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Climate, Agriculture, and Migration: Exploring the Vulnerability and Outmigration Nexus in the Indian Himalayan Region

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Climate change is increasingly affecting mountain communities around the world with major implications for human livelihoods and wellbeing. With its predominantly rural population and limited resources, the Indian Himalayan Region is particularly vulnerable. While previous research has highlighted the destructive potential of climate change, we focused on the socioeconomic and ecological drivers of climate vulnerabilities and their links to migration and depopulation trends, which can be observed in the area. A mixed-methods case study approach was used to explore these relationships in the state of Uttarakhand in the western Indian Himalayan Region. Combining evidence from an aggregate vulnerability index, migration data, and insights from qualitative interviews, we found a close link between local climate vulnerabilities and migration. Considering different drivers, we show that limited adaptive capacities are the decisive factor shaping vulnerabilities and migration in the region, in particular, the high dependency on rainfed agriculture together with ecological, infrastructural, human, and financial constraints. With higher vulnerability, migrants tend to become younger, engage more in short-term migration, and increasingly employ migration in response to structural vulnerabilities and livelihood risks. The outmigration of young males has major implications for their origin communities, as the population left behind becomes older and more feminized.

Keywords: *climate-related migration; vulnerability; agricultural adaptation; Indian Himalayan Region; mountain communities; rural livelihoods.*

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Introduction

In the last century, climate change has caused significant warming in the Indian Himalayan Region (IHR) (Subramanian 2016; NITI Aayog 2018; Sabin et al 2020), triggering a multitude of biophysical and socioeconomic impacts, such as glacial melting, biodiversity loss, and irregular precipitation (Pepin et al 2015; Wester et al 2019). A national projection made by the Indian Network for Climate Change Assessment estimates a rise in temperature of 1.7–2.0°C by 2030 (baseline 2010) and a decline in per capita availability of water, affecting crop yields (Subramanian 2016: 18). At the same time, the region is also confronted with an increasing frequency and intensity of extreme weather events, such as heavy rainfall, which can result in severe flooding and landslides (Kumar et al 2010; Das 2013; World Bank and ADB 2013; Kumar and Jaswal 2016; Sati 2020).

With a predominantly rural population and limited adaptive capacities, the IHR is highly vulnerable to these changes. Poverty and inequality, lack of infrastructure, and a strong dependence on rainfed agriculture aggravate conditions for the communities (Bhagat 2018; NMSHE 2018). Socioeconomic factors together with degrading environmental conditions have resulted in increased pressure to find alternative livelihoods, amplifying migration from rural areas (Arlikatti et al 2018; Naudiyal et al 2019; Siddiqui et al 2019; Upadhyay et al 2021). The resulting outmigration has changed the size and demographic composition of the mountain communities: Young men leave in search of employment, while the elderly and women remain (Goodrich et al 2017; Joshi 2018; Lama et al 2021; Tiwari and Joshi 2016).

In this study, we focused on the state of Uttarakhand, located in the western IHR. The state is heavily exposed to a range of environmental hazards and is characterized by a high level of rural-to-urban migration (Banerjee et al 2011; Macchi et al 2015; Tiwari and Joshi 2015; Mamgain and Reddy 2017; Pathak et al 2017; RDMC 2018). Since 2011, continued outmigration has led to the abandonment of 734 villages, showing the significance of the depopulation trend in the rural areas of the state (RDMC 2018; Upadhyay et al 2021).

We employed a combination of quantitative and qualitative research methods to explore how climate vulnerabilities shape migration patterns and to understand how communities in the region are affected. The quantitative evidence is complemented with findings from qualitative interviews carried out in the region, providing an in-depth perspective on some of the underlying mechanisms and processes linking hazards, vulnerability, and migration (Upadhyay et al 2015). While this study was explorative and descriptive in nature, it adds to our understanding of the specific challenges faced by mountain communities in the IHR and the ways in which they respond and adapt to them.

Conceptual framework

The concept of climate vulnerability is multifaceted and has evolved over time (Adger 2006). The Intergovernmental Panel on Climate Change (IPCC) (IPCC 2014a, b) defines it as the propensity or predisposition of a system to be adversely affected by climatic changes. In this study, vulnerability encircles the contextual socioeconomic, social, and environmental factors characterizing a community (Adger 2006; Foresight 2011; IPCC 2014a; NMSHE 2018). The concept is operationalized using a set of indicators that are compiled into 2 subcomponents: sensitivity and adaptive capacity. While sensitivity indicates the susceptibility of a system owing to its ecological and socioeconomic characteristics, adaptive capacity refers to a community's ability to minimize risk (Cutter et al 2014; Shukla et al 2016).

Climate vulnerabilities are closely linked to migration decisions (Adger 2006; McLeman and Hunter 2010; Kaczan and Orgill-Meyer 2020). For some households, migration can be a possible strategy to adapt to the changing environmental conditions and to reduce, diversify, or mitigate livelihood risks (Black, Adger, et al 2011). For others, migration represents an action of last resort to ensure survival if an adaptation to the local conditions is no longer viable (Penning-Rowsell et al 2013; Upadhyay and Mohan 2014; Upadhyay et al 2015; McLeman 2018). Researchers have argued that in reality a mix of both is likely, with migration being an effective adaptation, contributing toward financial access and increased livelihood opportunities, while at the same time representing a failure of the socioecological system to cope with change (Upadhyay and Mohan 2014; Singh and Basu 2020).

Rural populations that occupy marginal lands—such as islands or high mountains—and depend on small-scale agriculture encounter the greatest risk of finding themselves forced to migrate (Afifi and Jäger 2010; Foresight 2011; Banerjee et al 2014; Maharjan et al 2018; Gopirajan et al 2021; Jha et al 2021). For example, variation in rainfall can directly affect economic resources of rural populations depending on rainfed agriculture, threatening a community's food security and livelihoods. Falco et al (2019) observed how, at a country level, dependence on agriculture leads to increased impact of weather anomalies on migration.

Migration is here defined as the movement of place of residence of an individual across administrative borders (Foresight 2011; IPCC 2014a; Adger et al 2019). The census of India in particular states: "When a person is enumerated in census at a different place than his/her place of birth, she/he is considered a migrant" (ORGI 2022: 1). Along the temporal axis, migration is categorized as seasonal, permanent, and semipermanent. The dataset used in this study subdivides migration between permanent (over 12 months) and semipermanent (6 to 12 months), while not differentiating between semipermanent and seasonal migration.

Migration is a highly context-specific process, requiring contextual knowledge to draw any conclusions on the reasons and needs of the people involved and challenging attempts to generalize between different cases (Grecequet et al 2017; Hoffmann et al 2020). In an environment facing multiple climatic risks, such as the IHR, high levels of climate vulnerability do not necessarily lead to more migration. For example, rapid-onset hazards, such as floods, might consume household resources, making the most vulnerable households unable to migrate. In this context, a community can find itself in a vicious cycle of increased vulnerabilities and reduced ability to move, effectively being trapped in place (Black and Collyer 2014; Nawrotzki and DeWaard 2018).

