can provide a pathway out of poverty and promote gender equity (Thomas et al., 2002).

Off-farm and non-farm income such as that from salaries and remittances is common in all EGP countries. Rates of internal (domestic) migration as a share of total population are 37 % in India, 10 % in Bangladesh, and 14 % in Nepal, and help households adapt to shocks and enhance resilience (Maharjan et al., 2020). Although the amounts of remittance may be small, they can help meet daily food consumption and contribute to household income through a combination of the remittance themselves and enabling access to loans.

The type of diversification undertaken can have very different impacts on diet diversity and nutrition for households and the different members within it. For example, crop diversification that only incorporates different kinds of cereals will have different impacts to one that includes pulses, vegetables or fruits. Data from land use statistics and the Indian National Family Health Survey (2015–16) indicated striking regional differences in the pattern of food crop diversification vis-à-vis nutritional outcomes, with an inverse relationship between undernutrition and crop diversification (Anuja et al., 2022). A review of relevant studies for South Asia showed that agricultural interventions that promote nutrient-rich crops and diversification to fruit, vegetables and aquaculture can improve nutritional outcomes for different household members, particularly when coupled with a focus on women's empowerment (Pandey et al., 2016). Farming systems that integrate aquaculture have improved productivity, micronutrient consumption and nutritional status (Murshed-E-Jahan and Pemsil, 2011). This demonstrates the interaction between livelihood patterns, nutrition and inclusion.

1.2. Filling key gaps

We need measures of diversification that go beyond area-based approaches to enable inclusion of livestock and ancillary enterprises which can have high value and therefore an impact on livelihoods (Sen et al., 2017). Many studies look at crop diversification only (Brown et al., 2023; Hoque et al., 2023; Islam et al., 2019) or agricultural diversification (which generally includes crop, livestock and fisheries) (Alam et al., 2023). Hoq et al. (2022) determine five main livelihood strategies (i.e. crop plus another option). We propose a livelihoods approach that also accounts for ancillary activities and non-farm income as being highly appropriate given that most farming households have multiple production and income streams that go beyond agriculture, depending on resource availability. Each smallholder household employs a different combination of components that make up their total livelihood strategy.

In this study, livelihood diversification options are categorized as crop (plot and non-plot), non-crop, non-plot (livestock and fisheries, off farm and non-farm). The reason for categorizing in this way is to understand the levels of diversification in each subcomponent and explore the factors that drive these, given that different diversification strategies

require access to different resources and can have different impacts on productivity, profitability, nutrition and inclusion. It can help identify where the opportunities for further diversification are, and where the focus should be on supporting and driving change.

Understanding the prevailing patterns of livelihood diversification can help inform strategies for how farming households can diversify in the future, in ways that fit with the aspirations of farmers, and which fit the agroecological and socioeconomic challenges that they face (van Zonneveld et al., 2020). As there are variable drivers of diversification, it is important to identify location specific determinants (Kumar et al., 2024) to enable targeted policies and programs. Additionally, it is not always obvious which diversification measures are chosen under which conditions (Hufnagel et al., 2020); this study draws out the determinants of different components of a diversified portfolio.

As identified in (Nandi et al. (2025); Brown et al., 2023), there are gaps in our understanding of diversification patterns across the EGP. This paper fills the following gaps:

1. Provides a more nuanced understanding of the patterns of livelihood diversification across the EGP, by considering diversity within different components of a livelihood portfolio.
2. Explores key factors influencing diversification across locations and components to inform policies for better targeting support for large-scale household livelihood diversification.

2. Methodology

2.1. Study sites

The Rupantar project is a research-for-development project with the primary objective of catalyzing the transformation and diversification of smallholder farmers' livelihoods across the EGP in Bangladesh, India, and Nepal. This project, funded by the Australian Centre for International Agricultural Research (ACIAR), aims to understand the best mechanism for scaling diversification options among smallholder farmers in the EGP, and builds on a portfolio of prior research that focused on improved food, energy and water security (Gathala et al., 2021; Jackson et al., 2023). As part of this initiative, a comprehensive baseline study was conducted, led by the International Maize and Wheat Improvement Center (CIMMYT) to assess the current status of diversification and livelihood practices in the project sites across these three countries. Specifically, the baseline study covered areas in Cooch Behar District of India, Rangpur Division in Bangladesh, and Koshi Province in Nepal (Fig. 1).

Selection of communities within this broader geographic region was conducted purposively based on a set of specific criteria, aimed at providing a comprehensive understanding of their agricultural potential and diversification possibilities. These criteria encompassed three main aspects. The communities were selected based on their potential for a) diversifying agricultural activities at the plot level; b) diversifying livelihood activities extending beyond individual plots, c) diversification regardless of irrigation constraints. Within each of the three specified criteria, communities were further categorized based on their proximity to markets. For each of these three categories, four communities were chosen where the distance to the nearest market was less than 5 km, and a further four communities were selected where the distance to the market exceeded 5 km. This approach resulted in a total of eight communities identified for each for plot-level diversification, non-plot-level diversification, and diversification in irrigation constrained areas. The survey covered 24 villages in each location in Bangladesh, India and Nepal making a total of 72 communities.

2.2. Diversification framework

We distinguish between plot and non-plot diversification options as a way of tracking different pathways associated with patterns of

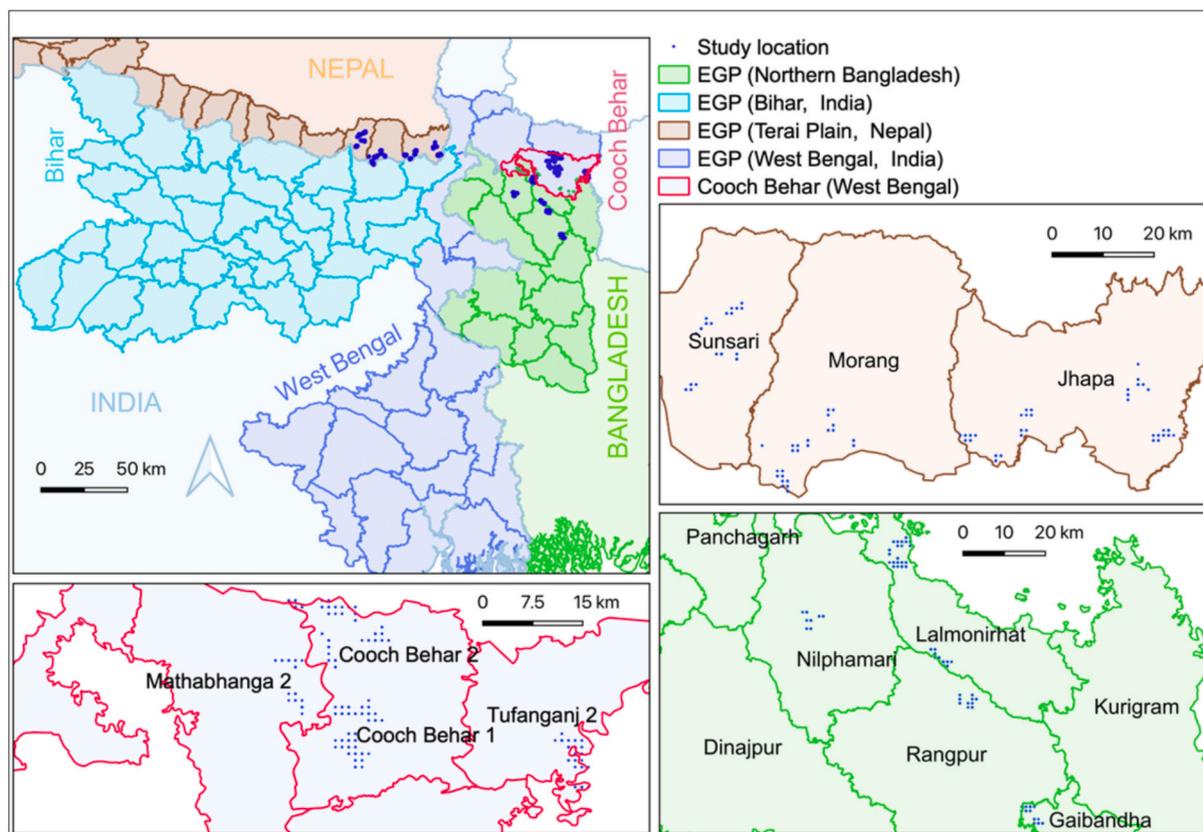


Fig. 1. Location of baseline survey (Nandi et al., 2025).

diversification. A similar approach has been used by (Isaure and Maurel, 2016). We define these components as:

- Plot (crop): all crops produced in farm plots (may be owned or rented);
- Non-plot (crop): crops produced elsewhere on the farm or household (i.e. household, ponds, bunds, home garden, perimeters, orchards); and
- Non-plot, non-crop: livestock and fisheries, value addition, off-farm, and non-farm activities.

