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Research article

Managing uphill cultivation under climate change – An assessment of adaptation decisions among tribal farmers in Nagaland state of India

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ABSTRACT

Tribal farmers in the Himalayas are vulnerable to climatic changes, as their rain-fed cultivation systems, practiced on steep, sloping terrain, are susceptible to changes in rainfall while at the same time being the primary means of livelihood. Soil and water conservation practices (SWCP) can improve the resilience of these cultivation systems to adverse climatic conditions. However, little is known about adaptation within these tribal farming communities. This is the first empirical study on the adaptation decisions of tribal farmers in the Himalayan uplands of Northeast India. Starting from the analysis of future climate risks, we surveyed 372 tribal farmers in Nagaland state to analyze perceived climate and environmental changes in relation to socio-demographic factors. We estimate current adoption rates of SWCP together with farmers' goals and values and employ a binary logit model (BLM) to quantify the influence of diverse factors on adaptation decisions. Our results show that increases in temperatures and crop diseases were the most perceived changes by tribal farmers. Climate projections indicate that precipitation amount and intensity, along with temperatures, will increase towards the end of the century, underlining the importance of SWCP. However, all considered SWCP were employed by less than half of the tribal farmers. Adoption probabilities for all practices were significantly increased when farmers participated in agricultural training. After that, participation in a civil society organization, livestock ownership, high-altitude locations, and perceived increases in droughts were found to increase adoption probabilities significantly, while socio-demographic factors were of only minor importance. If the most effective factor was employed to all farmers, average adoption rates of SWCP could at least double. Adoption decisions were mainly motivated by improving livelihoods, sustaining natural resources, reducing workload, and preserving cultural aspects of cultivation. This research contributes to understanding adaptation decisions of tribal farmers and quantifies the untapped potential for climate change adaptation of marginalized and climate-vulnerable farming communities in mountain regions.

1. Introduction

While negative impacts from climate change on productivity have been reported for many regions of the world, severe impacts are expected in mountain ecosystems and agriculture (IPCC, 2022). Due to projected changes in hazards and the water cycle in mountain regions, particularly in south and central Asia, the IPCC has recently emphasized the importance of adaptation for warming rates above 1.5 °C (IPCC, 2022). Besides the changing climate and difficult topographic conditions, political and social marginality have made mountain communities highly vulnerable (FAO, 2015).

In the Himalayas, warming rates are higher than the global average, while steep topographies and shallow, nutrient-poor soils favor erosion-caused land degradation (ICIMOD, 2010; Pepin et al., 2015). In addition, farming communities in the Himalayas are often marginalized, show high poverty levels, low literacy rates, and poor access to resources,

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markets, and off-farm employment, thus depending on subsistence agriculture (FAO, 2015; Ghosh-Jerath et al., 2021; Rana et al., 2021). Because of their climate-sensitive production systems and low adaptation capacities, Himalayan farming communities are particularly vulnerable to climate change (Rai et al., 2019).

These characteristics apply in particular to the indigenous tribal farming communities in Northeast India, designated as Scheduled Tribes by the Indian government (Ghosh-Jerath et al., 2021). Their centuries-old rain-fed, low-input, and thus purely organic production systems play a key role in securing local food supply and preserving the culture and traditions of the tribal population (Pandey et al., 2020). Climate change puts these production systems at risk because of their strong dependence on timely rainfalls and intact fertile soils.

The application of soil and water conservation practices (SWCP) has been advised to reduce the vulnerability of tribal farming communities to increasing climatic risks in the Himalayan region (Schröder et al., 2023; Xuan Minh et al., 2017). This raises the question of what internal and external factors influence farmers' decisions to adopt or not adopt such practices. Knowledge about how climate change perception, farmers' values, but also socio-demographic, economic, and location factors influence adaptation decisions may improve agricultural policies to support smallholder adaptation to climate change.

A wide academic literature has discussed socio-demographic and economic determinants of farmers' adaptation to climate change in diverse geographic contexts. It was found that gender, age, education, household size, and access to credit can significantly affect adaptation (Ahmed et al., 2021; Jin et al., 2016; Marie et al., 2020; Mwinkom et al., 2021). However, many factors have been proven to be context-dependent, with studies from Ethiopia identifying access to extension services, climate information, and household income as relevant (Adego and Woldie, 2022; Bryan et al., 2009; Deressa et al., 2009; Eshetu et al., 2021), while studies from Pakistan observed farm size (Abid et al., 2015; Ali and Rose, 2021; Amir et al., 2020; Khan et al., 2020), and from Vietnam membership in a local community organization as influential factors for adaptation (Huong et al., 2017; Truong et al., 2022; Vo et al., 2021). Consequently, findings from one geographical setting can hardly be transferred to other contexts where climate, environmental, and socio-political dynamics differ, thus making adaptation research focusing on the context of Himalayan tribal farmers necessary (Ghosh-Jerath et al., 2021).

A few studies on climate change perception and adaptation in the Himalayas have been conducted already; however, they did not focus on soil conservation (Rymbai and Sheikh, 2018; Singh et al., 2017), which will be increasingly important with changing rainfall regimes. Also, these studies did not address farmers' values and related goals and preferences in the adaptation process, nor was their research linked to established theories of adaption behavior (Bhalerao et al., 2022; Datta and Behera, 2022a; Jha and Gupta, 2021; Lone et al., 2022).

Due to the particular vulnerability of Himalayan tribal farming communities, this study seeks to close this research gap. We conducted a large-scale quantitative survey with tribal farmers from Nagaland State in Northeast India, the state with the second largest share of tribal population and the highest amount of families practicing shifting cultivation, a typical uphill farming system in the Himalayas (Government of India, 2015). Based on this survey and climate model projections, our research seeks to answer the following questions: 1.) Which climate futures can be expected for the region? 2.) Which climate and environmental changes do tribal farmers perceive, and how are they connected to socio-demographic factors? 3.) What are current adoption rates of SWCP, which factors influence adoption, and to what extent can adoption rates be increased? 4.) Which personal values do tribal farmers consider in the adaptation process?

2. Theoretical framework

This research builds on established theories of adaptation behavior, namely the Model of Private Proactive Adaptation to Climate Change (MPPACC) (Grothmann and Patt, 2005) and the Values Beliefs Norms Theory (VBN) (Stern, 2000). MPPACC defines a two-stage process preceding the adaptation decision, which consists of a "climate change risk appraisal" and an "adaptation appraisal". Based on the Protection Motivation Theory (PMT) (Rogers et al., 1983), MPPACC assumes that adaptation presupposes the perception of climatic risks, thereby accounting for cognitive biases, heuristics, and social discourses on climate change, influencing people's perception of risk and adaptive capacity. The model also considers the effect of past experiences on risk perception and an objective adaptive capacity, including, e.g., economic and social constraints that enable or impede people from turning adaptation intentions into actions. VBN assumes a similar causal chain leading to pro-environmental behavior but emphasizes the role of personal values and norms in the risk perception and adaptation process. Our research builds on these theories with regard to three aspects: First, we analyze how climate change perception is shaped among tribal farmers and how these perceptions influence the adoption of SWCP. Second, we address the objective adaptive capacity by identifying other factors supporting or constraining adaptation. Third, we assess which values and norms of tribal farmers are relevant in the adaptation process. Thereby, we assume that personal values not only influence the risk evaluation but also goals and preferences of farmers. A schematic illustration of the resulting theoretical framework is provided in Fig. 1.

3. Material and methods

3.1. Study area

We selected Nagaland state of Northeast India as a study area for our research because it has one of the largest proportions of tribal population (87%) relying on traditional farming practices such as shifting cultivation, an extensive, uphill, subsistence farming system. While the distribution of shifting cultivation in many tropical regions has decreased over the last decades because of political and economic pressures (van Vliet et al., 2012), in Northeast India, particularly Nagaland State, the practice is still widely distributed, with approximately 116,000 families being engaged in the practice (Government of India, 2015).

Located in the Himalayas' foothills, Nagaland is traversed by mountain ranges. About 98% of the state is mountainous (Jayahari and Sen, 2015), with altitudes ranging from 194 to 3840 m above sea level (Government of Nagaland, 2019). Accordingly, steep slopes dominate the region, with 63% of the area having slopes steeper than 30% and even 26% steeper than 50% (NASA SRTM, 2013). Because of its steep topography, Nagaland is especially threatened by soil erosion.

The climate of Nagaland ranges from sub-tropical to sub-montane temperate. It is characterized by high rainfall intensities during summer, with 85% of the total annual precipitation being recorded during the Indian summer monsoon between mid-May and the end of September. Total annual precipitation is 1200–2500 mm (Government of Nagaland, 2019; Jayahari and Sen, 2015).