Background: livelihoods in the Indian Himalayan Region

This study focused on the state of Uttarakhand, which is one of the 13 states in the western IHR. Administratively, the state is divided into 13 districts and 95 community development blocks, which formed the basis of our analysis (ORGI 2011). Of the 13 districts, 10 lie on the slopes of the Himalaya and are generally referred to by authorities and laypeople as hill or mountain districts, while 3 (Dehradun, Udham Singh Nagar, and Haridwar) are mostly located in the Indo-Gangetic plains and are consequently referred to as plain districts. However, this is not a clear-cut distinction, as development blocks within mountain districts may be located in the plains and vice versa. The hill districts are mainly rural and have subsistence-focused agricultural economies, while plains are mostly urban, with industrial development, higher human development scores, higher per capita income, and better access to markets, infrastructures, and education (IHD 2018; Joshi 2018; RDMC 2018).

The 2011 census recorded a population of 10.09 million, with almost 70% living in rural areas (Joshi 2018). The census also showed a decline in population growth, where 2 districts, Almora and Pauri Garhwal, had an absolute decline of 17,868 persons from 2001 (ORGI 2011). Several studies attribute depopulation to outmigration (Mamgain and Reddy 2017; Pathak et al 2017; IHD 2018; RDMC 2018). Increased outmigration has led to the abandonment of lands, houses, and even entire villages in the mountain areas, affecting the sustainability of rural livelihoods (Joshi 2018; RDMC 2018).

The agricultural sector has been steadily declining over the past 2 decades (IHD 2018). Only 14% of the state's land is suitable for agriculture, and the majority of land holders own less than 1 ha of land (RDMC 2018). Access to irrigation infrastructures remains limited, and less than half (47%) of net sown area is under irrigation, with a disproportionate spread of 10% in the hills and 87% in the plains (UEPPCB 2018: 135). About 70% of the rural population depends on rainfed agriculture for its subsistence (Guha et al 2017; Naudiyal et al 2019), and changes in rainfall patterns have a direct impact on livelihoods and food security (Pandey and Jha 2012; Pandey et al 2016).

Observed rainfall between 1989–2018 shows an annual rainfall variability of 19% (Guhathakurta et al 2020). Projected average rainfall for the near future (2020–2050) and the far future (2070–2100) under RCP2.6 and RCP4.5 shows stagnated rainfall trends, with a significantly decreasing trend (–0.007 mm/d) under RCP8.5 (Banerjee et al 2020). Observed winter warming is particularly pronounced, over 1.41°C between 1880–2012 (Das et al 2018; Das and Meher 2019). Projections indicate that the average annual maximum temperature could further increase by 1.6°C (2021–2050), 2.4°C (2051–2080), and 2.7°C (2081–2099) under RCP4.5(Upadhyay et al 2021).

Migration in Uttarakhand is linked to constraints in mountain agriculture. A survey study showed that 47% of the respondents identified declining agriculture productivity as a major reason for migration (Hoermann et al 2010). Increasing climate impacts are further reducing crop yields and land productivity, thereby increasing outmigration pressures (Hoermann et al 2010; Jain 2010; GU 2014; Tiwari and Joshi 2015; Isaac and Isaac 2017). The Uttarakhand Action Plan on Climate Change also noted that "the region does not have alternative gainful employment opportunities and climate change-driven uncertainty in mountain agriculture has forced people to migrate from the hills in search of employment" (GU 2014: 105).

Migration in the state tends to take place in a stepwise manner, first from rural to rural, then rural to urban, and finally urban to urban (RDMC 2018). These migratory movements reflect the economic development of the state, and to a larger scale that of the IHR (Hoermann et al 2010). Industrialization and urbanization in the plains have failed to provide economic development to rural communities in Uttarakhand through the flow of remittances as seen in other states (Mamgain and Reddy 2017). Instead, the increased migration mirrors the state's lack of development policies in the rural areas (Mamgain and Reddy 2017).

Data and methods

To study the role of climate vulnerability in migration patterns, a vulnerability index was constructed, reflecting the socioeconomic and environmental conditions in the area. The index was based on prior work by Shukla et al (2016), who developed an index specifically for Uttarakhand. The index consists of a weighted sum of various indicators representing salient aspects of vulnerability in the state, which are then compiled into several levels of subcomponents.

As the main data source, we relied on information from the last held *Census in India* (ORGI 2011). Socioeconomic and demographic indicators were combined with other sources of information on local vegetation, water balance, and topography based on remote-sensing data (Copernicus, Landsat-7, and ASTER GDEM). Figure 1 gives an overview of the index composition, while a detailed description of the data sources and of its construction can be found in Appendices S1 and S2 (*Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00058.1.S1). Data on migration were obtained from the *Interim Report on the Status of Migration in Uttarakhand* (RDMC 2018). The dataset was created through an extensive survey conducted at the development block level between 2017 and 2018 and based on migration data between 2007 and 2017 (RDMC 2018). The RDMC dataset was selected because it is the only available source of data on migration at the development block level. The dataset differentiates between permanent and semipermanent migration, as well as containing data on the age of the migrants and on the main reasons for migration.

The use of demographic indices from 2011 poses a limitation on the relevance of the vulnerability index constructed using these data. However, these data are believed to be valid as research shows that the population dynamics observed in the state have been taking place at least since its institution in the year 2000 (Mamgain 2004; Mamgain and Reddy 2017; Joshi 2018).

To investigate the effects of elevation, the 95 development blocks were assigned to 2 elevation classes based on their average elevation calculated in the geographic information system: Blocks with an elevation <1200 m were considered as "plains," and blocks with an elevation ≥1200 m were considered as "mountains/hills." This enabled us to classify blocks regardless of whether the district in which they were located is commonly considered a hill or a plain district.

The study utilized a mixed-methods approach by complementing ordinary least square (OLS) linear regression models with qualitative insights from semistructured interviews (Appendices S3 and S4, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00058.1.S1). The OLS method uses vulnerability as a predictor and migration as a response variable. We further varied the baseline model to test for the impact of the different vulnerability subcomponents, and to test for varied migration outcomes, considering different types of migration or the mobility of different subgroups in the population (duration, age, and reason for migration).