Table 1
Livelihood framework aligned with Plot and Non-Plot characterization (adapted from Brown et al., 2023 and modified by the authors).

Component	Sub-component	Category	Name	
Crop	Plot	1	Cereals	
		2	a	Pulses
			b	Oilseeds
			c	Tubers
			d	Fibre
			e	Fodder
			f	Green manure
Crop	Non-plot	3	a	Vegetable
			b	Mushroom
			c	Spice
			d	Fruit
			e	Floriculture/ornamentals
Non-crop	Non-plot	4	a	Large livestock (meat)
			b	Dairy
			c	Poultry
		5	Fisheries capture and culture	
		6	Off-farm	
		7	Non-farm	
		Livelihood	Sum of all	

The characterization of different diversification options is shown in Table 1.

For the farm household livelihood portfolio, several metrics were explored: [1] the proportion of households participating in each livelihood component (prevalence); [2] the degree of diversification measured by the Simpson Index of Diversity; and [3] the factors that significantly affect the level of livelihood diversification, by location and component.

2.3. Data collection

2.3.1. Questionnaire development

The questionnaire was developed with the help of the Decision-making Dartboard (DmD) framework (Brown et al., 2021, p. 257). Additionally, the Rupantar Livelihood framework (Fig. 1) played a vital role in categorizing livelihood options. Leveraging these categories, and with inputs from the project team captured in a collaborative exercise, the question schedule was crafted to capture essential information related to current livelihood categories of the farmers.

The baseline study comprised of two questionnaires sets: one for the main agricultural decision maker of the household and one for the spouse. The main form in the baseline interview encompassed seven modules, each designed to gather specific information. Module 1 covered current livelihood practices, including land ownership, existing cropping patterns, livestock, fisheries, and fruit and plantation cultivation. Module 2 focused on capturing past experiences and recent changes in agricultural practices, and identifying sources of information for farming and livestock, group affiliations, and support received by the respondents. Module 3 delved into the future aspirations and preferences of smallholder farmers, including market preferences and envisioned future farming activities. Module 4 centered around understanding dietary patterns and assessing household food security. Module 5 focused on the status of agricultural mechanization and the

current utilization of machinery, and preferences for future mechanization practices. Module 6 gathered demographic information about the respondents. Finally, Module 7 captured data on household assets. The spouse form included Modules 1, 2, 3, and 4. The question schedule was prepared in English and subsequently translated into the local languages (Nepali and Bangla). Ethics Approval was granted by the University of Adelaide Human Research Ethics Committee (Number H-2022-062).

2.3.2. Participant selection

The study primarily targeted the main agricultural decision makers of the household, including both men and women farmers as respondents. Recognizing the potential limitation that women farmers who are also the decision-makers may be fewer in number, women spouses of 25 % of the main decision makers were interviewed. This included both interviews with the main decision makers and their spouses, resulting in a combined total of 600 interviews in each study location.

Simple random sampling was used wherein the skip number was determined based on the total population of the villages being studied. All villages included in the study had a population range of 250 to 300 households, so a skip number of four was used to ensure at least 10 % of the population was surveyed. Every fourth household within the village was chosen for the interview, and 25 interviews were conducted in each village. For every fourth household head interview conducted, the spouse interview was conducted. This method allowed for an equitable representation of women respondents within the overall sampling framework.

In each location, a team of 15 enumerators were selected to carry out the surveys in local languages. This commenced with a comprehensive four-day training program which included pilot interview sessions held in different communities. The interviews were conducted after the Rabi planting season but before the Rabi harvest, between February and April 2023. This ensured that the respondents had relatively more time available and were not overwhelmed by agricultural activities. In total 1800 farmers participated in the survey. For each interview the interview duration ranged from 60 to 90 min. The interviews were carried out using the KoboCollect app. Interviews were conducted only after obtaining the respondents' consent.

2.4. Analytical techniques

The data were analysed to explore several components that constitute pathways of diversification: [1] plot level; [2] non-plot level; [3] non-plot, non-crop level agricultural diversification. There are different methods of estimating household livelihood diversification, such as the Simpsons Index of Diversity (SID), Herfindahl Household Diversification Index (HHDI), Gibbs, and Martin's indexes and others. In this study, the SID was used to estimate the level of production diversity among households in the EGP. The SID considers both the number of livelihood components engaged in according to the crop and non-crop (plot and non-plot) level, and how evenly the distributions of diversification of various livelihood sources.

$$SID = 1 - \sum_{i=1}^n P_i^2 \tag{1}$$

In Eq. (1) n is the number of total livelihood components for each respondent and P_i is the proportion from the i^{th} livelihood components. The value of SID ranges from 0 to 1, where 0 means perfect specification and 1 means perfect livelihood diversification.

In this study the value of P_i can be estimated as follows:

$$P_i = 1 - \sum_{i=1}^n \left(\left(\frac{Crop\ plot}{Total\ count} \right)^2 + \left(\frac{Crop\ non\ -\ plot}{Total\ count} \right)^2 + \left(\frac{Non\ -\ crop\ plot}{Total\ count} \right)^2 \right) \tag{2}$$

From Eq. (2), where *Cropplot* represents the category 1; *Cropnon-*

plot represents the category 2. On the other hand, *Non-crop non-plot* represents category 3 which mentioned in Table 1. To determine the proportion of each level score, we employ the sum values of each household's involvement in different livelihood sources.

2.4.1. Theoretical background and empirical estimation approach

The ordinary least square regression is not appropriate for regression with a bounded dependent variable, such as index variables. If the response variable is restricted to the interval (0,1), the fitted values for the variable of interest might exceed its lower or upper bounds. Hence, inference based on the normality assumption can be misleading. The econometric estimation approach is chosen based on the nature of the dependent variables along with the model selection results. In our cases, to determine the degree or extent of the livelihood diversification, SID was used whose index value lies between 0 and 1; the value zero indicates that the farm household is completely specialized, while a value of one indicates higher degree of diversification.

Censored models, particularly the Tobit model, are employed when dealing with restricted continuous variables. Assuming a normally distributed random error, the Tobit model yields consistent estimation results (Loudermilk, 2007). Nevertheless, fractional regression models are designed to overcome the econometric limitations faced by other models.

The fractional response model (FRM) (Papke and Wooldridge, 1996), serves to empirically model dependent variables constrained to accumulate at one of the corners. The FRM offers several benefits: (a) there is no requirement to transform the values observed at the bounds; (b) it considers nonlinearity in the data; (c) it demonstrates robustness under generalized linear model (GLM) assumptions, and (d) it enables the direct retrieval of the regression function for the dependent variable based on the set of predictors. The basic assumption underlying the FRM can be summarized as (3):

$$E(y|x) = G(x_i\beta) \forall i, \dots \tag{3}$$

where $G(\cdot)$ is a known function with $0 < G(z) < 1 \forall z \in \mathbb{R}$, which satisfies the requirement that fitted values lie in the unit interval. Examples of nonlinear functional forms used for G include the logistic function $G(x) \equiv \Lambda(z) \equiv \frac{\exp(z)}{1+\exp(z)}$ and $G(x) = \Phi(z)$, where Φ is the standard normal cumulative distribution function (CDF).¹

The Bernoulli quasi-maximum likelihood estimator (QMLE) is used to estimate parameters, ensuring consistency and asymptotic normality regardless of the dependent variable's distribution. This flexibility contributes to the FRM model's wide applicability to various research settings (Gallani and Krishnan, 2015). Hence, in this article, a fractional correlated probit model is applied. Following Papke and Wooldridge (2008), the equations are structured as follows (5):

$$E(S_i|X_i, v_i) = \Phi(X_i\beta + v_i), i = 1, 2, \dots, N \tag{4}$$

Where $\Phi(\cdot)$ is the standard normal cumulative distribution function (that leads to computationally simple estimators with unobserved heterogeneity). In order to consistently estimate the β and the average partial effects (APE), we need to assume that conditional on v_i and X_i is strictly exogenous and that v_i , conditional on X_i is distributed normally (6):

$$(v_i|X_{i1}, X_{i2}, \dots, X_{iN}) \sim N(\psi + \bar{X}_i\xi, \sigma_v^2) \tag{5}$$

We can consistently estimate the β (up to a scale parameter) and the APE, provided that there are no perfect linear relationships among X_i

¹ A key difference between the FRM and the logit (or probit) regressions is that the FRM estimates the conditional expected value of the response variable, while logit and probit models predict the probability of occurrence of a certain event, which could require arbitrary dichotomizations of the dependent variable.

and that there is time variation in all elements of it². We use the Bernoulli QMLE estimator, the pooled fractional probit estimator, obtained from the probit log-likelihood. The estimating equation is given by (7):

$$S_i = f(1, X_i, \bar{X}_i) \dots \dots \dots (6)$$

and is estimated using a GLM approach, with adjustments to the standard errors. The general inference deriving from the application of the FRM is directionally consistent with the Tobit results, but the FRM provides additional benefits in interpreting the results. Finally, we have chosen a functional form that ensures estimates of $E(y|x)$ are between zero and one, and a quasi-likelihood function that leads to a relatively efficient QMLE under a popular auxiliary assumption (Papke and Wooldridge, 1996). Fractional probit models are the preferred model when the true data generation process is fractions of three or more choices that sum to 1 and can include real 1 s and 0 s where a single choice dominates all others (Murteira and Ramalho, 2014).