3.2. Data

3.2.1. Farmer survey

To investigate farm-level management strategies, we surveyed Nagaland state between November 2021 and April 2022. We first selected six districts using simple randomization. In a second step, we selected four villages per district with a suitable number of families actively engaged in cultivation and available for interviews during our field visit (Fig. 2). Extension officers from the local Krishi Vigyan Kendras (KVKs) supported the identification of these villages. From each village, all households actively involved in cultivation activities during our field visit and willing to participate were interviewed using a fully structured questionnaire on diverse socio-demographic, economic, and

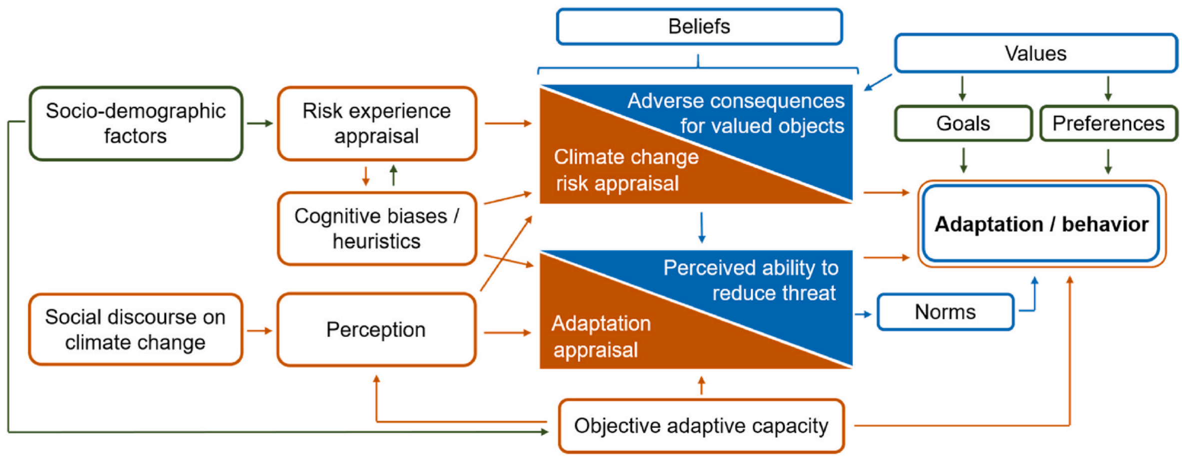

Fig. 1. Theoretical framework. *Note:* Orange elements relate to the MPPACC (Grothmann and Patt, 2005), blue elements relate to the VBN Theory (Stern, 2000). Elements in green were added to the framework by the authors. MPPACC and VBN Theory are shown in a simplified and reduced way; for the original theories the reader is referred to Grothmann and Patt (2005) and Stern (2000).

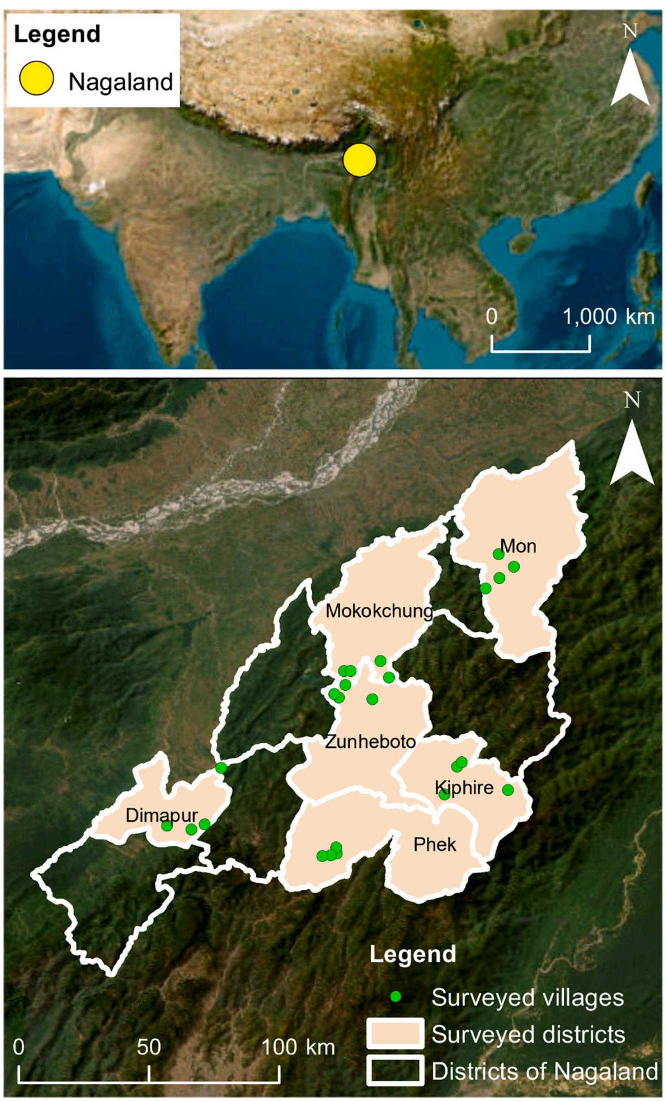

Fig. 2. Study area with surveyed villages. Source of satellite image: ESRI, Maxar, Earthstar Geographics, and the GIS User Community

network variables, as well as farming practices, perceptions, and opinions (see Supplementary Material B).

From the collected data, we included only those data entries that were complete regarding the variables used in the final analysis. We excluded all data entries with logical errors. After data cleaning, 372 farmer interviews remained for the statistical analysis, with 41–88 entries per district and 6–25 per village (see Supplementary Material Tab. A1).

3.2.2. Climate data

To identify climatic trends in the study region, we used daily climate model data from phase 3b of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3b) (Lange, 2019b; Lange and Büchner, 2021). ISIMIP3b climate data are available for three climate scenarios, a low-end (SSP126), a medium-high (SSP370), and a high-end (SSP585) future forcing scenario as well as five models of phase 6 of the Coupled Model Intercomparison Project (CMIP6): GFDL-ESM4, MPI-ESM1-2-HR, MRI-ESM2-0, UKESM1-0-LL, and IPSL-CM6A-LR. ISIMIP3b data were statistically downscaled to a 0.5° spatial resolution and bias-adjusted by Lange (2019b) using the EWEMBI dataset (Lange, 2019a) with a global coverage at 0.5° spatial resolution (see also Frieler et al. (2017) for a detailed description of the EWEMBI dataset). We downloaded the ISIMIP3b climate data in February 2022 from the ISIMIP repository (https://data.isimip.org/search/). We intersected the ISIMIP grid with the locations of the surveyed villages using ArcGIS software and extracted daily maximum and minimum temperatures and precipitation for the six remaining ISIMIP grid cells. For further analysis, daily mean values over the six grid cells were derived. We computed daily mean temperatures by taking the average of daily maximum and minimum temperatures. To address rainfall intensity, we computed the rainfall peak volume, which we defined as the total precipitation of the ten wettest days per year. We defined drought frequency during the growing period from March 1st to September 1st as the number of non-overlapping periods with at least ten consecutive days without rainfall. To assess long-term climatic trends, we computed annual mean values for temperature, rainfall amount, rainfall peak volume, and drought frequency for a historical period from 1901 to 2014 and the three climate scenarios between 2015 and 2100. All computations and plotting operations were carried out in R software.

3.3. Statistical model

We applied a binary logit model (BLM) to estimate influencing factors of farmers' management strategies. BLMs describe the binary decision of farmers on whether to adopt a certain strategy or not based on various factors, which can include both categorical and continuous variables. The model allows for analyzing different adaptation strategies independently, thus providing a suitable method for contexts where farmers apply multiple management strategies simultaneously (Abid et al., 2015; Ali and Rose, 2021). Further, it provides a clear interpretation via the odds ratios which can inform targeted interventions and policy recommendations. Lastly, using a BML is not restricted by assumptions of linear regressions, such as normality, linearity, and homoscedasticity (Ali and Rose, 2021). Because of these capabilities, the model has already been applied in various similar studies and has yielded valuable insights into farmer adaptation behavior, i.e., in Bangladesh (Ahmed et al., 2021), China (Jin et al., 2015, 2016), Vietnam (Huong et al., 2017; Thoai et al., 2018; Vo et al., 2021), Pakistan (Abid et al., 2015; Khan et al., 2020; Ali and Rose, 2021), and Ethiopia (Sertse et al., 2021). By utilizing a consistent and established methodology, we build upon existing research and facilitate comparisons with prior findings.

The model can be specified as

$$Y_{ij} = \alpha + \sum X_k \beta_k + \varepsilon_{Yij} \tag{1}$$

where Y_{ij} is the dichotomous dependent variable with subscript i referring to the farmer, who is taking the management decision, and j representing the management strategy. X_k is a vector of various factors influencing farmers' management decisions, with subscript k referring to the specific independent variable, whereas β_k indicates a vector of binary coefficients. α shows the model intercept, and $\mathcal{E}_{Yij}$ denotes the error term (Ali and Rose, 2021; Sertse et al., 2021).