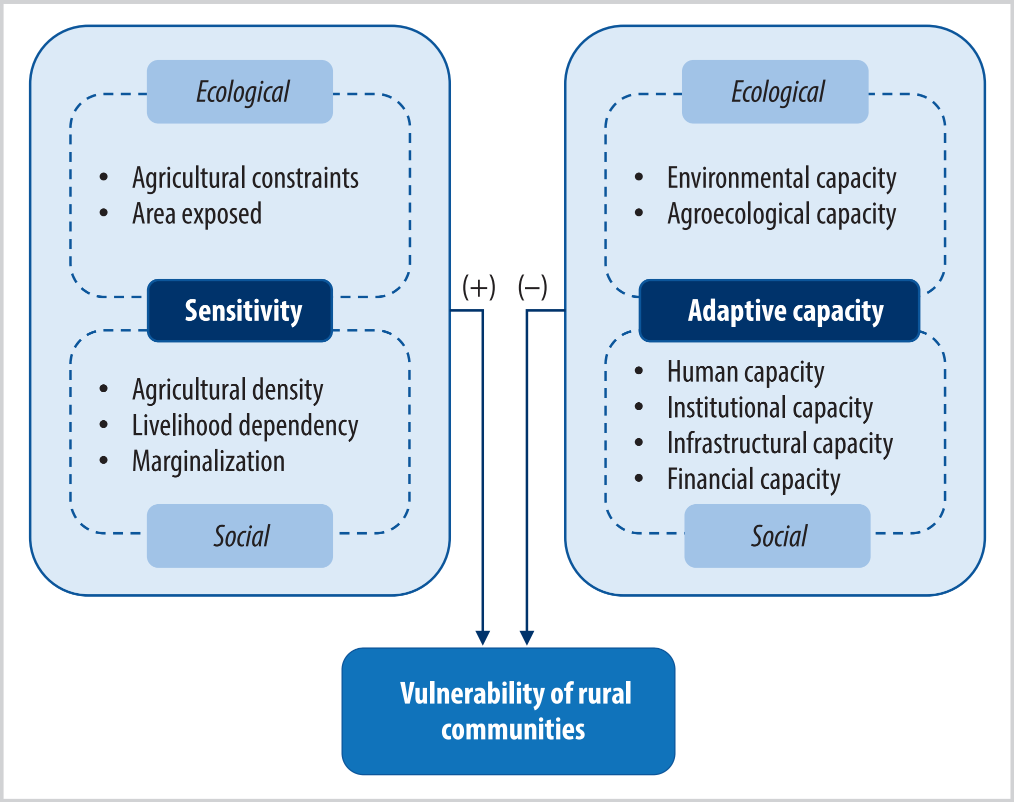
We complemented our findings with qualitative insights from semistructured face-to-face interviews, which were conducted between September–November 2019 in Uttarakhand. In total, 55 interviews were conducted with the local population, and 15 interviews were conducted with key informants, such as policy experts, nongovernmental organization representatives, and scientists (Appendix S4, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00058.1.S1).

Results

Descriptive statistics

Table 1 shows summary statistics for the key quantitative indicators considered in the analysis. The vulnerability of the development blocks ranges from 0.308 to 0.699 on a scale from 0 to 1, with an average of 0.542, highlighting the substantial differences in vulnerability in the state. While

FIGURE 1 Hierarchical composition of the vulnerability index (based on Shukla et al 2016).



some areas are characterized by an increased level of sensitivity, the main driver of increased vulnerabilities is limited adaptive capacity. Of the subcomponents, it is particularly the low average levels of agroecological, financial, human, and institutional capacities that explain the overall reduced adaptive capacity and increased vulnerability in the region (Appendix S2, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00058.1.S1).

Table 1 also shows the distribution of the population and migration outcomes. The decadal outmigration rate varies considerably. On average, the development blocks have experienced an outmigration of 10.8% relative to the total population. Across blocks, migrants are typically older than 25 (72.8%) and consist mostly of long-term permanent migrants (76.8%). The main reasons for migrating are a lack of livelihood opportunities (52.3%) as well as limited access to public facilities and infrastructure (24.7%). A substantial variation in these indicators is observable across development blocks.

Figure 2 shows the distribution of vulnerability across the development blocks in the state. Although there is some variation, vulnerability is generally higher in the mountain/hills (average elevation of block ≥1200 masl) as compared to the plains (average elevation of block <1200 masl) (Figure S2 in Appendix S5, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00058.1.S1). Likewise, we see increased levels of outmigration in the mountain/hills, with some development blocks having lost more than 20% of their population from 2007 to 2017. Both sensitivity and adaptive capacities show a similar spatial distribution (correlation $r = 0.415$, $P < 0.01$), with clusters of high vulnerability mostly located in the districts Pauri Garhwal, Almora, and Rudraprayag, at the lower reaches of the mountain ridge.

Exploring the relationship between vulnerability and outmigration

Table 2 shows the results of our main models, regressing migration on the vulnerability index and its 2 main components, sensitivity and adaptive capacity. The variables were included in the models in an iterative way to illustrate their differential association with migration. The displayed relationship coefficients show the marginal effects of a 1% change in vulnerability on the outmigration rate as the share of migrants in the population. All standard errors were heteroscedasticity corrected.

The regression models show a strong positive relationship between the level of vulnerability in an area and the observed outmigration rate. According to model 1, a 1% increase in vulnerability is associated with a 0.246 percentage point higher outmigration rate (SE 0.023). The effects are statistically significant and meaningful, indicating an important role for climate vulnerabilities in shaping migration patterns in the region (Appendix S6, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00058.1.S1).

The results further indicate that the strong vulnerability effect is mainly driven by differences in adaptive capacities in the communities as compared to differences in sensitivity, although the latter exerts a significant effect as well. A 1% increase in sensitivity is associated with a 0.117 percentage point (SE 0.032) increase in the outmigration rate, and a 1%

TABLE 1 Key indicators considered in the analysis, with summary statistics.

Key indicators	Min	Max	Mean	SD
Main outcomes[a)]				
Vulnerability	0.308	0.699	0.542	0.094
Sensitivity	0.166	0.466	0.339	0.062
Adaptive capacity	0.316	0.785	0.610	0.116
Subcomponents of sensitivity[a]				
Agricultural constraints	0.031	0.856	0.375	0.176
Area exposed	0.146	0.674	0.386	0.128
Agricultural density	0.018	0.758	0.224	0.118
Livelihood dependency	0.025	0.659	0.357	0.140
Marginalized population	0.037	0.898	0.262	0.147
Subcomponents of adaptive capacity[a)]				
Environmental capacity	0.047	0.963	0.298	0.217
Agroecological capacity	0.308	0.967	0.761	0.192
Human capacity	0.034	0.923	0.618	0.169
Infrastructure capacity	0.009	0.791	0.522	0.205
Financial capacity	0.000	1.000	0.738	0.268
Institutional capacity	0.136	0.987	0.705	0.159
Population and migrant characteristics[b)]				
Population of development block	21,199	312,254	72,100	53,352
Number of migrants (2007–2017)	139	17,041	5345	3552
Normalized outmigration rate	0.001	0.393	0.108	0.073
% migrants younger than 25	0.000	52.900	27.200	10.500
% migrants older than 25	47.100	100.000	72.800	10.500
% permanent migrants	37.600	99.700	76.800	12.200
% nonpermanent migrants	0.300	62.400	23.200	12.200
Reasons for migrating (% of migrants)[b)]				
Lack of livelihood opportunities	0.300	100.000	52.300	16.900
Lack of facilities and infrastructures	0.000	51.800	24.700	11.600
Decreasing agricultural yields	0.000	14.000	4.800	3.500