To apply the above model, we reviewed prior research to select the appropriate variables which are commonly the determinants of the diversification patterns, along with considering the data availability. Annex 1 represents the variables and measurement for the analysis.

3. Results

3.1. Household characteristics – regional and by location

Table 2 presents the characteristics of the 1397 households surveyed. The average age of a Household Head falls within the 35–54 year range, with more than half of the households fitting into this category. Most Household Heads have at least some primary schooling, although nearly 30 % are either illiterate or have no formal education. Primary school attendance rates are higher in West Bengal (53–65 %) compared to Nepal (40–45 %) and Bangladesh (38 %). On average, households consist of around five members, with three of them engaged in agricultural work.

Average land ownership is 0.92 ha, ranging from 0.62 ha in Rangpur to 0.93 ha in Cooch Behar 1. Average land cultivated is higher than owned in all locations, indicating common patterns of land rent across the region. Many households (average 62 %) have off-farm income ranging from 48.9 % in Mathabanga 2 to in 76.3 % Morang. Around 44 % of households own an irrigation pump, ranging from just 11.88 % in Sunsari up to 78.35 % in Cooch Behar 1. Bangladesh has around 28 % pump ownership.

3.2. Diversification patterns

We are interested in developing a nested understanding of the components that make up household level diversification: [1] plot level crop diversification; [2] non-plot level crop diversification; [3] non-plot, non-crop level diversification.

3.2.1. Prevalence of diversification options

The proportion of farming households participating in different livelihood categories is shown in Fig. 2. This shows several key important trends. Rice is the most widely grown crop, produced by almost all households. Second in prevalence is livestock, fruit and tree crops which are produced by 91 %, 87 % and 81 % of households. Around 20 % of households have off-farm income. Diversification is highly variable across geographical locations, including in the different plot and non-plot components identified in Table 1.

For crop-plot diversification, the different crop types vary widely

among locations, although rice is the main crop grown by most households across locations. For example, wheat is not produced in Bangladesh and West Bengal, but remains important in Sunsari (37 %) and Morang (69 %) in Nepal. Maize is relatively important (37 % on average) and varies even in neighbouring blocks in West Bengal. Oil-seeds are more common in Nepal and India. Pulses are primarily grown in Nepal, and not at all in Bangladesh. Tuber and fibre crops are more common in West Bengal than Nepal and Bangladesh.

For non-crop, non-plot diversification options, livestock is produced by over 90 % of households. This ranges from 77.5 % in Tufanganj to 95.7 % in Mathabanga. Fisheries is less prevalent with only 7 % of households overall participating. This ranges from 1.9 % in Sunsari, to 13.8 % in Morang (neighbouring districts of Nepal). In Bangladesh, only 2.9 % of households are participating in fisheries, while in West Bengal it ranges from 2.5 % – 10.6 %. Off-farm income streams are present for around 21 % of households, again varying between 10 % (Morang) and 36 % (Cooch Behar 1). Non-farm livelihood options are present in around 17 % of households, ranging from 13.1 (Morang) to 25 % (Tufanganj).

For crop non-plot diversification, fruit and tree crops are the most widely grown, followed by spices, floriculture and vegetables. Fruits are produced by 87.4 % households on average ranging from 77.1 % in Rangpur to 95.6 % in Cooch Behar 2 and Sunsari. Tree crops are produced by 80.6 % on average, ranging from 68 % in Cooch Behar 1 and 2 to 97.9 % in Mathabanga. Spices are produced by 50.4 % households, ranging from 19.4 % in Morang to 64.4 % in Cooch Behar 1. Floriculture is 16.6 % average, ranging from 2.5 % in Bangladesh to 37.1 % in Cooch Behar 2. Vegetables are produced by 9.2 % households on average ranging from 2.5 % in Rangpur to 14.5 % in Cooch Behar 2.

3.2.2. Simpson's index of diversity

The SID for different livelihood components is shown in Table 3. The value of SID ranges from 0 to 1, where a value of 0 means perfect specialisation and a value of 1 means perfect livelihood diversification. Thus, we can see that for crop diversification, the average value of 0.13 indicates specialisation. This is variable, Rangpur being more specialized (0.05) and Cooch Behar 2 (0.20) less so. For other crops grown outside farm plots, the average value of 0.52 indicates there is more diversification in this component of the livelihood portfolio, ranging from less diversified in Jhapa (0.47) to more diversified in Cooch Behar 2 (0.59). For non-crop/plot diversification options, the average is the same (0.52), ranging from less diversified in Morang (0.48) and more diversified in Cooch Behar 1 (0.52).

The Livelihood SID is the average of all categories; this shows an overall average value of 0.39 demonstrating low levels of diversification across the livelihood portfolio. This is variable, with Rangpur having the lowest diversification (0.34) and Cooch Behar 1 and 2 having the highest diversification (0.5).

Fig. 3 presents the distribution of our key explanatory variable (SID), across the sampled households using the kernel density estimate overlaid by a fitted normal density. Although the kernel density plot is more peaked than the normal density plot, the graph clearly shows that it is skewed. Given this, the mean for the SID of agricultural diversification is used as the cutoff point to create a binary variable of whether a household diversified its agricultural activities. Households below the mean of the diversification index were assigned a value near to zero (did not diversify), and those above the mean are assigned a value of one (completely diversified) followed by the findings Nkonde et al. (2021). This binary variable is used as a dependent variable in the selection equation for our econometric results discussed later.

3.3. Factors affecting diversification

3.3.1. Livelihood diversification - general

This study used fractional logit model to identify the factors that affecting the livelihood diversification. Prior to the estimation of the

² The coefficients must be adjusted using the scale parameter after estimation to make them comparable with the coefficients of the random effects Tobit and linear unobserved FE models (Papke and Wooldridge, 2008).

Table 2
Characteristics of survey households.

Characteristic	Regional	India				Nepal			Bangladesh
		Tufanganj 2	Mathabhanga 2	Cooch Behar 1	Cooch Behar 2	Sunsari	Morang	Jhapa	Rangpur
Survey responses	1397	79	44	182	143	159	159	154	477
Age of HH Head (Years)					%				
18–24	1.04	0	0	1.0	0.6	0.0	0.6	0.6	2.1
25–34	11.60	5	5.0	10.3	13.8	6.3	6.9	10.6	16.7
35–44	27.01	13.75	13.80	28.9	17.0	32.5	18.8	28.1	31.9
45–54	31.18	43.75	43.80	33.0	30.2	43.8	41.3	27.5	21.9
55–64	21.74	32.5	32.50	20.6	30.8	10.6	21.3	22.5	21.5
65 or over	7.43	5.00	5.00	6.2	7.5	6.9	11.3	10.6	6.0
Education (% Head)									
Illiterate	12.78	13.75	4.26	15.46	10.06	6.25	20.00	15.63	12.08
No formal Education	16.74	6.25	10.64	14.43	7.55	26.25	8.13	15.63	23.13
Primary Middle school (1–8)	46.88	62.5	55.32	53.09	64.78	40.00	45.00	43.75	38.96
Higher Secondary (9–12)	19.17	17.5	21.28	10.82	13.21	25.00	24.38	21.25	20.21
Graduate	4.44	0	8.51	6.19	4.40	2.50	2.50	3.75	5.63
Household members									
Average number of household members	5.03	4.65	5.10	4.65	4.96	5.17	5.71	4.96	4.91
Average number of agricultural members	3.16	2.97	2.99	2.97	2.97	3.61	3.62	3.32	3.0
Male	1.62	1.54	1.55	1.55	1.55	1.83	1.82	1.65	1.56
Female	1.53	1.42	1.44	1.42	1.42	1.78	1.80	1.67	1.46
Resources									
HH with off farm earners (%)	62.00	73.8	48.9	54.1	64.2	67.5	76.3	61.9	57.3
Average land ownership (ha)	0.92	0.93	0.91	0.93	0.92	0.89	0.91	0.95	0.62
Average land cultivated (ha)	0.98	0.95	0.93	0.95	0.94	0.98	1.03	1.21	0.66
Average number of plots (Rabi)	2.35	2.63	2.68	2.62	2.62	1.74	1.75	1.33	3.00
Average number of plots Kharif	2.86	3.02	3.07	3.00	3.01	2.47	2.52	2.80	3.36
Average number of plots (Pre Kharif)	2.35	2.55	2.56	2.55	2.55	1.65	1.67	2.17	2.64
Irrigation pump ownership (%)	44.10	65.00	74.47	78.35	69.81	11.88	35.00	46.88	28.13

Source: Authors calculation, 2024.