We focused our statistical analysis on adaptation measures conserving soil and water resources, including cover crops, mulching, intercropping with legumes, manure, and rainwater harvesting (RWH). Both cover crops and mulching protect soils from high-intensity precipitation by providing soil coverage. Cover crops also stabilize soil aggregates through their roots, while mulching recycles nutrients and improves the soil water balance by increasing infiltration and reducing evaporation (Kaye and Quemada, 2017; Ngangom et al., 2020). Intercropping with legumes improves soil fertility through nitrogen fixation and reduces soil loss by providing additional soil cover (Sharma et al., 2017). The application of manure increases soil productivity by delivering nutrients and organic matter and can likewise act as a protective cover, reducing soil detachment and thus erosion (Ramos et al., 2006). Lastly, RWH increases water resources available for irrigation, thus potentially improving the soil water balance when rainfall is absent.

Similar to previous studies (Abid et al., 2015; Amir et al., 2020; Datta and Behera, 2022a; Deressa et al., 2009), we based the choice of explanatory variables on literature review and the specific characteristics of the study area, as also suggested by Dang et al. (2019). In contrast to many previous studies, we opted against the integration of gender in the statistical model, as in our study area management decisions are typically made by the entire farming household. Perception variables were reduced to those directly relevant for the analyzed SWCP, including an increase in temperatures and drought frequencies, any change related to rainfall, and an increase in erosion. Continuous variables were tested on linearity with log odds. Where possible, the non-linearity of independent variables and log-odds was solved by converting continuous into categorical variables (farming experience, elevation, distance to market), while others had to be excluded from the set of input variables (age, family size, total cultivated area). Lastly, all variables were tested on multicollinearity. As in Jin et al. (2015) we computed the "tolerance" (TOL) and "the variance inflation factor" (VIF) indices for multicollinearity diagnosis. Strong multicollinearity is indicated by TOL values below 0.1 and VIF values greater than 10 (Jin et al., 2015; Menard, 2002). In our models, TOL values ranged from 0.3 to 0.9 and VIF values from 1.1 to 3.0, confirming low multicollinearities for all models. We provide a detailed explanation of all independent variables used in the final model in Table 1. In addition to the listed variables, we initially also included a perceived increase in temperature and erraticness of rainfall and the reception of financial support but excluded them in the final model as their coefficients for all management strategies turned out to be statistically insignificant. We run all tests and models in R software.

4. Results

4.1. Climatic trends for Nagaland

Climate model data indicate a steady increase of temperatures in the study region during the end of the 20th and beginning of the 21st century (Fig. 3). Compared to the beginning of the 20th century, temperatures increased by at least 1° Celsius until 2014. By contrast,

Table 1
Summary statistics of variables included in the BLM.

	Variable	Description	Occurrence*	
Dependent	Cover crops	Dummy 1 if adopted, 0 otherwise	14%	
	Mulching	Dummy 1 if adopted, 0 otherwise	40%	
	Intercropping	Dummy 1 if adopted, 0 otherwise	46%	
	Manure	Dummy 1 if adopted, 0 otherwise	29%	
	RWH	Dummy 1 if adopted, 0 otherwise	31%	
Independent	Training	Dummy 1 if farmer received training, 0 otherwise	Fig. 6	
	Extension contact	Dummy 1 if farmer has regular (at least yearly) contact to governmental extension worker, 0 otherwise	75%	
	Civil society organization	Dummy 1 if farmer participates in a civil society organization, 0 otherwise	87%	
	Off-farm income	Number of non-farming household income sources: 0 = no income sources; 1 = one income source; 2 = more than one income source	$\bar{x} = 1.0$	$\sigma = 0.7$
	Livestock ownership	Dummy 1 if farmer rears livestock, 0 otherwise	76%	
	Rainfall quantity decrease	Dummy 1 if farmer perceived decrease in rainfall quantity, 0 otherwise	57%	
	Drought frequency increase	Dummy 1 if farmer perceived increase in frequency of droughts, 0 otherwise	40%	
	Rainfall intensity increase	Dummy 1 if farmer perceived increase in rainfall intensity, 0 otherwise	9%	
	Rainfall quantity increase	Dummy 1 if farmer perceived increase in rainfall quantity, 0 otherwise	7%	
	Erosion increase	Dummy 1 if farmer perceived increase in soil erosion, 0 otherwise	50%	
	Farming experience	Dummy 1 if farming experience is at least 20 years, 0 otherwise	64%	
	School education	0 = no schooling; 1 = primary; 2 = secondary; 3 = above secondary	$\bar{x} = 1.1$	$\sigma = 0.8$
	Elevation	Dummy 1 if elevation of village is above 1000 m, 0 otherwise	42%	
	Market distance	Dummy 1 if distance to nearest market is at least 10 km, 0 otherwise	57%	

Note: * Occurrence within sample is given. For binary variables, the percentage of farmers where the variable takes the value 1 is shown, for other categorical variables, mean ($\bar{x}$) and standard deviation (σ) are given.

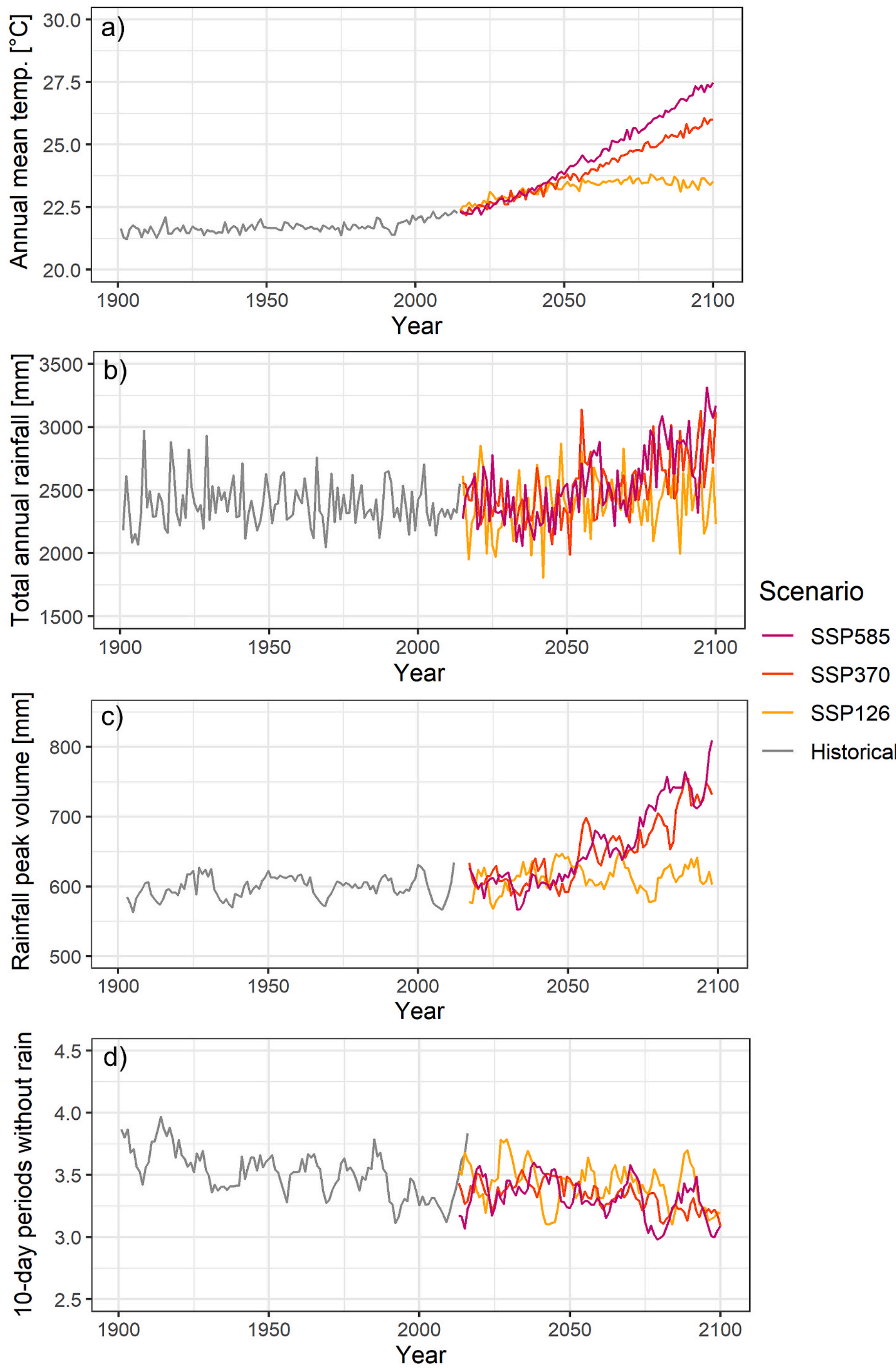

Fig. 3. Historical and future climatic trends of Nagaland under SSP126, SSP370, and SSP585 scenarios. *Note:* Figure shows a) annual mean temperatures in °C, b) annual precipitation in mm, c) rainfall peak volume in mm, defined as the cumulative precipitation of the ten wettest days per year as a proxy for rainfall intensity, d) number of non-overlapping periods with at least 10 rain-free days during the growing season (March 1st – September 1st) as a proxy for drought occurrence. For c) and d), a 5-year moving average is shown for readability. Data source: ISIMIP3b (Lange and Büchner, 2021).

precipitation data do not reveal systematic changes for this period. Despite substantial interannual variability in annual precipitation, neither precipitation amount nor intensity, described by peak volume, has shown a clear trend until 2014. However, the frequency of droughts, here defined as 10-day periods without rainfall during the growing season, reveals a slightly decreasing trend.