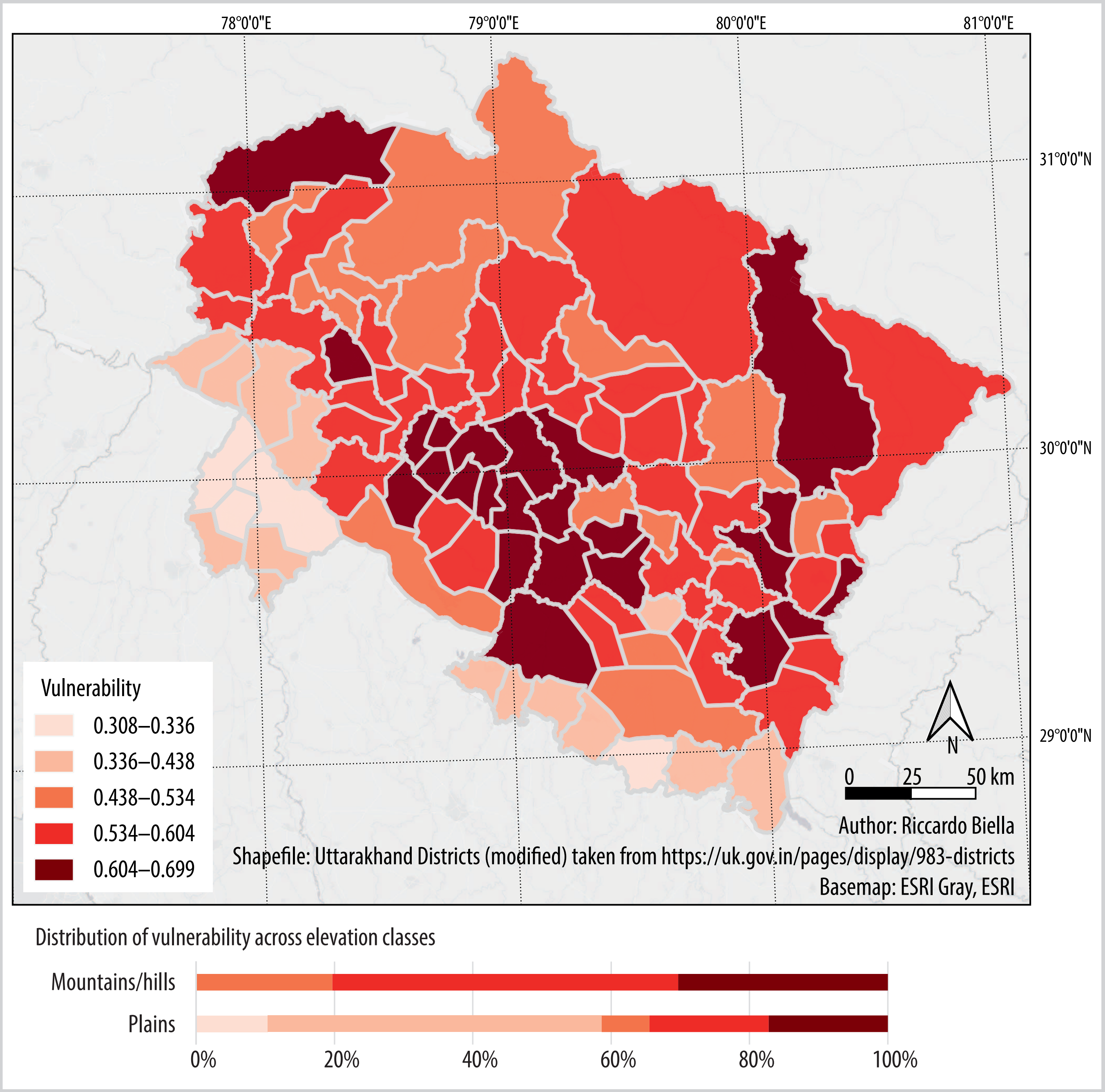
Note: Min, lowest value among all development blocks; Max, highest value among all development blocks; Mean, mean value among all development blocks; SD, standard deviation.
[a)] Values calculated according to the methodology described in Appendix S2 (*Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00058.1.S1).
[b)] Values from the *Interim Report on the Status of Migration in Uttarakhand* (RDMC 2018).

reduction in adaptive capacity is associated with a 0.225 percentage point (SE 0.021) increase in the outmigration rate in a development block. These relative differences also persist once both variables are included in one model 4, suggesting that the lack of capacities to adapt in the rural communities plays an important role for migration.

The evidence collected in the qualitative interviews confirmed the important role of adaptive capacities in shaping vulnerabilities to climate change. The agricultural channel is of particular relevance for the region. The high dependency on rainfed agriculture increases the vulnerability of the agrarian population and intensifies the migration pressures. As an expert noted:

> *Uttarakhand has only 14% of the total area available for cultivation. Only 14%. And [. . .] more than 70% of the population depends on 14% of the land for its livelihood as well as food. So it doesn't mean that agriculture is very prosperous and the productivity is very high. In fact, the productivity is very low and the dependency is very high. Over the years, low productivity and climate change impacts have led to a loss*

FIGURE 2 Distribution of vulnerability in Uttarakhand as calculated using the vulnerability index described in Appendices S1 and S2 (*Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00058.1.S1); 0 indicates the lowest possible vulnerability, and 1 indicates the highest. Elevation classes: mountains/hills ≥1200 masl; plains <1200 masl.



of traditional agriculture-based livelihoods. And that's compelling people to outmigrate.

(*Male, 51, Nainital District*)

The importance of agriculture in migration decisions was further confirmed by a farmer who recounted how he was affected by uncertain rainfall and could no longer depend on agriculture for food and income security.

Migration is already increasing. People who are here are basically stuck in the village. Migration will increase as farming is becoming increasingly difficult. It does not rain on time anymore and that is why people are migrating from here. And then there are no jobs or livelihood alternatives. So, what will people do? People migrate to Rudrapur and work in the industries there. Then they live there and don't come back to the village.

(*Male, 47, Nainital District*)

TABLE 2 Linear regression models describing the role of climate vulnerability for migration.