Households participating in various livelihood categories (%)

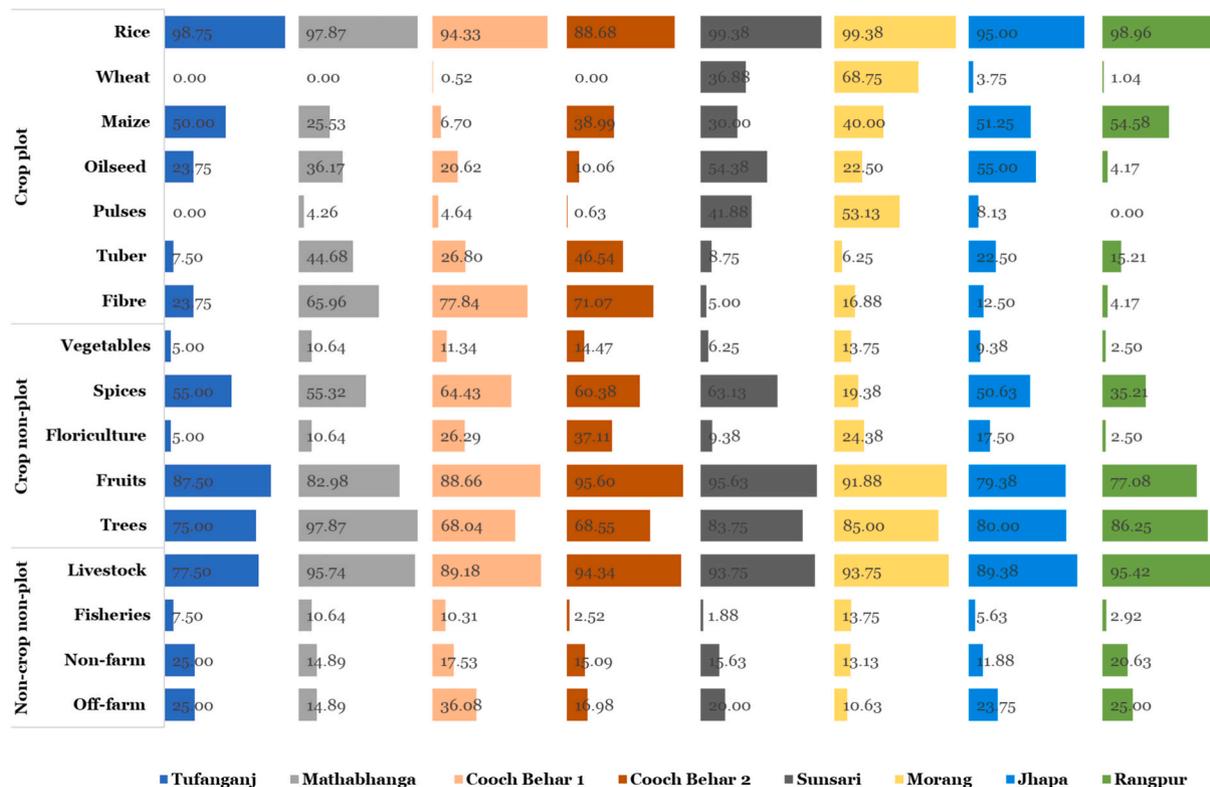


Fig. 2. Households participating in each livelihood component, average and for each location (%).

Table 3
SID for livelihood components and location.

Livelihood sources	All (average)	Tufanganj	Mathabhanga	Cooch Behar 1	Cooch Behar 2	Sunsari	Morang	Jhapa	Rangpur
Crop-plot	0.13	0.08	0.19	0.19	0.20	0.17	0.15	0.19	0.05
Crop-non-plot	0.52	0.56	0.54	0.57	0.59	0.51	0.48	0.47	0.50
Non-crop non plot	0.52	0.48	0.51	0.52	0.51	0.50	0.47	0.49	0.48
Livelihood (average)	0.39	0.37	0.41	0.43	0.43	0.39	0.37	0.38	0.34

Source: Authors calculation, 2024.

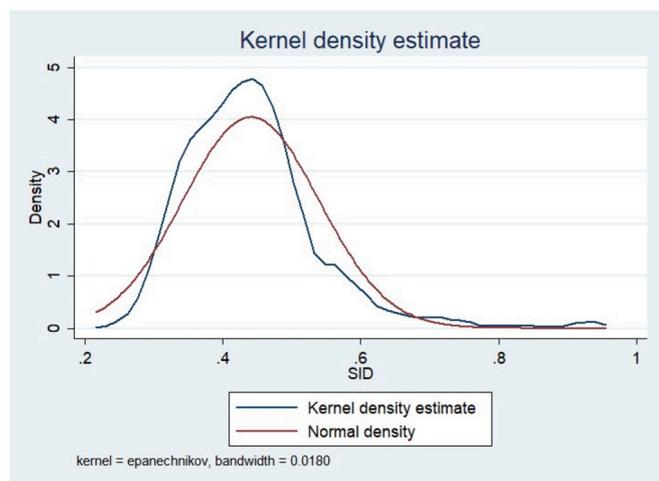


Fig. 3. The graphical representation of the distribution of SID.

model, a multicollinearity test was done for explanatory variables. All variables have a Variance Inflation Factor (VIF) of less than two, and the mean value was 1.19 (Annexe 2), which implies that there is no problem among the explanatory variables. A total of 21 explanatory variables were included in the model, wherein eight of them were found to be statistically significant in determining the level of livelihood diversification.

The significant variables are gender, agricultural decision making, male and female involvement in agriculture, irrigation pump ownership, credit access, marketing management and cash incentives of the farming households. These results, however, are not directly used to evaluate the magnitude and sign of the coefficients (Table 4).

For this purpose, marginal effects were calculated, and the results of the marginal effects analysis with significance levels are the projected percentage point change (in hundredths) in the pattern of livelihood diversification. For continuous independent variables, the marginal effect measures the change of probability given a one-unit change of the independent variable, holding all other variables at their mean (Verbeek, 2008). For dummy variables a change from 0 to 1, leaving all other variables constant at their mean, is reported. For categorical variables, a change within the categories holding reference category constant³ is reported. From the estimates in Table 4, we can see that the Wald Chi²-test is 173.72 with a probability of less than 1 % is highly significant, indicating that the overall model significance is very good for the data used in the analysis.

The marginal effects pertaining to the gender variable (GEN) reveal that the anticipated likelihood of diversification is 0.019 units higher for female individuals than their male counterparts within farm households, with statistical significance at the 10 % level.

In the case of categorical variables with more than two potential values, such as agricultural decision-making process (AGDS), the

³ The category that is dropped is known as the reference category. Mathematically speaking, this could be the category that has the largest representation in the data.

marginal effects highlight variations in predicted probabilities compared to the reference category. Specifically, the marginal effect associated with the decision-making process “My spouse and I discuss together” indicates the reduced likelihood of diversification compared to cases where respondents make decisions independently. The findings suggest that individuals who opt for diversification through joint discussions with their partners exhibit a 1.5 % lower likelihood than those who decide independently, reaching statistical significance at the 1 % level.

The coefficient value (−0.007) associated with the participation of male members (MCF) in agricultural tasks implies that a one-unit increase in male member involvement results in a 0.7 % decrease in the diversification pattern. Conversely, a one-unit increase in female member involvement in agricultural tasks corresponds to a 0.8 % increase in the diversification pattern, with statistical significance at the 1 % level.