Until the end of the 21st century, ongoing increases in temperatures are projected (Fig. 3). These will be particularly high for the medium-high (SSP370) and high-end (SSP585) emission scenarios, under which daily mean temperatures will exceed 26 °C, compared to approximately 22.5 °C in 2014. Likewise, increases in the amount and intensity of precipitation can be expected, particularly during the second half of the century and for the higher emission scenarios. In line with increasing precipitation, drought conditions are projected to decrease slightly without considerable differences between the scenarios.

Although these climate data are subject to large uncertainties and inaccuracies related to their spatial resolution and the complex terrain of the study region, they reveal relevant general climatic trends with important implications for upland cultivation in the region. Due to increases in temperatures and hence potential evapotranspiration, plant-available water might decrease even under increasing total annual precipitation. Since precipitation intensities are projected to increase simultaneously, runoff and hence soil erosion will most probably increase as well, making SWCP increasingly important.

4.2. Perceived climatic and environmental changes

While climate model data quantify objective, large-scale trends, surveys allow to understand subjectively perceived climatic and environmental changes at the local scale. Our survey results show that temperature increase is the most important change observed by farmers (Fig. 4). Over 80% of all respondents perceived an increase in temperatures, with slightly higher perception rates among farmers with at least secondary education. There are no notable differences between male and female farmers and those with longer and shorter farming experience. Most farmers (57%) also perceived a decrease in rainfall, which was more often observed among farmers with longer farming experience (64%). In follow-up discussions with farmers, we found that this decrease in rainfall was particularly observed in the month of February and March, suggesting a shift in the monsoon season, as observed by 16% of all respondents. An increase in the frequency of droughts is the third most noticeable climatic change, which was clearly more often perceived by female (50%) than by male (34%) farmers and by farmers with secondary education (49%). However, perception rates of increased drought frequencies drop again among farmers with post-secondary education. All other changes, including those related to increasing rainfall quantity or intensity, were clearly less often perceived.

Among the environmental changes perceived by farmers, an increase in crop diseases is the most important, which was perceived by 64%, particularly by the more experienced and more educated farmers (Fig. 5). Crop diseases and climatic changes seem to affect productivity adversely. Productivity declines were perceived by 54% of all farmers and 63% of those with longer farming experience. In addition, risks related to soil instability were perceived as an increasing problem, with 50% of all farmers perceiving an increase in erosion and 25% an increase

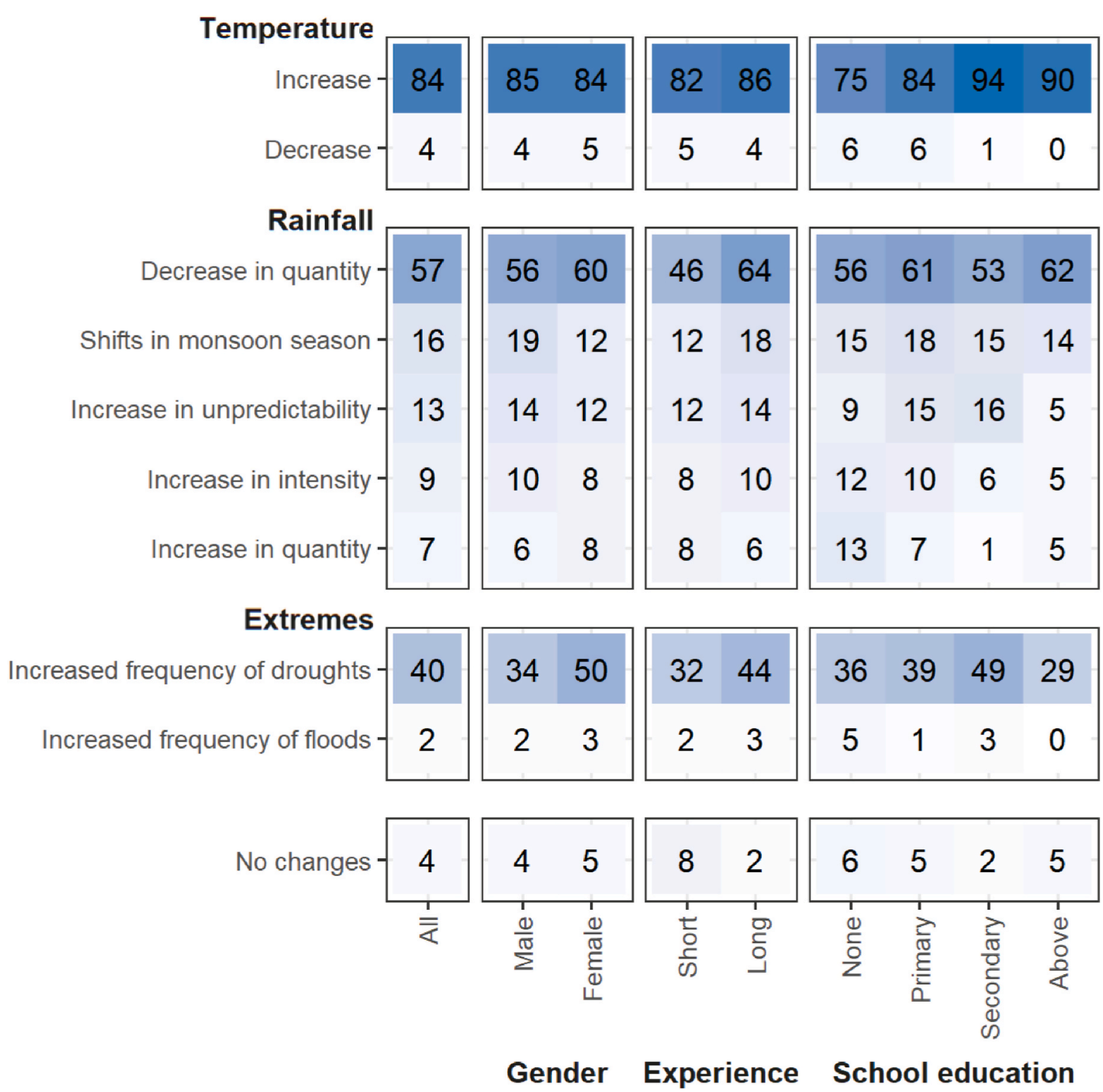

Fig. 4. Climatic changes perceived by farmers. *Note:* Values indicate the percentage of farmers who perceived the changes given on the y-axis. The leftmost column ("All") shows the percentage of all respondents who perceived the changes on the y-axis; the other columns show the percentage of farmers within individual groups, differentiated by gender, farming experience, and school education, who perceived a change. Short and long experience is defined as a farming experience of below and at least 20 years. School education refers to the level of schooling attained by farmers.