Model	Dependent variable: outmigration rate			
	1	2	3	4
Vulnerability (log)	0.246**			
	(0.023)			
Sensitivity (log)		0.117**		0.009
		(0.032)		(0.025)
Adaptive capacity (log)			0.225**	0.221**
			(0.021)	(0.025)
Constant	0.263**	0.237**	0.224**	0.232**
	(0.018)	(0.035)	(0.015)	(0.025)
Observations	94	94	94	94
Adjusted R^2	0.429	0.093	0.432	0.429
Residuals	0.056	0.070	0.056	0.056
Breusch–Pagan Test	0.071*	0.653	0.078*	0.204
F statistic	71.000	10.600	71.800	35.600

Note: OLS coefficients in cells with robust standard errors in parentheses. An explanation of the methodology can be found in Appendix S3 (*Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00058.1.S1).
* $P < 0.1$.
** $P < 0.01$.

Heterogeneity by region and elevation class

Even though, on average, a positive relationship between vulnerability and migration is observable, larger variation in migration is observable in areas with higher vulnerability (Figure S3 in Appendix S6, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00058.1.S1). In the following, we explore some of the underlying heterogeneities by further distinguishing communities by their geographical location and remoteness of the area.

Figure 3 shows the distribution of the vulnerability index across the 13 districts of the state of Uttarakhand. A close correlation between the vulnerability and migration is observable for districts with higher vulnerability, showing on average a larger outmigration. Both variables are characterized by a substantial variation, both across districts as well as within districts, highlighting the need to consider local characteristics in understanding climate vulnerabilities and migration outcomes. Future research could explore these differences.

Communities at higher elevations show higher levels of vulnerability and outmigration, likely ascribable to economic inequality between the hill and plain districts. As explained by an expert in the region:

> *[A]ll economic activities which are able to generate economic growth and provide employment are located in the plains areas. And this increases the trend of migration from the hills because it provides employment to the unskilled, untrained people with lower education.*
>
> (*Male, in his 50s, Nainital District*)

The regional economic inequality also translates into differences in income levels, where the plains offer higher incomes than the hills. A young male working on a railway project in the state capital elaborated:

> *I think I will continue to work outside as in the village you cannot earn more than 7000 Indian rupees (≈ US$ 80) while in the plains I am earning 25,000 Indian rupees (≈ US$ 285).*
>
> (*Male, in his 20s, Pauri Garhwal District*)

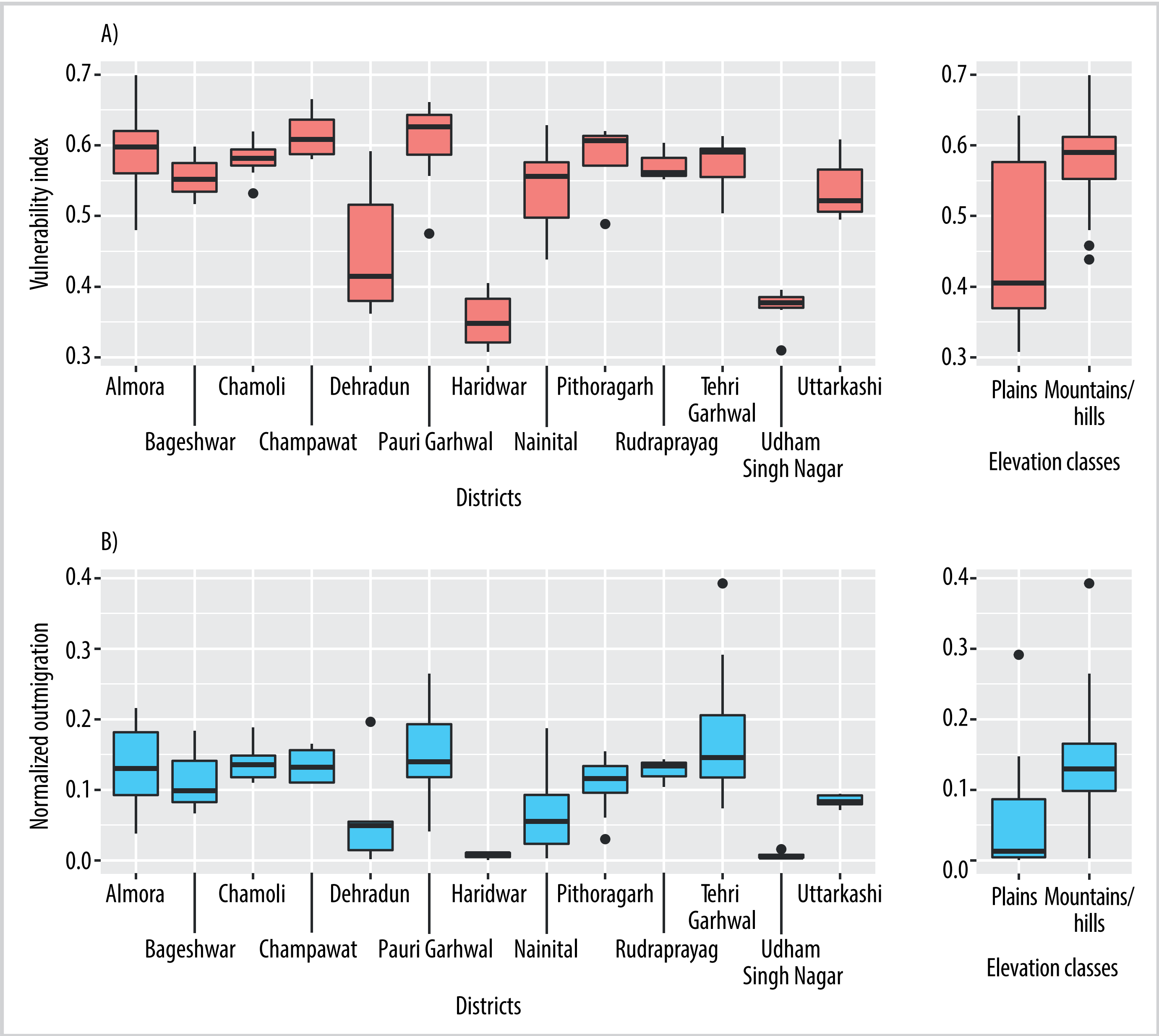
As people become educated, they prefer to outmigrate and find employment, as interest in farming is decreasing in rural villages (Carling and Collins 2018). A villager noted:

> *A girl who is an engineer will never pick cow dung in the village. She would want to go to the city and work as an engineer. She will insist that I am engineer and will work as one in the city and she will quit the rural village life. It is also about status and the ideas of what is success.*
>
> (*Male, 42, Almora District*)

Assessing the importance of different vulnerability subcomponents

Some aspects of a region's vulnerability are more relevant for migration than others. Figure 4 shows the relationship coefficients separately for the different vulnerability subcomponents. We distinguish between subcomponents related to the sensitivity (Figure 4A) and adaptive capacity (Figure 4B) of an area. As in the baseline models above (Table 2), the coefficients show the estimated change in migration with a 1% change in the respective vulnerability indicator (for full models, see Table S1 in Appendix S1, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-21-00058.1.S1).