Concerning ownership of an irrigation pump (IRP), the expected probability of diversification is 0.041 units greater for those without an irrigation pump compared to those who possess one, reaching statistical significance at the 1 % level.

The expected probability of diversification is 0.009 units greater for those who do not have credit access compared to those who have access which is significant at the 10 % level. Similarly, the coefficient value (0.031) associated with the cash incentives (CSIN) in agricultural diversification implies that a one-unit increase in the variable indicating that not having access to cash incentives is associated with a 3.1 % increase in the likelihood of changing the diversification pattern.

The coefficient value (−0.016) associated with the marketing management (MKTM) in agricultural diversification implies that a one-unit increase in the variable indicating a lack of management in marketing activities is associated with a 0.016 decrease in the likelihood of changing the diversification pattern.

3.3.2. Location specific determinants

From Fig. 2 we know that livelihood portfolios vary widely between locations, so in addition to the significant factors influencing diversification of all households as explored in Section 3.3.1, it is useful to explore the country specific factors. There is only one common significant variable across the three countries; not owning an irrigation pump increases livelihood diversification by 0.664 units ($p < .001$), 0.119 units ($p < .001$) and 0.038 units ($p < .05$) in India, Nepal and Bangladesh respectively (Table 5).

In India, the significant factors affecting livelihood diversification are joint agricultural decision making, irrigation pump ownership, male contribution to farm tasks, access to credit and NGO support. For agricultural decision-making process (AGDS), the marginal effect associated with the decision-making process “My spouse and I discuss together” indicates the reduced likelihood of diversification by −0.06 ($p < .01$) compared to cases where respondents make decisions independently and inform their spouse later ($p < .05$), which increases diversification by 0.118. Not having access to credit increases diversification ($p < .001$) by 0.052. Male contribution to farm tasks reduces diversification ($p < .01$) by 0.026. Households with no NGO support have a reduced incidence of diversification ($p < .05$) by 0.068.

In Nepal, the significant factors affecting diversification include agricultural decision making, irrigation pump ownership, gendered

Table 4
Determinants of livelihood diversification.

SID	dy/dx	Coefficient	Robust Std. Err.	z
AGE	-0.001	-0.003	0.006	-0.540
Male		Reference category		
2.Gender (Female)	0.019*	0.047*	0.027	1.770
EDUC	-0.003	-0.007	0.007	-1.040
Decision (Only me)		Reference category		
2 (My spouse and I discuss together)	-0.015***	-0.039***	0.014	-2.750
3 (My spouse only informs me once he has taken the decision)	0.003	0.008	0.040	0.210
4 (Only the male household members decide)	-0.011	-0.028	0.026	-1.060
5 (Other family members decide)	0.007	0.019	0.049	0.380
Pond ownership (No)		Reference category		
Pond ownership (Yes)	-0.011	-0.027	0.070	-0.390
Family size	-0.002	-0.005	0.004	-1.300
Male contribution to farm tasks	-0.007*	-0.018*	0.011	-1.720
Female contribution to farm tasks	0.008**	0.020**	0.010	1.940
Electricity access (Yes)		Reference category		
Electricity access (No)	-0.002	-0.006	0.065	-0.100
Irrigation pump ownership (Yes)		Reference category		
Irrigation pump ownership (No)	0.041***	0.103***	0.013	8.020
Credit access (Yes)		Reference category		
Credit access (No)	0.009*	0.023*	0.014	1.680
Machinery uses (Yes)		Reference category		
Machinery uses (No)	-0.004	-0.011	0.030	-0.350
Farmers group involvement (Yes)		Reference category		
Farmers group involvement (No)	-0.008	-0.020	0.014	-1.440
NGO support (Yes)		Reference category		
NGO support (No)	-0.002	-0.004	0.015	-0.290
Preferred market mechanism (Direct to middleman from home)		Reference category		
2 (Selling at the market myself)	-0.016***	-0.040***	0.014	-2.930
97 (Others)	0.001	0.002	0.036	0.070
Seed subsidy (Yes)		Reference category		
2.Seed_subsidy (No)	0.000	0.000	0.027	0.000
Fertilizer subsidy (Yes)		Reference category		
Fertilizer subsidy (No)	0.006	0.015	0.039	0.390
Agricultural tools subsidy (Yes)		Reference category		
Agricultural tools subsidy (No)	0.016	0.041	0.040	1.030
Other input subsidy (Yes)		Reference category		
Other input subsidy (No)	0.014	0.035	0.061	0.580
Subsidy for animals (Yes)		Reference category		
Subsidy for animals (No)	0.005	0.013	0.044	0.300
Cash incentives (Yes)		Reference category		
Cash incentives (No)	0.031***	0.079***	0.021	3.660
Constant		-0.284	0.092	-3.100
		Wald chi2(43) = 173.72		
		Prob > chi2 = 0.00		
		Pseudo R2 = 0.003		
		Log pseudolikelihood = -970.94714		

Note: Significant level ***($p < .01$), **($p < .05$), and *($p < .1$). Std. Err. denotes standard error.

Source: Authors estimation, 2024.

contribution to farm tasks and access to NGO support. For agricultural decision making, "Other family members deciding" increases diversification by 0.143 units ($p < .05$) compared to cases where respondents make decisions independently. Female contribution to farm tasks increases diversification by 0.046 ($p < .01$). Not having NGO support reduces diversification by 0.067 units ($p < .05$) (Table 5).

In Bangladesh, the significant factors affecting diversification include gender of the respondent, irrigation pump ownership and market mechanisms. Females have higher levels of diversification by 0.121 units ($p < .001$) compared to male respondents. For preferred market mechanisms, alternative market mechanisms increase diversification by 0.141 units ($p < .05$) compared to Direct to middleman from home (the reference category).

3.3.3. Factors determining components of diversification

This study distinguishes between plot and non-plot diversification options as a way of tracking different pathways associated with patterns of diversification. These components of a diversified livelihood (i.e. crop-plot, crop non-plot and non-crop, non-plot) may be affected by different factors, given that they have different resource requirements (i.e. land, labour, capital, water) and impacts on the household and its members, as shown in Table 6.

For crop-plot diversification, there are five significant factors. For agricultural decision making, 'Other family members decide' increases diversification by 0.313 units ($p < .01$) compared to decisions being made independently by the head of the household. Female contribution to farm tasks increases diversification by 0.0958 units ($p < .01$). Not being involved in a farmers group reduces diversification by 0.157 units ($p < .01$). For marketing, selling at the market by themselves and alternative forms of market arrangements reduce diversification by 0.320 and 0.259 units ($p < .001$) compared to selling directly to the middleman from home. Not having access to cash incentives reduces diversification by 0.175 units ($p < .05$).

For crop non-plot diversification, there are six significant factors. For agricultural decision making, joint decision making between spouses results in an increased level of diversification by 0.0424 units ($p < .05$) compared to decisions being made independently by the head of the household. Selling at market directly increases diversification by 0.0548 units ($p < .01$) compared to selling directly to the middleman from home. Not owning an irrigation pump reduces diversification by 0.116 units compared to those who own an irrigation pump ($p < .05$). Female contribution to farm tasks reduces diversification by 0.0215 units ($p < .01$). Not having access to credit reduces diversification by 0.0319 units ($p < .01$). Similarly, not having access to cash incentives reduces diversification by 0.0912 units ($p < .05$).

For non-crop, non-plot diversification, there are five significant variables, most of which are different to those affecting the other components of livelihood diversification. Age increases diversification by 0.0415 units ($p < .001$). Female household heads have increased likelihood of diversification by 0.0999 units ($p < .001$) compared to male household heads. Higher levels of education increase diversification by 0.0436 units ($p < .001$). Not owning an irrigation pump reduces diversification by 0.0526 units compared to those who own an irrigation pump ($p < .05$). Not getting subsidies for animals increases diversification by 0.166 units ($p < .05$).

4. Discussion

4.1. Diversification patterns in different locations

The proportion of farming households participating in different livelihood categories shows several key important trends. Rice is the most widely grown crop, produced by almost all households. Second in prevalence is livestock, fruit and tree crops which are produced by 91 %, 87 % and 81 % of households. Around 20 % of households have off-farm income. Diversification is highly variable across geographical locations, and in the different plot and non-plot components identified.

The diversification options at the household level are often chosen to minimize risks to securing food and nutritional security. Accumulating adequate grain in the form of rice in the food basket is often the top priority for the smallholder farming communities of this region, demonstrated by the prevalence of rice production in the kharif (wet)

Table 5
Location specific factors affecting livelihood diversification.