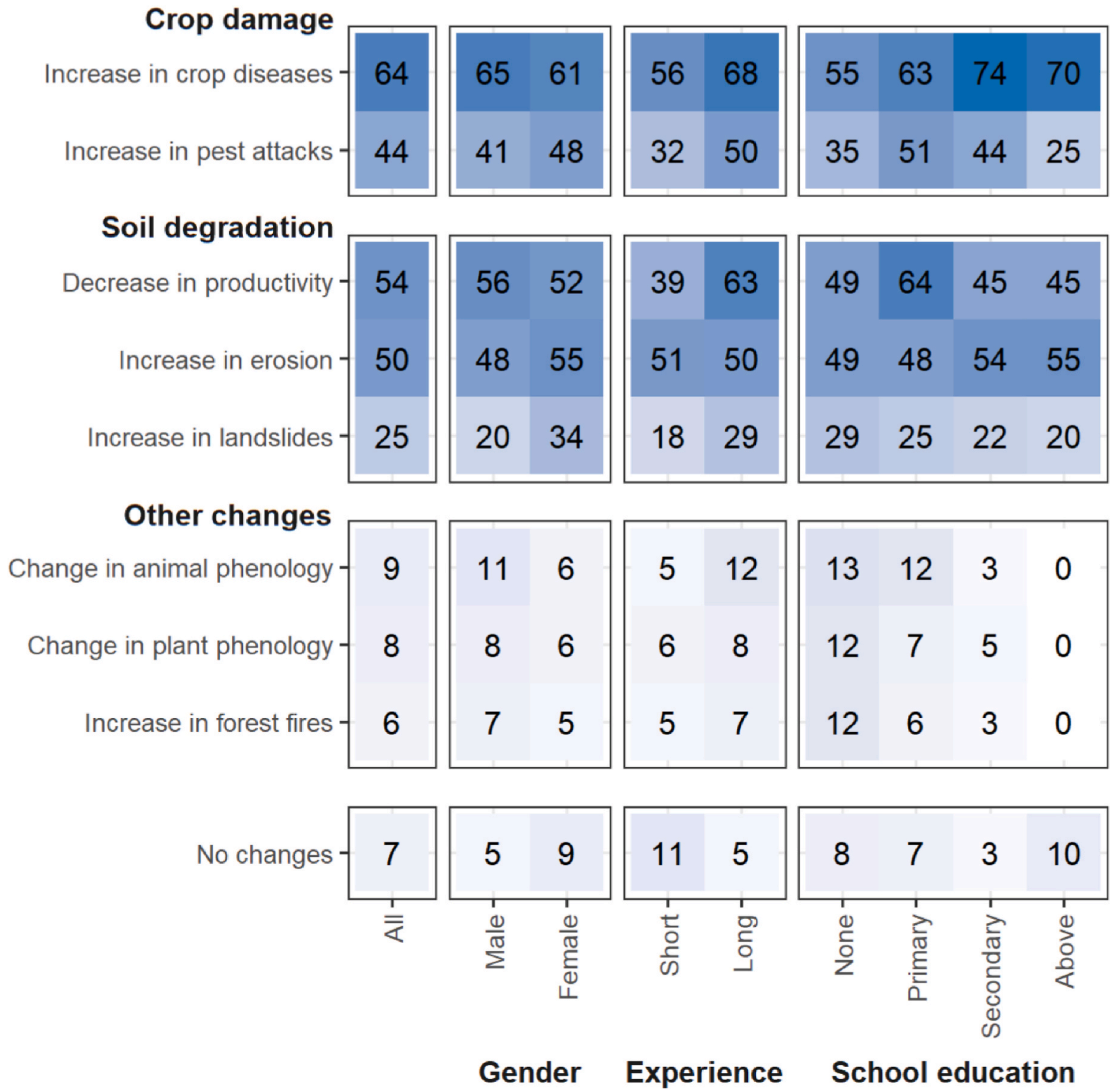

Fig. 5. Environmental changes perceived by farmers. *Note:* Values indicate the percentage of farmers who perceived the changes given on the y-axis. The leftmost column ("All") shows the percentage of all respondents who perceived the changes on the y-axis; the other columns show the percentage of farmers within individual groups, differentiated by gender, farming experience, and school education, who perceived a change. Short and long experience is defined as a farming experience of below and at least 20 years, respectively. School education refers to the level of schooling attained by farmers.

in landslides. Lastly, 44% of all respondents perceived an increase in pest attacks. Other changes, such as in animal or plant phenology or increases in forest fires, were only rarely reported.

We conclude that farmers were particularly concerned about increasingly dry conditions, which large-scale climate model data do not suggest in the first place. In addition, increasing incidents of crop diseases, pests, and erosion events seem to have already adversely affected productivity.

4.3. *Adoption of conservation practices*

Tribal farmers in Nagaland have embraced various SWCP; however, overall adoption rates remain relatively low (below 50%; see Table 1). Among the considered measures, intercropping with legumes is the most widely applied (46%), followed by mulching (40%), herein meaning covering the soil with biological material, e.g., crop residues. RWH and application of manure show similar adoption rates, with 31% and 29%, respectively. Cover crops have the lowest adoption rate, with only 14% of all interviewed farmers using them.

Model results indicate significant determinants for adoption probabilities (Table 2). We divide the independent variables into five groups: Variables related to the formal or informal exchange of information, economic variables, variables related to the perception of specific changes, as well as socio-demographic and location variables.

4.3.1. *Information exchange*

We analyzed the effect of measure-specific training, civil society organizations, and extension services on adopting conservation practices. Our results clearly show that participation in training was the most important variable, positively influencing the adoption of all five measures at a 1% significance level. This finding is also supported by Fig. 6, showing that the three practices on which most farmers participated in a training, namely mulching, intercropping with legumes, and RWH, corresponded to the most widely used practices. Participation in a civil society organization had a significant positive effect on three out of five measures, namely mulching, intercropping, and RWH. Among the civil

Table 2
Coefficients from the BLM indicating significant influencing factors of adoption decisions for five different conservation practices.

	Variables	CC	MU	IC	MA	RWH
INF	Training	1.475***	2.133***	1.822***	2.201***	1.358***
		(4.370***)	(8.438***)	(6.182***)	(9.033***)	(3.889***)
	Extension contact	3.051***	−2.824***	−1.576***	−3.609***	1.742***
		(21.145***)	(0.059***)	(0.207***)	(0.027***)	(5.707***)
	Civil society organization	−0.804	1.401**	0.970*	0.392	1.424**
		(0.448)	(4.059**)	(2.639*)	(1.481)	(4.153**)
ECN	Off-farm income (1)	1.334*	−0.136	0.158	−0.422	0.038
		(3.797*)	(0.873)	(1.171)	(0.656)	(1.039)
	Off-farm income (2)	2.799***	−0.166	1.196***	−0.455	0.638
		(16.423***)	(0.847)	(3.305***)	(0.634)	(1.892)
	Livestock ownership	0.646	1.402***	1.562***	2.821***	−0.463
		(1.907)	(4.065***)	(4.768***)	(16.786***)	(0.629)
PCP	Rainfall quantity decrease	−0.65	−0.299	−0.072	−0.029	1.235***
		(0.522)	(0.742)	(0.931)	(0.971)	(3.438***)
	Drought frequency increase	0.876**	0.542	0.691**	1.075***	1.415***
		(2.400**)	(1.719)	(1.996**)	(2.930***)	(4.117***)
	Rainfall intensity increase	0.71	0.341	1.062**	0.329	1.012*
		(2.034)	(1.407)	(2.892**)	(1.39)	(2.751*)
	Rainfall quantity increase	−1.912	0.075	−0.977	−3.554***	0.064
		(0.148)	(1.078)	(0.376)	(0.029***)	(1.066)
	Erosion increase	1.196***	0.654**	−0.286	0.281	0.411
		(3.306***)	(1.923**)	(0.751)	(1.325)	(1.509)
SCD	Farming experience	0.218	0.865**	0.112	−0.022	−0.423
		(1.244)	(2.375**)	(1.118)	(0.979)	(0.655)
	School education (3)	−0.948	0.729	1.022	0.37	1.171*
		(0.388)	(2.074)	(2.777)	(1.448)	(3.225*)
LOC	Elevation	0.937**	−0.282	0.613*	0.311	0.938***
		(2.552**)	(0.754)	(1.847*)	(1.365)	(2.554***)
	Market distance	−1.513***	−0.56	−1.127***	−0.162	−0.354
		(0.220***)	(0.571)	(0.324***)	(0.85)	(0.702)
	Constant	−6.198***	−1.936***	−2.084***	−1.955**	−5.928***
		(0.002***)	(0.144***)	(0.124***)	(0.142**)	(0.003***)
	Observations	372	372	372	372	372
	Log Likelihood	−105.003	−166.869	−179.539	−132.278	−162.422
	Akaike Inf. Crit.	246.006	369.738	395.078	300.555	360.844
	Pseudo R^2	0.294	0.336	0.300	0.407	0.294

Note: ***, **, * are significant at 1%, 5%, and 10%, respectively.
Positive coefficients indicate a positive effect on adaptation, negative coefficients a negative effect. The magnitude of the effect is given by odds ratios, indicated in brackets. Odds ratios were computed by $OR = \exp(coef(model))$. They define the ratio between the probability of adopting a conservation practice when the value of the independent variable is increased by one unit compared to the probability of adoption if it's not. This means for binary variables, e.g., if a farmer participated in a training on cover crops, (s)he is 4.4 times more likely to adopt cover crops than if (s)he did not participate in a training, keeping all other variables constant. The independent variables are further explained in Table 1.
Abbreviations: INF = Variables related to the exchange of information; ECN = Economic variables; PCP = Perception variables; SCD = Socio-demographic variables; LOC = Location variables

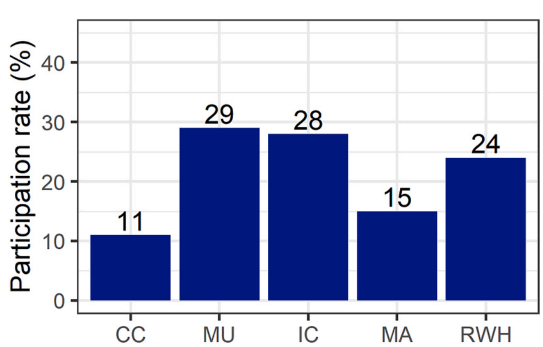

Fig. 6. Percentage of respondents who participated in training on different management practices. Abbreviations: CC = Cover crops; MU = Mulching; IC = Intercropping with legumes; MA = Manure; RWH = Rainwater harvesting.

society organizations, self-help groups were the most important, with over 50% of all farmers indicating their participation (Supplementary Material Fig. A1). Besides these, religious institutions and village councils, with 30% and 28% participation, respectively, played an important role in connecting farmers and supporting information exchange. Our results also indicate a highly significant ($p < 0.01$) influence of regular contact with extension services; however, the direction of the effect depends on the adaptation measure, being positive for cover crops and RWH, and negative for mulching, intercropping, and manure.