FIGURE 3 Distribution of vulnerability (A) and migration (B) across districts and elevation classes (plains <1200 masl; mountains/hills ≥1200 masl).



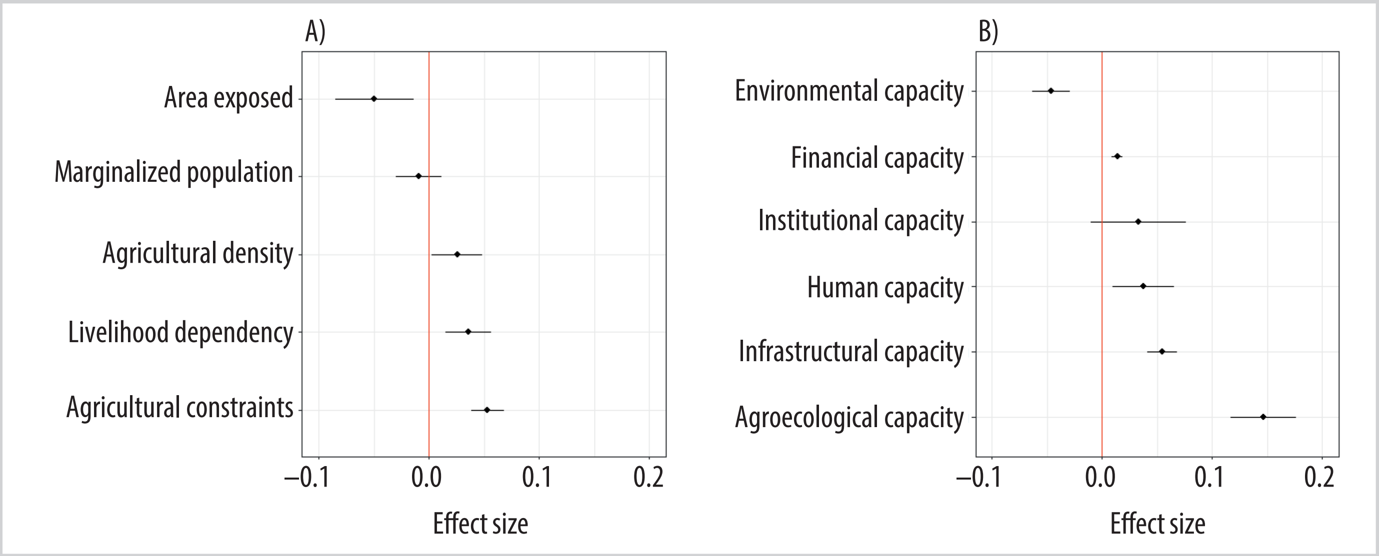
The coefficient plots highlight once more the important role of adaptive capacities for local livelihoods and migration. While some of the sensitivity subcomponents, such as the agricultural density, livelihood dependency, and agricultural constraints, also exert a significant positive effect on migration, effect sizes are consistently larger for the adaptive capacity subcomponents. Agroecological, infrastructural, and human capacities, together with agricultural constraints, are most strongly related with migration patterns in the mountainous regions.

Both in terms of sensitivity and adaptive capacity, the subcomponents related to agricultural conditions and practices are most strongly linked to migration. A high agricultural density and strong dependency on agriculture, captured here as livelihood dependency, increase the sensitivity to environmental change and play a significant role for migration. Similarly, steep slopes and a high elevation, which impose constraints on agricultural production, are found to be important.

Among all considered factors, the availability of infrastructure and the capacity of the agroecological system are the aspects of adaptive capacities that exert the strongest effects on migration. Constraints in irrigation, lack of irrigation facilities, and missing power supplies for agriculture are also all strongly correlated with outmigration. These indicators highlight the important roles of agricultural infrastructure and irrigation practices in the productivity and capacities of the agricultural sector (Shukla et al 2016).

In the qualitative interviews, the interviewees also noted the lack of infrastructure regarding education (schools), medical facilities (hospitals and qualified doctors), and employment opportunities in the area as a major issue. As a driver noted:

FIGURE 4 Differential migration impacts of different subcomponents of sensitivity (A) and adaptive capacity (B).



[. . .] we don't have a good hospital there [Almora]. We are in such a poor situation that right now a pregnant woman who lives in the mountains is referred to plains for delivery. I know as I drive patients so often. Imagine a pregnant woman has to go through the ordeal of a long mountain journey to give birth. Why the government is not able to set up a good hospital? The reason is that doctors don't want to live in the mountains.

(*Male, 42, Almora District*)

Citing climate change impacts on the agroecology of the region, a farmer shared her ordeal:

We are now living in the times where we have to buy potatoes. Earlier we produced enough potatoes that we could sell them in the market. But now what's happening is that we are buying potatoes that are irrigated as rainfed potatoes are no longer growing as it is not raining. Rain has gone all wrong. When it should rain, it doesn't rain. In the mountains there are some areas, irrigation happens but, in our village, we are dependent on rainfall. It is raining at the wrong time. Right when the harvest is ready for us to eat, this weather betrays us. I had harvested millets, but then it rained and now it's all spoiled. Now, what do we eat? I am so fed up.

(*Female, 64, Almora District*)

Impacts of vulnerability on different types of migration

As a final step of our analysis, we considered the role of vulnerabilities for different typologies of migration, as well as other characteristics from the dataset. Figure 5 shows the relationship between the vulnerability index on the *x* axis and different types of migration on the *y* axes. Here, we distinguish migration by whether migrants resettled permanently or semipermanently (Figure 5A), different age groups of migrants (Figure 5B), and different reasons for migrating (Figure 5C). The measures related to the different migration types all capture relative shares of the different types relative to the total number of migrants in an area.

The results show that different forms of migration are differently affected by vulnerability. While most migrants resettle permanently, we find that the vulnerability of an area is stronger related to nonpermanent forms of migration, expressed through a steeper slope of the fitted curve in the graph. The share of nonpermanent migrants among all migrants increases from about 10% in the blocks with least vulnerability to around 30% in those with the highest levels of vulnerability. That suggests an increase in short-term migration, labor migration, and possibly seasonal migration.

Similarly, while we observe that in all development blocks, older migrants outnumber the younger ones, we find that the share of younger migrants increases from 20% to 30% with increasing vulnerabilities. Thus, the data show that younger people are more likely to migrate from more vulnerable communities. The interviews also suggest that the expectation to migrate is particularly placed on the young under difficult conditions.

They tell their sons, what are you doing in the village? Roaming around aimlessly. Go make something useful of yourself in Delhi, get a job. So, it is the parents who start to chant go outside and get a job! Here in the village, we tell our sons to go be independent.