Variables	India		Nepal		Bangladesh	
	Coef.	z	Coef.	z	Coef.	z
SID						
Age	0.009	1.100	-0.002	-0.110	-0.004	-0.470
Male			Reference category			
2.Gender (Female)	-0.021	-0.580	0.004	0.080	0.121***	2.730
Education	0.002	0.210	-0.014	-0.890	-0.003	-0.290
Decision (Only me)			Reference category			
2 (My spouse and I discuss together)	-0.060*	-2.570	-0.045	-1.470	0.016	0.780
3 (My spouse only informs me once he has taken the decision)	0.118**	2.310	-0.041	-0.390	-0.056	-1.200
4 (Only the male household members decide)	-0.041	-0.970	-0.033	-0.420	0.004	0.120
5 (Other family members decide)	-0.018	-0.260	0.143**	1.950	0.065	0.850
Pond ownership (No)			Reference category			
Pond ownership (Yes)	0.049	0.560	-0.002	-0.010	-0.129	-0.770
Family size	-0.004	-0.750	-0.007	-0.850	-0.007	-0.980
Male contribution to farm tasks	-0.026**	-1.990	-0.022	-1.040	-0.015	-0.930
Female contribution to farm tasks	0.002	0.110	0.046*	2.570	-0.005	-0.340
Electricity access (Yes)			Reference category			
Electricity access (No)	-0.172	-1.490	-	-	0.042	0.850
Irrigation pump ownership (Yes)			Reference category			
Irrigation pump ownership (No)	0.064***	2.940	0.119***	4.420	0.038**	1.930
Credit access (Yes)			Reference category			
Credit access (No)	0.052***	2.740	0.051	1.150	-0.015	-0.740
Machinery uses (Yes)			Reference category			
Machinery uses (No)	0.028	0.930	0.099	0.830	-0.054	-1.270
Farmers group involvement (Yes)			Reference category			
Farmers group involvement (No)	-0.013	-0.630	-0.033	-1.120	0.000	0.000
NGO support (Yes)			Reference category			
NGO support (No)	-0.068**	-2.030	-0.067**	-2.220	0.025	1.270
Preferred market mechanism (Direct to middleman from home)			Reference category			
2 (Selling at the market myself)	-0.033	-1.460	-0.005	-0.190	0.011	0.360
97 (Others)	-0.028	-0.500	0.010	0.220	0.141**	2.020
Seed subsidy (Yes)			Reference category			
2.Seed_subsidy (No)	-0.006	-0.160	-0.016	-0.340	0.055	1.440
Fertilizer subsidy (Yes)			Reference category			
Fertilizer subsidy (No)	-0.075	-0.870	0.062	0.770	-0.005	-0.120
Agricultural tools subsidy (Yes)			Reference category			
Agricultural tools subsidy (No)	0.058	0.790	0.051	1.130	-0.117	-0.680
Other input subsidy (Yes)			Reference category			
Other input subsidy (No)	0.126	1.280	-0.033	-0.310	0.102	0.930
Subsidy for animals (Yes)			Reference category			
Subsidy for animals (No)	-0.048	-0.850	0.073	0.470	0.075	0.640
Cash incentives (Yes)			Reference category			
Cash incentives (No)	0.033	1.380	-0.055	-0.750	0.035	0.710
Constant	-0.274	-1.750	-0.174	-0.770	-0.193	-0.860
Log pseudolikelihood =	-310.64227		Log pseudolikelihood =		-328.28357	
Number of obs =	461		Number of obs =		479	
Wald chi ² (41) =	80.33		Wald chi ² (40) =		213.15	
Prob > chi ² =	0.0002		Prob > chi ² =		0	
Pseudo R ² =	0.002		Pseudo R ² =		0.0044	
					Log pseudolikelihood =	
					-331.05568	
					Number of obs = 480	
					Wald chi ² (41) =58.46	
					Prob > chi ² = 0.0377	
					Pseudo R ² = 0.0017	

Note: (-) means omitted variable (electricity access) for Nepal model. t statistics in parentheses * $p < .05$, ** $p < .01$, *** $p < .001$.

Source: Authors estimation, 2024.

season. The kharif rice growing season coincides with South-West monsoon rains and this is the only crop that can tolerate high-intensity rainfall without any yield penalty. Moreover, rice production approaches in the region are water-intensive and depend on the monsoon for growing rice in the entire study region (Mitra and Das, 2015; Mitra et al., 2018). Socio-economic factors like labour and resource availability also favour the cultivation of rice, as do policy settings in all three countries which have prioritised rice for food security and self-sufficiency (Nandi et al., 2024; Choudhary et al., 2022; Debnath et al., 2018). In addition to rice, every household tries to accommodate various components of food like protein and other essential nutrients by retaining animal components (livestock, poultry, fish) and fruit trees respectively. Off farm employment can also be an important part of a livelihood strategy, and contribute to income generation, risk management and dietary diversity (Bai et al., 2024).

In recent years, one of the important challenges in wheat production was the occurrence of wheat blast which appeared in Bangladesh in 2015–16, causing huge crop loss (Mottaleb et al., 2018). In an attempt to

curb the spread of the disease in India, policymakers in the region announced a wheat holiday, banning of wheat cultivation for several years in areas adjacent to Bangladesh. This is why wheat was not prevalent in the India and Bangladesh study sites. On the contrary, rice-wheat systems are still popular in Nepal from a food and nutritional security perspective. Among cereals, the cultivation of Rabi maize in Cooch Behar has recently expanded significantly, attributed primarily to its high productivity levels. Due to late harvest of preceding medium-long duration rice varieties as well as wet soil conditions, sowing is delayed for most of the Rabi crops which invariably reduces the yield (Mitra et al., 2014). However, Rabi maize has a flexible sowing window extending from Mid-November to End-December which enables the farmers to opt for this crop without any yield penalty. Furthermore, the marketing of Rabi maize is relatively streamlined in this region, as local vendors directly purchase the grain from farmers at competitive prices. Crops like potato have also emerged as an important crop during rabi season. Again, introduction of quality processing varieties through contract farming has opened new markets, particularly for chip-grade

Table 6
Determinants of the diversification by component.

Variables	Crop plot	Crop non-plot	Non-crop non-plot
Age	-0.0214 (-0.68)	0.000837 (-0.13)	0.0415*** (-5.35)
Male		Reference category	
2.Gender (Female)	-0.163 (-1.32)	-0.0489 (-1.75)	0.0999*** (-3.45)
Education	-0.0248 (-0.76)	0.00623 (-0.83)	0.0436*** (-4.87)
Decision (Only me)		Reference category	
2 (My spouse and I discuss together)	-0.0792 (-1.18)	0.0424** (-2.72)	-0.0142 (-0.79)
3 (My spouse only informs me once he has taken the decision)	0.128 (-1.13)	-0.0374 (-0.81)	0.0895 (-1.28)
4 (Only the male household members decide)	0.0903 (-1.34)	0.026 (-0.86)	0.0356 (-0.96)
5 (Other family members decide)	0.313* (-2.23)	-0.0306 (-0.52)	0.0977 (-1.18)
Pond ownership (No)		Reference category	
Pond ownership (Yes)	0.00976 (-0.07)	0.0171 (-0.19)	0.0494 (-0.48)
Family size	0.00926 (-0.74)	0.00615 (-1.4)	-0.00551 (-1.10)
Male contribution to farm tasks	-0.0445 (-1.12)	0.0192 (-1.73)	-0.00543 (-0.46)
Female contribution to farm tasks	0.0958* (-2.52)	-0.0215* (-1.99)	0.0135 (-1.12)
Electricity access (Yes)		Reference category	
Electricity access (No)	0.732 (-1.94)	-0.00852 (-0.10)	0.0857 (-0.91)
Irrigation pump ownership (Yes)		Reference category	
Irrigation pump ownership (No)	0.0852 (-1.39)	-0.116*** (-7.95)	-0.0526** (-3.04)
Credit access (Yes)		Reference category	
Credit access (No)	-0.0448 (-0.68)	-0.0319* (-2.07)	0.0184 (-0.94)
Machinery uses (Yes)		Reference category	
Machinery uses (No)	-0.288 (-1.72)	0.0163 (-0.47)	0.0072 (-0.18)
Farmers group involvement (Yes)		Reference category	
Farmers group involvement (No)	-0.157* (-2.45)	0.0258 (-1.73)	0.013 (-0.73)
NGO support (Yes)		Reference category	
NGO support (No)	0.0302 (-0.48)	0.0055 (-0.35)	-0.00127 (-0.07)
Preferred market mechanism (Direct to middleman from home)		Reference category	
2 (Selling at the market myself)	-0.320*** (-6.02)	0.0548*** (-3.66)	-0.0336 (-1.93)