4.3.2. Economic variables

Among the economic variables, off-farm income sources and livestock ownership showed a significant effect on adaptation. Adoption probabilities of cover crops and intercropping increased significantly when farm households had access to at least two off-farm income sources. Owning livestock significantly increased the adoption probability of mulching, intercropping, and manuring. Having received financial support didn't have a significant effect on adaptation.

4.3.3. Perceptions

Perceived changes have influenced the adoption of SWCP in diverse ways. Most importantly, perceived increase in droughts has affected adaptation, showing a significant, positive correlation with the adoption of cover crops, intercropping, manure, and RWH, while the latter was also positively influenced by a perceived decrease in rainfall quantity. Interestingly, perceived increase in rainfall intensity increased adoption probabilities of intercropping and RWH, while perceived increase in precipitation quantity did not, highlighting again the positive influence of extreme events on adaptation. The perception of an increase in soil erosion significantly and positively influenced the adoption of cover crops and mulching. Perceived temperature rises and increasingly erratic rainfalls did not show a significant effect.

4.3.4. Socio-demographic factors

The socio-demographic variables' effect on adaptation was relatively small. Farmers with at least 20 years of farming experience were more likely to adopt mulching ($p < 0.05$). As farming experience is typically strongly connected to the farmers' age, our results suggest that older farmers were, by tendency, more likely to use mulching. We also tested the effect of different education levels and found that education levels above secondary significantly and positively influenced the adoption of RWH ($p < 0.1$).

4.3.5. Location factors

Our results show that farmers situated at elevations above 1000 m were significantly more likely to adopt cover crops, intercropping, and rainwater harvesting. This suggests that physical factors related to elevation, such as slope gradients, soil properties, and weather conditions, significantly affect adaptation, most likely because they make the application of SWCP more necessary. On the other hand, a market distance of 10 km or more negatively influenced the adoption of cover crops and intercropping, underlining the importance of market accessibility in the adaptation process.

4.4. Predicted adaptive capacities under different scenarios

Our results reveal large unused potentials for the adoption of SWCP (Fig. 7). Model-based predictions under five different scenarios show that adoption rates of all measures could be at least doubled when exposure to effective influencing factors was improved.

Adoption of cover crops could increase to above 60% when all farming households had access to at least two off-farm income sources. Participation in a training could improve adoption rates of mulching to more than 80%. Likewise, intercropping with legumes could be applied by over 80% of farmers when they received the appropriate training or were involved in livestock rearing. Participation in a training and livestock ownership could also triple the application of manure. Adoption rates of RWH could reach about 60% if all farmers participated in a training or were engaged in a civil society organization. If all farmers had above-secondary education levels, RWH adoption rates could be doubled. Fig. 7 demonstrates that participation in a training increases the adoption probability of all practices by a factor of 2 (e.g., intercropping, mulching, RWH) to 5 (e.g., cover crops).

Our results show that even changing a single factor can have a significant impact on adaptation probabilities.

4.5. Goals and values of tribal farmers

While the BLM provides a picture of the factors influencing adaptation decisions, it doesn't answer the question of which personal values and, thus goals, norms, and preferences drive these decisions. To answer this question, we asked farmers why they decided to implement adaptation practices. Specifically, we asked farmers how much they agreed that the six goals suggested in Fig. 8 were the motivation for

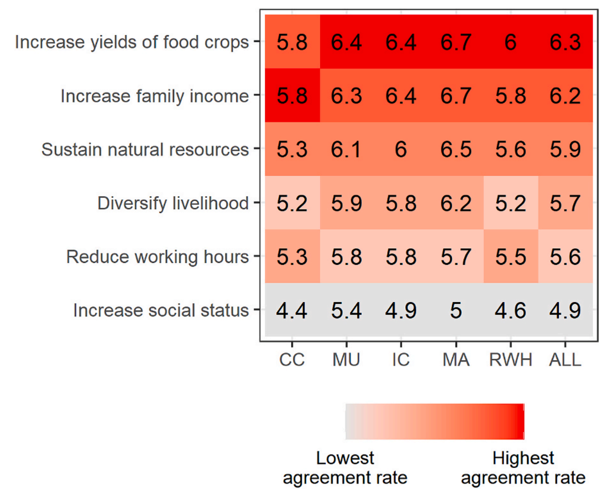

Fig. 8. Agreement of farmers to goals in adaptation. *Note:* Figure shows agreement rates of farmers that the suggested goals on the y-axis were the reason for adaptation. Values inside the boxes indicate the average rate of agreement among respondents on a scale from 1 (strongly disagree) to 7 (strongly agree). Respondents were grouped into farmers who applied cover crops (column 1), mulching (column 2), intercropping with legumes (column 3), manure (column 4), rainwater harvesting (column 5). Farmer groups are shown on the x-axis. The last column ("ALL") includes all respondents. For each farmer group on the x-axis, goals have been ranked according to the received agreement rates; red indicates the highest agreement rate, grey the lowest.

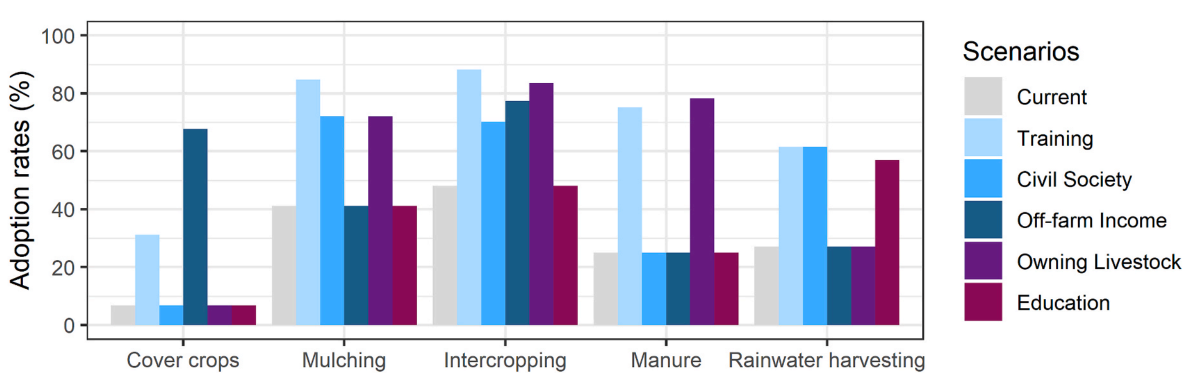

Fig. 7. Estimated adaptation potential from BLM for different scenarios. *Note:* Adoption rates were computed from probabilities and odds ratios (see Table 2). Estimated adoption rates are given for current conditions and five scenarios: The training scenario assumes that all farmers participated in a measure-specific training; civil society scenario assumes that all farmers participate at least in one civil society organization; off-farm income scenario assumes that all farming households have at least two income sources in addition to farming; owning livestock scenario assumes that all farming households are also engaged in livestock rearing; education scenario assumes that all farmers have above secondary education levels. For each scenario, only the given variable was changed, while all other model variables were kept constant.

implementation.

Increasing yields of food crops and family income were the most important motivations for tribal farmers in making adaptation decisions (Fig. 8). Thereof, increasing food crop yields was slightly more important than income, although both are strongly interlinked. The subsequent motivating factors varied slightly across practices but generally included efforts to sustain natural resources, diversify livelihoods, and cut down on work hours. Increasing social status was clearly of the least importance for tribal farmers.

In addition, we asked farmers to indicate their level of agreement with different norms and preferences regarding cultivation and adaptation (Fig. 9). As shifting cultivation, locally called *jhum*, is the dominant cultivation practice of the region, we also asked farmers about their motivations to continue this type of practice.

Our results reveal that most farmers prefer management practices that conserve natural resources. Also, farmers prefer practices that are less work-intensive, possibly because the available workforce for farming in tribal communities is limited to family members, mostly to the older generation, while the younger population tends to leave farming for education or off-farm employment. Our results further underline the relevance of cultural and social values in farming decisions. Respondents strongly favored a continuation of shifting cultivation because of its cultural value and farming practices that are employed by the majority of the village community. In contrast, migration was not one of the preferred adaptation options, as evidenced by the relatively low agreement scores it received.

5. Discussion

5.1. Modeled and perceived climatic trends

Our results have shown that climate change in the study region, on a larger spatial scale, will most probably increase precipitation intensities and the total precipitation amount per year, while periods without any rainfall during the growing season are expected to decrease slightly. With this, we show for the first time that the dominant risk of precipitation changes in the region stems from increasing intensities which may result in rising crop damages and soil erosion, rather than from decreasing rainfall quantity, even though there may be varying trends on smaller spatial scales.