(*Male in his 30s, Pauri Garhwal District*)

Another aspect of youth migration is the link to upward social mobility. Being able to migrate to a city and sending back remittances is regarded as progress. As a villager retorted:

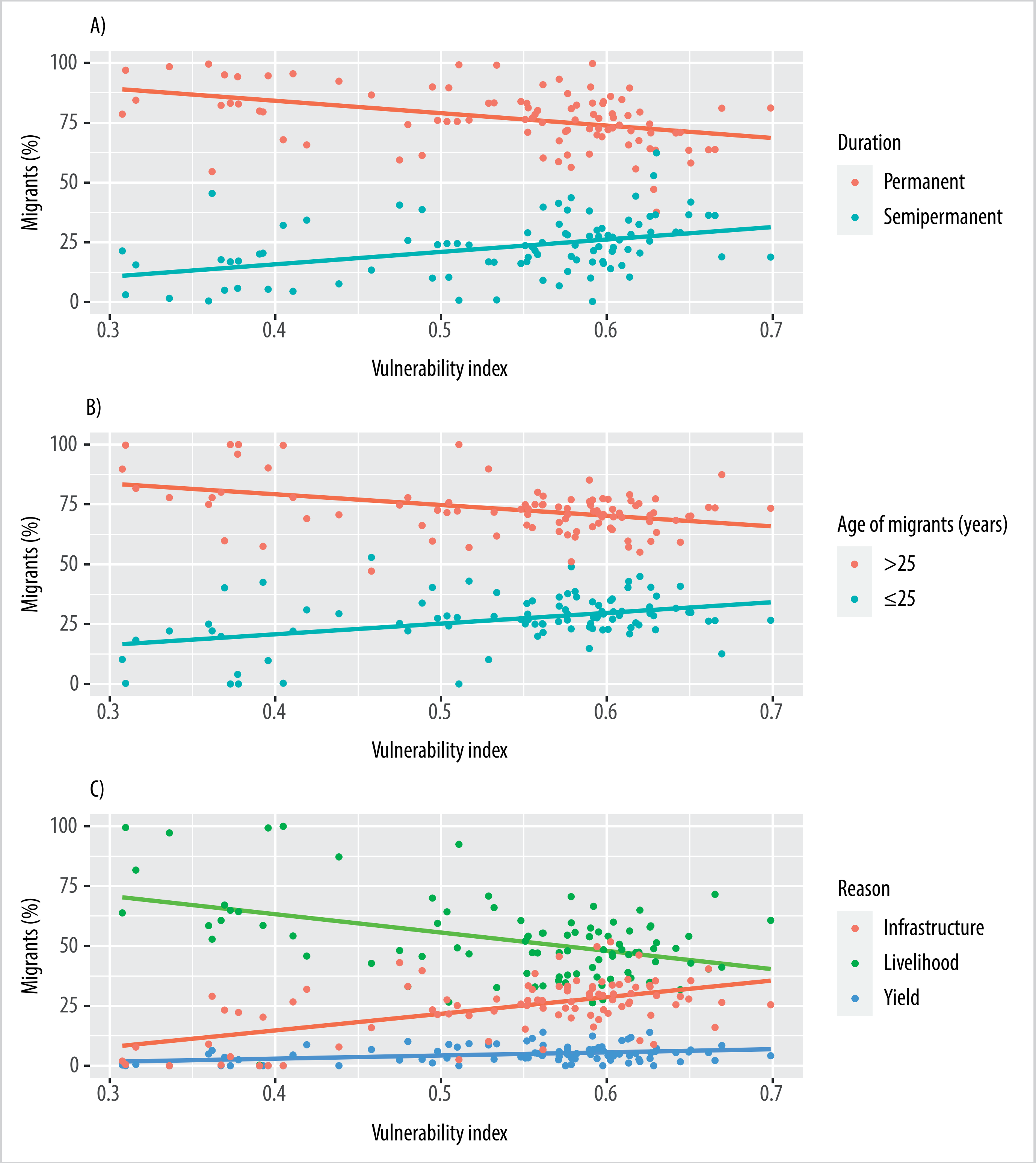
Look it's like this, when you are young, you are pulled to outside world. It's sort of a rites of passage sort of thing. If you are educated today, you must migrate. Why will you stay here?

(*Female, 65, Pauri Garhwal District*)

Gender also plays an important role. The climatic impacts and resulting population dynamics have different consequences for men and women. In Uttarakhand, migration has led to an increased workload and responsibilities for women. As noted by a resident:

Imagine the workload of a mountain woman who is doing farming and taking care of the household. She will cut grass and put it on her head and walk for kilometers; she will take care of the animals, cook, clean,

FIGURE 5 Linear regression model characterizing the relation between vulnerability and aspects of migration: (A) permanence; (B) age; and (C) reason for migrating. The *y* axes represent the shares of the different types relative to the total number of migrants in each development block.



farm in the fields, take care of the elderly. A woman has to do all these tasks. And she is not even allowed to complain. Their responsibility and work increase as men migrate. The limited number of men who do remain in the village don't do much, as they waste their time drinking. Alcohol is real problem in the mountains.

(*Male, 42, Almora District*)

As it is mostly men who migrate, the agricultural workload for women increases (Bhandari and Reddy 2015). Even though women are referred to as the backbone of the agrarian economy in Uttarakhand, they are often invisible, working as unremunerated laborers in family agriculture. The share of female agriculture workers in Uttarakhand is

48.5% (Pattnaik and Lahiri-Dutt 2017), one of the highest in India. While the important role of women in undeniable, the feminization of agriculture does not translate to equal ownership of land or having a say in making decisions for the farm. Additionally, it is important to underline that marginalized groups tend to be underrepresented in climate adaptation research; they show the highest vulnerability, yet they are the least visible (Borderon et al 2021). For example, if female migration was more local, it would not show in a dataset only displaying migration as movement across administrative borders.

Among the reasons to migrate, the "lack of livelihood and employment opportunities" remains the most cited reason for migrating across all communities, yet its prominence progressively decreases with growing vulnerability, from 70% to around 40%. On the other hand, "lack of facilities and infrastructure" increases from about 10% to 40%, suggesting that related limited adaptive capacities can represent an important reason for migrating, as discussed in the previous section. Outmigration can hence reflect the constraints of local infrastructure and agricultural capacities. A horticultural worker explained the acute impacts of uncertain rainfall:

> *It is raining less. And also it is not raining on time. This time the rain came 25 days late. We had to plant the flowers [. . .] but as rain didn't come we planted them late. Thereafter only leaves came, but they didn't flower.*
>
> (*Male, 51, Almora District*)

Discussion and conclusion

This study shows the important role of climate vulnerability in understanding migration in the IHR. Limited adaptive capacity of the agricultural sector is the driver of vulnerabilities and outmigration. For many households, the unsustainability of rainfed agriculture and lack of any other alternative livelihood options are central to migration decisions. This is further compounded by other structural factors (road access, irrigation infrastructure, small land holdings), as well as changing rainfall patterns affecting crop yields (Mishra 2014; Joshi 2018). With climate change, these factors are expected to become more significant for the already vulnerable mountain communities (Banerjee et al 2014; IPCC 2014b; Tiwari and Joshi 2015; Siddiqui et al 2019; Maharjan et al 2020, 2021). Our quantitative analysis highlighted the multicausal nature of migration (Black, Stephen, et al 2011), which was further supported by the interviews. While agricultural and ecological factors are critical in shaping outmigration, social and economic aspects, such as the lack of education and communication facilities, access to markets, and the availability of financial resources, also have an influence. The Most relevant vulnerability variable depends on the local context and conditions.