Table 6 (continued)

Variables	Crop plot	Crop non-plot	Non-crop non-plot
97 (Others)	-0.259*** (-4.63)	0.00615 (-0.16)	0.0695 (-1.57)
Seed subsidy (Yes)		Reference category	
2 Seed subsidy (No)	0.116 (-0.95)	-0.00132 (-0.04)	-0.0622 (-1.70)
Fertilizer subsidy (Yes)		Reference category	
Fertilizer subsidy (No)	-0.194 (-1.82)	-0.0203 (-0.48)	0.0453 (-0.93)
Agricultural tools subsidy (Yes)		Reference category	
Agricultural tools subsidy (No)	0.067 (-0.9)	-0.0458 (-1.03)	-0.0374 (-0.73)
Other input subsidy (Yes)		Reference category	
Other input subsidy (No)	-0.0296 (-0.28)	-0.0484 (-0.68)	0.0492 (-0.65)
Subsidy for animals (Yes)		Reference category	
Subsidy for animals (No)	0.0418 (-0.4)	-0.00593 (-0.11)	0.166** (-2.7)
Cash incentives (Yes)		Reference category	
Cash incentives (No)	-0.175** (-2.79)	-0.0912*** (-3.63)	-0.0112 (-0.31)
Constant	2.261*** (-8.3)	-0.296** (-2.84)	0.217 (-1.8)
	Log pseudolikelihood = -217.2296 Wald chi2(43) = 139.07 Prob > chi2 = 0 Pseudo R2 = 0.0334	Log pseudolikelihood = -887.72326 Wald chi2(43) = 194.28 Prob > chi2 = 0 Pseudo R2 = 0.004	Log pseudolikelihood = -826.79877 Wald chi2(43) = 98.21 Prob > chi2 = 0 Pseudo R2 = 0.0028

Note: t statistics in parentheses * p < .05, ** p < .01, *** p < .001
Source: Authors estimation, 2024.

potatoes, in the northeastern states of India and neighbouring countries, notably Nepal and Bhutan (Das et al., 2021). The Cooch Behar region also offers an ideal environment for jute cultivation, leading to a dominant jute-rice cropping system (Mitra and Samajdar, 2013). The crop takes the advantage of residual fertility as it is mostly grown after high fertilized potato and high monsoon rain also favours the post-harvest retting process. Pulses are grown in sporadic patches in West Bengal study sites primarily due to its lower productivity. Overall, the cultivation of crops other than rice show significant variation, indicating diverse agricultural ecosystems and practices.

For crop non-plot diversification, tree species and fruit crops are predominant. Trees are an inseparable part of agrarian life due to their multidimensional utility in daily life including supplying wood for cooking fuel. These are mostly grown in homestead land for almost all farming households. Most of the households have some plantations in the homestead area; for example, synergistic interaction with shade loving black pepper crops under areca nut mixed farming helps to bring higher productivity in West Bengal (Waman et al., 2021). Floriculture is one of the main-stream commercial activities in West Bengal and has opportunities for value-addition (Chakraborty, 2019). Vegetables crops are also grown sporadically, Coochbehar 2 block being the traditional vegetable growing belt has the highest acreage under vegetables.

4.2. Factors affecting diversification

Livelihood diversification can be driven by distress or prosperity; with different goals and strategies employed. This is similar to the decision made to migrate, where households who are both in the wealthier

and poorer households migrate, the former group because they have the resources to do so (Martin and Lorenzen, 2016); and the latter because they have no other survival options in the surrounding location (Nienkerke et al., 2023).

In the EGP, male members of the household often migrate for employment and economic opportunities, and female headed households almost always have male members who have migrated for work. Where there are more lucrative options for the male member, this prompts the decision to migrate (Nienkerke et al., 2023). In response to this migration, female members of the household are directly engaged in agricultural diversification, to manage and sustain the household income in the absence of the male member. This result is aligned with the findings of de Brauw et al. (2021) and Ram Mohan et al. (2022). In similar research conducted in West Bengal, there was a significantly higher contribution of women in livelihood diversification in Uttar Dinajpur District, India (Saha and Bahal, 2010). Both the argument of choice and the report on higher involvement of women demonstrate that the guiding force of diversity differs in different locations.

Diversification is higher for those who do not own an irrigation pump compared to those who do. Households with irrigation pumps may have a more stable and secure water supply for their existing crops. Households with irrigation pump access may opt to go for cereal crop production rather than other high value crops (Thapa et al., 2017). This security might reduce the perceived need for diversification, as they can sustain their current agricultural activities without major challenges. Higher asset value has been reported (Khatun and Roy, 2012; Lama and Kuri, 2015) to have an enabling effect on livelihood diversification and the same can relate to the asset like holding an irrigation pump which indicates an individual's wealth base. It is recognized that in the region, many farmers buy water through informal rental markets, so not owning a pump does not mean there is no access to water for irrigation. Access to irrigation varies in the region, and as groundwater is the main source of irrigation, access is heavily influenced by access to and price of electricity and to a lesser extent diesel. Policy settings for water, energy and agriculture in Bangladesh and West Bengal have encouraged intensive groundwater use (Mukherji et al., 2021). In contrast, Nepal has lower levels of access to irrigation, with around half of arable land area irrigated, low levels of efficiency, and gendered challenges to access (Nepal et al., 2024).

A lack of management in marketing activities is associated with a decrease in the likelihood of diversification. If farming households are not actively engaged in managing marketing activities, they might be less inclined or equipped to explore and implement changes in their diversification strategies. This could be due to various factors, such as a lack of awareness about market trends, limited access to information, or a hesitance to venture into new agricultural products or practices without a strategic marketing plan. This study showed that where market connectivity is improved, diversification often follows, for example where potato production has increased in West Bengal with better connectivity to new markets.

Households with credit access have a reduced inclination to diversify their activities and may be more risk-averse due to the financial obligations associated with borrowing. This could make them hesitant to experiment with diversification, as it introduces uncertainties and potential risks. Access to cash incentives provides farming households with additional capital to invest in diversification efforts. This financial support can enable them to experiment with new crops, technologies, or agricultural practices.

Government institutions and NGOs provide information about various schemes and technical know-how related to existing or new livelihood activity of a farm family. These are often a driving force behind successful livelihood diversification pathways (Khatun and Roy, 2012). The current findings confirm that the NGO plays a positive role in diversifying livelihood activities. Support in the form of subsidies to procure critical inputs for animal husbandry practices and for plot level agricultural activities like fertilizer and seed is likely to attract farming

household towards the enterprises particularly in the Indian part of the present study locations.

In the current study it is evident that in Coochbehar district of India, unlike that of Bangladesh, livelihood diversification is reduced when decided by women. Women in general do not own land and most of the time have lower levels of education compared to their male counterparts. In the cases of decision-making process in Indian context, traditionally or culturally women may find it inappropriate to decide on their own (Choithani, 2019). In the Indian context if the agricultural task is contributed by male members the diversity is found to be significantly adversely affected which is not the case for Nepal and Bangladesh.

In Nepal, the significant factors affecting diversification include agricultural decision making, irrigation pump ownership, gendered contribution to farm tasks and access to NGO support. Rahut et al. (2014) also found that gender was an important determinant of rural livelihood strategies in Nepal, with male headed households more likely to diversify into strategies that include non-farm activities and wage labour. The result is consistent with Thapa et al. (2017) where it was found that female headed households had significant positive association with agricultural diversification in terms of production of high value crops in Nepal. Similarly, access to NGO support significantly increases livelihood diversification in Nepal. NGO extension support has a significant positive impact on the technical efficiency of crop producing farms (Bhatta et al., 2008).

In Bangladesh, the significant factors affecting diversification include the gender of the respondent, irrigation pump ownership and market mechanisms. Gender is one of the important factors for livelihood diversification, with women respondents having a positive and significant effect on the livelihood diversification. This may be because in the rural areas of Bangladesh, women's participation in Income Generating Activities (IGAs) are now higher (Hasan et al., 2015) and both agricultural (vegetables cultivation, tree plantation, poultry and domestic animal rearing, tree plantation, fish culture) and non-agricultural (cottage industry, rice processing and small business) IGAs are operated by rural women (Kabir et al., 2019). Sarker et al. (2020) also found a significant positive relationship between gender and decisions related to livelihood diversification among rural households of disaster-prone riverine islands in Bangladesh. Similarly, Kannari et al. (2023) revealed that gender of the household head is a significant determinant for the adoption of both crop diversification and income diversification of rural Bangladesh. A similar situation was found in Ethiopia in relation to livelihoods diversification of rural households in Ethiopia (Alemu, 2023). On the other hand, Ahmed et al. (2018) revealed that male-headed households had a positive and significant effect on the extent of livelihood diversification among the rural households (at 1 % level of significance). This result is consistent with some other studies on income diversification in Nigeria (Babatunde and Qaim, 2009) and livelihood diversification patterns in West Bengal, India (Saha and Bahal, 2014).