With regard to historical trends, climate data have shown similarities but also discrepancies with farmers' observations. While there is a large agreement with regard to rising temperatures, certain inconsistencies exist for rainfall trends. There may be several reasons for this: First of all, the topography of the region is complex; hence, the spatial and temporal distribution of climate variables, particularly rainfall, is complex as well. There may be strong variations in rainfall even at small spatial scales (Shrestha et al., 2017) that are not represented by climate models operating at larger spatial scales and relying on scarce observational data typically from mountain valleys. Resulting uncertainties in climate simulations and observations demand the integration of social science methods in climate research (Dhakal et al., 2020). However, people's perceptions of climatic factors are likewise influenced by inherent biases and heuristics (Dhakal et al., 2020). For example, perceptions largely rely on recent experiences; hence, dry spells in the year of the survey or preceding years, even if only related to the inter-annual variability of precipitation, might have disproportionately influenced farmers' perceptions of climatic trends (Hasan and Kumar, 2020a). This assumption is supported by a previous survey conducted in 2017 which found over 70% of farmers from Northeast India had perceived an increase and only 25% a decrease in rainfall quantity (Bhalerao et al., 2022). A meaningful comparison between farmers' perceptions and climate data can hence only be made for short-term trends (Hasan and Kumar, 2020a). In addition, perceptions might be influenced by other biotic and abiotic factors, such as perceived temperatures by humidity (Dhakal et al., 2020), and by social discourses on climate change (Grothmann and Patt, 2005), e.g., when climate change in the social discourse is predominantly associated with water scarcity, this might steer farmers' climate change perceptions accordingly.

Surprisingly, although only 9% of farmers perceived increasing rainfall intensities, increases in erosion and landslides were perceived by 50% and 25% of the respondents, respectively. This suggests that recent

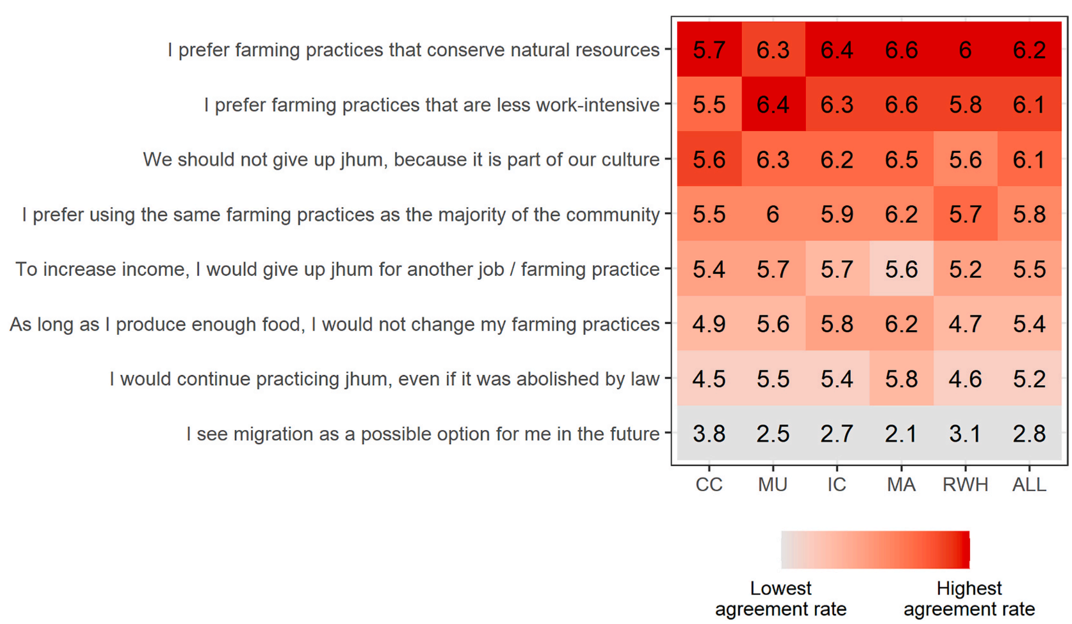

Fig. 9. Agreement of farmers to norms and preferences in cultivation and adaptation. *Note:* Figure shows agreement rates of farmers to the suggested norms and preferences on the y-axis. Values inside the boxes indicate the average level of agreement among respondents on a scale from 1 (strongly disagree) to 7 (strongly agree). Respondents were grouped into farmers who applied cover crops (column 1), mulching (column 2), intercropping with legumes (column 3), manure (column 4), rainwater harvesting (column 5). Farmer groups are shown on the x-axis. The last column ("ALL") includes all respondents. For each farmer group on the x-axis, norms and preferences have been ranked according to the received agreement rates; red indicates the highest agreement rate, grey the lowest. *Jhum* is the local term for shifting cultivation.

soil loss could be rather linked to intensified land use than to climate change. Except for Bhalerao et al. (2022), we are not aware of any previous study in India that has considered the perceived risk of increasing land degradation outlined by our study.

Farmers' perceptions of increasing temperatures, crop diseases, pest attacks, and decreasing productivity were also reported by other studies from northern India and can thus be considered the biggest challenge of recent changes (Bhalerao et al., 2022; Datta and Behera, 2022b; Sharma et al., 2020; Shukla et al., 2016).

5.2. Adoption of conservation practices

Our results revealed large unused adaptation potentials among tribal farmers in Northeast India, showing for the first time that adoption rates of SWCP could be at least doubled when the most influential factor per practice was fulfilled. Thereby, the current adoption rates of 14–46% could theoretically be increased to 62–88%.

Observed adoption rates were relatively low compared to previous studies on the Himalaya region, which found that a majority of farmers had adapted to climate change (Datta and Behera, 2022a; Lone et al., 2022; Rymbai and Sheikh, 2018). This difference in observed adaptation rates might be because of the specific regional and social context of the farming communities studied here or because previous studies focused on other adaptation practices, such as changes in crop types, cropping calendars, and irrigation, while we assessed specifically those practices that conserve soil and water resources.

To increase adoption rates of SWCP, our findings emphasized the outstanding importance of agricultural training. Though some previous studies have already indicated a positive effect of training on adaptation (Asfaw et al., 2019; Thoai et al., 2018), none has found a similarly dominant role of training in the adaptation process as our study. This could be either explained by the specific regional context of this study or by the methodological reason that this study asked for training received on the specific management practice, while previous studies analyzed access to or attendance in an agricultural or climate change training in general. Considering the low participation rates in training (Fig. 6), we suggest that increasing participation in measure-specific training might considerably accelerate climate change adaptation. This assumption is supported by Bhalerao et al. (2022) who found that a lack of training poses a major barrier to climate change adaptation in Northeast India.

Besides training, we found participation in a civil society organization to have a significant positive influence on adaptation, which is in line with previous findings (Panta et al., 2020; Vo et al., 2021). Presumably, local organizations provide a space for farmer-to-farmer interactions where experiences, knowledge, and information are shared, thus encouraging adaptation decisions, as also suggested by Zamasiya et al. (2017). The relevance of information exchange among farmers for adaptation was also pointed out by Abid et al. (2016). Moreover, it can be assumed that farmers who participate in local organizations have a better social network than others and consequently improved access to diverse forms of support (institutional, labor, financial, etc.).

Surprisingly, we did not observe a clearly positive effect of regular contact with extension services on the adoption of SWCP, even though most farmers indicated relatively frequent contacts (Supplementary Material Fig. A2) and mentioned extension workers as their main source of information on adaptation measures (Supplementary Material Fig. A3). While many previous studies found a positive effect of extension services on climate change adaptation (Abid et al., 2015; Adeagbo et al., 2021; Bryan et al., 2009; Khanal et al., 2018; Sertse et al., 2021; Zamasiya et al., 2017), our results confirmed this effect only for two out of five practices, namely cover crops and RWH. By contrast, the adoption of the three other practices was negatively associated with regular contact with extension services. A possible explanation could be that the focus of discussions with extension officers is limited to specific practices, while other practices are less promoted. Since the ambiguous influence of extension contacts on climate change perception and adaptation was also found in other studies (Hasan and Kumar, 2020b), further research is needed to identify the role of extension officers in farmers' adoption or non-adoption of conservation practices.

Concerning economic determinants, our results confirmed previous findings from India (Jha and Gupta, 2021) and other places of the world (Adeagbo et al., 2021; Bryan et al., 2013; Koç and Uzmay, 2022) showing that off-farm income has a significant positive effect on adaptation. Previous studies indicated that among these income sources, remittances from migrated family members are of particular importance for the adoption of new agricultural technologies (Datta and Behera, 2022a; Jha and Gupta, 2021), which make up 17% of all off-farm income sources in our study area (Supplementary Material Fig. A4). The positive effect of livestock on adaptation is likewise in line with previous studies and was associated with flexibility regarding financial resources facilitating climate change adaptation (Jha and Gupta, 2021).

The predominantly positive effect of perceived climatic changes on adaptation is in line with previous studies (Hasan and Kumar, 2019; Jin et al., 2016; Khan et al., 2020) as well as established adaptation theories, postulating that adaptation decisions are influenced and preceded by a risk or threat appraisal stage (Grothmann and Patt, 2005; Rogers et al., 1983).

We also found relationships between socio-demographic factors and adaptation; however, these were clearly less important than the above factors related to information exchange, economic characteristics, and perceptions. The positive effect of education on adaptation, observed in numerous previous studies from diverse countries, including Nepal (Adhikari et al., 2022; Khanal et al., 2018), Pakistan (Abid et al., 2015; Ali and Rose, 2021; Amir et al., 2020), China (Jin et al., 2016), and India (Jha and Gupta, 2021; Lone et al., 2022), was herein only found for the adoption of RWH, while the relationship for all other practices was insignificant. In a follow-up discussion with farmers, we found that the educated, mostly younger community members often migrate to urban areas to pursue studies or non-farm jobs, so they are no longer involved in farming.

For farming experience, previous studies observed a positive relationship with adaptation (Abid et al., 2015; Huong et al., 2017; Jin et al., 2016; Lone et al., 2022), suggesting that the more experienced farmer has a broader observation-based knowledge of farming practices and climate change, thus increasing adaptation likelihood (Dang et al., 2019). However, our study found this relation only for mulching.

The negative effect of longer market distances on adaptation found in this study is in line with Huong et al. (2017), suggesting that spatial proximity to local markets facilitates the purchase of needed inputs, the sale of produce, and the search for off-farm employment, providing opportunities for additional household income generation and thus supporting adaptation (Huong et al., 2017).

5.3. Goals, norms, and preferences of tribal farmers

Only a few studies have analyzed farmers' personal values in adaptation; hence this research tackles an important research gap to understand the driving motivations behind adaptation of tribal farming communities. Our findings revealed that sustaining livelihoods was the most important goal in adaptation among tribal farmers. This is not surprising, as Zobeidi et al. (2022) found that adaptation is, in the first place, an economic undertaking. According to the authors, normative considerations associated with climate change adaptation are only of secondary importance. Nevertheless, it's worth noting that tribal farmers preferred increasing yields of food crops over income as a strategy for sustaining livelihoods. This indicates a skeptical attitude of tribal farmers about the reliability of markets to secure local food supplies and underscores the importance of uphill cultivation for local food security. In contrast to previous studies, our findings additionally emphasized sustaining natural resources as the second most important value, after sustaining livelihoods, within the adaptation process. We interpret this as a specific characteristic of tribal farming communities in the Himalayas, which have a particularly strong appreciation of the natural environment (Pandey et al., 2020). Our results also showed that the preservation of cultural aspects of cultivation was important for tribal farmers. This extends findings from Warner (2016), who identified the preservation of personal identity as an important goal of smallholder farmers by the aspect of a common cultural identity. Low agreement levels for migration as a potential adaptation option were also found by Dang et al. (2014) for Vietnam. Nevertheless, one has to consider that those farmers who emigrated already were not captured in the survey; thus, a certain bias cannot be ruled out.

5.4. Relation to adaptation theories

Our research shows that farmers' probability of adopting SWCP was significantly increased when they had perceived increases in soil erosion and changes in rainfall. In accordance with the 'risk experience appraisal' in MPPACC (Grothmann and Patt, 2005) we confirm that the past experience of a risk positively influences the risk appraisal and thus the adaptation intention. Further, our research adds to the 'climate change risk appraisal' of Grothmann and Patt (2005) that the perception of climatic and environmental changes is influenced by socio-demographic variables, such as gender, education, and farming experience. While the importance of personal characteristics in the 'adaptation appraisal' appears evident, we show that these already play a role in the initial stage of risk perception. As outlined in section 5.1, our research further suggests that cognitive biases, heuristics, and social discourses may affect the perception of climatic changes, as also considered in Grothmann and Patt (2005).

Besides the perception of climatic and environmental changes, the adoption of SWCP is significantly increased by diverse forms of resources, such as off-farm income, livestock, and, even more importantly, information provided by civil society organizations and agricultural training. This confirms the importance of an 'objective adaptive capacity' as conceptualized by Grothmann and Patt (2005) in the adaptation process.

Finally, our study reveals shared values among tribal farmers regarding cultivation, with natural resource conservation being most important after the improvement of livelihoods. Based on Stern (2000), it can be expected that a serious threat to soil resources, e.g., through increasing erosion, when perceived by farmers, will activate pro-environmental behavior. As shown above, a significant link between the application of SWCP and perceived increases in rainfall intensities and erosion was observed, supporting the VBN theory (Stern, 2000).

We conclude that our findings on perceptions, influencing factors, and values in the adaptation process of tribal farmers are largely consistent with established theories of adaptation behavior.

5.5. Study limitations

While this study offers valuable insights, it also has certain limitations that should be acknowledged. Due to limitations of the available climate data, this study only looked at large-scale general climatic trends without considering small-scale spatial variations. Likewise, we focused on long-term trends; therefore, climate variables were aggregated annually. As a consequence, seasonal changes, including potential shifts in the monsoon precipitation, were not analyzed.

Another limitation is the sampling bias resulting from the selection of only tribal families actively engaged in farming, which may affect the generalizability of the findings and the study's representation. In addition, the lack of randomization in village selection and reliance on extension officers raise concerns about potential biases.

The statistical model applied in this study can only reveal relationships between a limited number of independent and dependent variables, but it cannot prove causality. Due to the limited number of variables considered, we might miss out on other relevant factors. For instance, we could not consider the specific influence of soil properties, slope aspect, and inclination on adaptation probabilities due to limited data availability and partially unknown field locations. Likewise, we could not parameterize neighborhood effects in the model. The role of neighboring farmers and villages in information flows is instead indicated in the Supplementary Material (see Fig. A3). As this study applied a binary logit model, potential interdependencies between the analyzed conservation practices were not considered. The application of a simultaneous equation model and seemingly unrelated regressions in further studies is suggested to assess whether these provide additional valuable insights. We also point out that the adoption of SWCP is not necessarily a reaction to climate change. In fact, farmers adapt their management in a complex ecological-social-economic environment (Dang et al., 2019); hence climate change is one but not the only driver for changes in the agricultural system.

Lastly, the execution of this survey was impeded by the Covid-19 pandemic and had to be postponed and interrupted several times. Due to entry restrictions, supervision of local staff during data collection was possible only to a limited extent. Hence, in spite of intensive data quality checks by the authors, which led to the exclusion of almost 50% of the collected data from the final dataset (as explained in section 3.2.1), some uncertainties related to the collection procedure cannot be ruled out completely.

Despite these limitations, the study provides valuable information and insights into climate change perceptions and adaptation decisions of tribal farming families.

6. Conclusion

Tribal farmers in Northeast India have experienced various climatic and environmental changes. Among the environmental changes, more than half of the farmers perceived increasing crop diseases and productivity declines, while among the climatic changes, increased temperatures, decreased precipitation quantity, and increased frequency of droughts were the most reported.

For the future, our analysis showed that, along with rising temperatures, total annual precipitation and precipitation intensities are likely to increase in the region, amplifying the need for SWCP. However, our study showed that current adoption rates of SWCP ranged only between 14% and 46%, which were relatively low compared to other contexts. By applying a BLM, we showed that the adoption probabilities of all analyzed conservation measures were significantly increased by participation in measure-specific training. In addition, participation in a civil society organization, livestock ownership, high-altitude residence, and perceived increases in droughts had significant, positive effects on at least three out of five SWCP. Surprisingly, regular contact with extension services was significantly negatively correlated with the adoption of a majority of the analyzed practices. Thus, contacts with extension workers outside of a training context appear to be less effective in promoting adaptation. The widely reported positive effect of education on adaptation was observed only for RWH but not for the other practices. Our findings revealed large unused adaptation potentials for all analyzed practices, which could more than double the current adoption rates. Adaptation decisions among tribal farmers were mainly driven by the goal of increasing food crop yields and income; however, sustaining natural resources and cultural identity were also highly valued by farmers.

This study contains important insights for regional authorities and identifies strategies for a more sustainable adaptation of uphill tribal farming systems to climate change. Particularly, effective strategies include improving farmers' awareness of future changes in precipitation patterns and increasing training programs on SWCP to exploit unused adaptation potentials of all analyzed practices. Lastly, our results suggest that future research is needed to identify current deficits and future potentials of extension services in the propagation of SWCP. This research contributes to a better understanding of the adoption processes towards more sustainable farming practices among tribal Himalayan farmers, thereby identifying unused potential for climate change adaptation for marginalized and climate-vulnerable farming communities in mountain regions.

Credit author statement

Lea S. Schröder: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing - Reviewing and Editing, Amol K. Bhalerao: Data curation, Writing - Reviewing and Editing, Khondokar H. Kabir: Conceptualization, Writing - Reviewing and Editing, Jürgen Scheffran: Conceptualization, Supervision, Writing - Reviewing and Editing, Uwe A. Schneider: Conceptualization, Funding acquisition, Project administration, Supervision, Writing - Reviewing and Editing

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.119473.

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