Irrigation development in Bangladesh was driven by the liberalisation of the agriculture equipment market, and a relaxation of well spacing rules, with around 1.5 million groundwater extraction structures by 2019 (Mukherji et al., 2021). This has had a profound impact on rural livelihood strategies through significant improvement in cropping intensity, grain production, household income from rice production, wage labour employment and irrigation service provision (Hasnip et al., 2002). Our results revealed that irrigation pump ownership had a positive and significant effect on the livelihood diversification among the rural households. Kannari et al. (2023) reported that usage of irrigation is a significant determinants of livelihood diversification of rural Bangladesh, and this has also been found in West Bengal, India (Khatun and Roy, 2012) and Ethiopia (Alemu, 2023).

Market mechanisms had a positive and significant effect on livelihood diversification in Bangladesh. This result is consistent with Khatun and Roy (2012) where it was found that marketing infrastructure (proximity to town) was a significant determinant for livelihood

diversification in West Bengal, India. Similarly, [Udaykumar and Umesh \(2020\)](#) and [Alemu \(2023\)](#) mentioned that distance to market had negative effect on diversification.

5. Conclusions and recommendations

This study presents a comprehensive examination of the patterns and determinants of livelihood diversification in the EGP, revealing a complex interplay of factors that influence smallholder farming households' diversification strategies. Our findings underscore the moderate yet significantly varied levels of diversification across regions, driven by a combination of socio-economic, institutional, and environmental factors. Notably, the presence of irrigation infrastructure, gender dynamics within households, access to credit and markets, and engagement with agricultural support services were identified as critical determinants of diversification.

The study highlights the pivotal role of diversification in enhancing the resilience, income stability, and food security of smallholder households in the EGP. Diversification into non-crop activities, including livestock and off-farm income sources, emerged as a key strategy for mitigating risk and coping with uncertainty, underscoring the importance of integrated farming systems. However, the impact of diversification on farm households varied, reflecting the diverse socio-economic contexts and resource endowments of the region.

Policy implications drawn from this study emphasize the need for targeted interventions to support effective diversification strategies. Specifically, policies should aim to improve access to resources such as water, credit, and markets, while also enhancing capacity through education and extension services. Gender-sensitive approaches are crucial, given the significant role of female household members in driving diversification efforts. Furthermore, fostering institutional support and facilitating market access can enable smallholders to capitalize on diversification opportunities, thereby promoting sustainable agricultural practices and enhancing livelihoods.

This study contributes to a deeper understanding of the dynamics of livelihood diversification in the EGP, offering valuable insights for policymakers, development practitioners, and researchers. By addressing the key drivers of diversification and recognizing the varied impacts on different household types, strategies can be developed to promote more inclusive, resilient, and sustainable farming systems in the region. Future research should focus on longitudinal studies to capture the evolving nature of diversification patterns and their long-term impacts

Appendix A. Annexe 1

Table 7
Definition of variables and measurement for statistical analyses.

Variables	Variable class	Acronyms of variables	Measurement and units	Expected sign
Dependent variable				
Patterns of Diversification	Continuous	PD	Simpson Diversification index (SID), value ranges between 0 and 1	NA
Independent variables				
Age	Continuous	AGE	Years	-
Gender	Dummy	GEN	1 = Male; 0 = Female	+/-
Education	Continuous	EDUC	Years of schooling	+
Agricultural decision making	Categorical	AGDS	1 = Only me; 2 = My spouse and I discuss together; 3 = My spouse only informs me once he has taken the decision; 4 = Only the male household members decide; 5 = Other family members decide	+/-
Pond ownership	Dummy	PDO	1 = Yes; 0 = No	+/-
Family size	Continuous	FAS	Number	+/-
Male contribution to farm tasks	Continuous	MCF	Number	+
Female contribution to farm tasks	Continuous	FCF	Number	+

(continued on next page)

on rural livelihoods.

CRediT authorship contribution statement

Tamara M. Jackson: Writing – review & editing, Writing – original draft, Resources, Project administration, Conceptualization. **Ravi Nandi:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Arifa Jannat:** Writing – review & editing, Writing – original draft, Formal analysis. **Arunava Ghosh:** Formal analysis. **Dilip Kumar Hajra:** Writing – original draft. **Biplab Mitra:** Writing – original draft. **Md Mamunur Rashid:** Writing – original draft. **Sagar Bista:** Writing – original draft. **Anjana Chaudhary:** Investigation. **Pragya Timsina:** Investigation. **Emma Karki:** Investigation. **Kali Rattan Chakma:** Investigation. **Gunjan Rana:** Investigation. **Avinash Kishore:** Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Tamara Jackson reports financial support was provided by Australian Centre for International Agricultural Research. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 7 (continued)

Variables	Variable class	Acronyms of variables	Measurement and units	Expected sign
Electricity access	Dummy	ELEC	1 = Yes; 0 = No	+/-
Irrigation pump ownership	Dummy	IRP	1 = Yes; 0 = No	+/-
Credit access	Dummy	CRA	1 = Yes; 0 = No	+
Machinery uses	Dummy	MCHN	1 = Yes; 0 = No	+
Farmers group involvement	Dummy	FRG	1 = Yes; 0 = No	+/-
NGO support	Dummy	NGOS	1 = Yes; 0 = No	+/-
Preferred market mechanism	Categorical	MKTM	1 = Direct to middleman from home; 2 = Selling at the market myself; 3 = Others	+/-
Seed subsidy	Dummy	SESU	1 = Yes; 0 = No	+
Fertilizer subsidy	Dummy	FERS	1 = Yes; 0 = No	+
Agricultural tools subsidy	Dummy	AGTS	1 = Yes; 0 = No	+
Other input subsidy	Dummy	INSU	1 = Yes; 0 = No	+
Subsidy for animals	Dummy	ANSU	1 = Yes; 0 = No	+
Cash incentives	Dummy	CSIN	1 = Yes; 0 = No	+

Source: Author’s selection based on literature review and aligned with the Baseline Survey.

Appendix B. Annexe 2

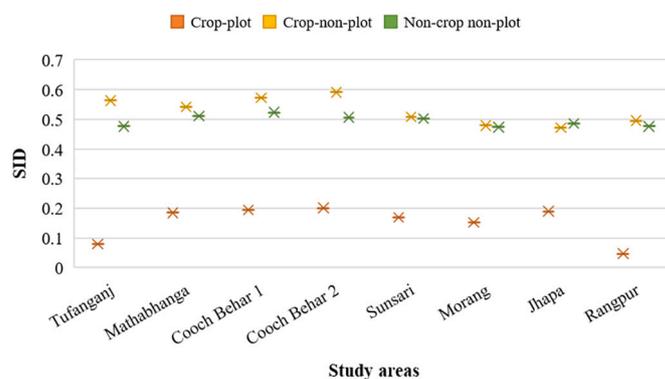


Fig. 4. Category wise livelihood diversification.

Appendix C. Annexe 3

Table 8
Multicollinearity test.

Variables	VIF	Tolerance
Family size	1.65	0.604
Male contribution	1.54	0.650
Fertilizer subsidy	1.53	0.653
Seed subsidy	1.52	0.656
Female contribution	1.45	0.691
Education	1.24	0.809
Age	1.23	0.814
Irrigation pump ownership	1.13	0.882
Input subsidy	1.12	0.894
Gender	1.1	0.907
NGO	1.1	0.911
Machinery subsidy	1.1	0.911
Agricultural decision making	1.07	0.932
Cash incentives	1.05	0.955
Preferred market mechanism	1.04	0.959
Farmers group involvement	1.04	0.960
Credit access	1.04	0.964
Machinery uses	1.03	0.968
Animals’ subsidy	1.03	0.972
Electricity access	1.02	0.979
Pond ownership	1.01	0.988
Mean VIF	1.19	

Data availability

The full dataset and associated metadata can be found in the Data in Brief article available at <https://doi.org/10.1016/j.dib.2025.111372>.

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