However, not every vulnerable household engages in migration, as reported by the higher variability in the migration outcomes even as vulnerability increases. This is in line with migration models (Foresight 2011; Kaczan and Orgill-Meyer 2020), which emphasize that migration is embedded in a broader range of adaptation and coping strategies used by households. Low levels of migration despite high vulnerabilities can also reveal a population trapped in place (Black and Collyer 2014; Nawrotzki and DeWaard 2018). Remote areas can limit the ability to migrate and be the cause of a community's invisibility to scientific research (Borderon et al 2021).

Climate change impacts are expected to be particularly severe in the vulnerable mountainous areas, and large parts of these impacts will be shouldered by women and the elderly, who are often the ones to stay (GU 2014; Joshi 2018; Upadhyay et al 2021). The demographic changes in rural areas result in vulnerable segments of the population in charge of the most climate-sensitive economic sector, which is rural agriculture (GU 2014; Mamgain and Reddy 2017; Joshi 2018). This in turn has further implications for migration. As Hoermann et al (2010) reported, decreasing agricultural yields force people to migrate. In this context, environmental impacts in the region must be understood against the backdrop of an already dwindling rural agricultural sector and uneven development processes (Mamgain and Reddy 2017; Anees et al 2020).

The change in population dynamics due to outmigration has an important implication for the size and composition of the populations in the areas of origin. As younger people increasingly migrate, home communities are left with an aging population, and this undermines sustainability of rural agriculture, which relies on family labor. The migration of the young labor force hence threatens food production and can have further local social, economic, and environmental impacts, such as abandonment of agricultural land and houses, loss of traditional norms and values, loss of community, and loss of traditional adaptive knowledge specific to the mountain environments (Speck 2017; Joshi 2018; Upadhyay et al 2021). This finding is supported by our study results, which indicate an increase in risk-reducing migration among the populations inhabiting the more rural areas. The rise in semipermanent and youth migration is consistent with an increase in short-term labor migration, especially among males (Jain 2010; RDMC 2018).

In order to ensure the sustenance of the rural livelihoods in the mountains, investments in a sustainable and climate-resilient agricultural sector are needed (IHD 2018). This requires measures capable to address the factors underlying vulnerability in the rural areas, such as the lack of infrastructure, access to markets, irrigation, and basic facilities, such as schools and health centers. While climate change certainly acts as a risk modifier, the roles of uneven development processes and inequality in the region remain paramount. Policies should therefore focus on narrowing this gap, by enabling sustainable rural mountain livelihoods while considering the needs for long-term adaptation.

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REFERENCES

Adger WN. 2006. Vulnerability. *Global Environmental Change* 16:268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006.

Adger WN, de Campos RS, Mortreux C. 2019. Mobility, displacement and migration, and their interactions with vulnerability and adaptation to environmental risks. *In:* McLeman R, Gemenne F, editors. *Routledge Handbook of Environmental Displacement and Migration*. London, United Kingdom: Routledge, pp 29–41. https://doi.org/10.4324/9781315638843-3.
Afifi T, Jäger J, editors. 2010. *Environment, Forced Migration and Social Vulnerability*. Abingdon, United Kingdom: Routledge. https://doi.org/10.1007/978-3-642-12416-7.
Anees MM, Shukla R, Punia M, Joshi PK. 2020. Assessment and visualization of inherent vulnerability of urban population in India to natural disasters. *Climate and Development* 12:532–546. https://doi.org/10.1080/17565529.2019.1646629.
Arlikatti S, Maghelal P, Agnimitra N, Chatterjee V. 2018. Should I stay or should I go? Mitigation strategies for flash flooding in India. *International Journal of Disaster Risk Reduction* 27:48–56. https://doi.org/10.1016/j.ijdrr.2017.09.019.
Banerjee A, Chen R, Meadows ME, Singh RB, Mal S, Sengupta D. 2020. An analysis of long-term rainfall trends and variability in the Uttarakhand Himalaya using Google Earth engine. *Remote Sensing* 12(4):709. https://doi.org/10.3390/rs12040709.
Banerjee S, Black R, Kniveton, D, Kollmair M. 2014. The changing Hindu Kush Himalayas: Environmental change and migration. *In:* Piguet, E., Laczko, F, editors. *People on the Move in a Changing Climate: The Regional Impact of Environmental Change on Migration*. Dordrecht, the Netherlands: Springer, pp 205–227. https://doi.org/10.1007/978-94-007-6985-4_9.
Banerjee S, Gerlitz J-Y, Hoermann B. 2011. *Labour Migration as a Response Strategy to Water Hazards in the Hindu Kush–Himalayas*. Kathmandu, Nepal: ICIMOD [International Centre for Integrated Mountain Development].
Bhagat RB. 2018. Climate change, vulnerability and migration in India. *In:* Irudaya Rajan S, Bhagat RB, editors. *Climate Change, Vulnerability and Migration*. London, United Kingdom: Routledge India, pp 18–42. https://doi.org/10.4324/9781315147741-2.
Bhandari G, Reddy BVC. 2015. Impact of out-migration on agriculture and women work load: An economic analysis of hilly regions of Uttarakhand, India. *Indian Journal of Agricultural Economics* 70(3):395–404.
Black R, Adger WN, Arnell NW, Dercon S, Geddes A, Thomas D. 2011. The effect of environmental change on human migration. *Global Environmental Change* 21:3–11. https://doi.org/10.1016/j.gloenvcha.2011.10.001.
Black R, Collyer M. 2014. Populations 'trapped' at times of crisis. *Forced Migration Review* 45:52–56.
Black R, Stephen R, Bennett G, Thomas SM, Beddington JR. 2011. Mobility as adaptation. *Nature* 478: 447–449.
Borderon M, Best KB, Bailey K, Hopping DL, Dove M, Cervantes de Blois CL. 2021. The risks of invisibilization of populations and places in environment-migration research. *Humanities and Social Sciences Communications* 8(1):314. https://doi.org/10.1057/s41599-021-00999-0.
Carling J, Collins F. 2018. Aspiration, desire and drivers of migration. *Journal of Ethnic and Migration Studies* 44:909–926. https://doi.org/10.1080/1369183X.2017.1384134.
Cutter SL, Ash KD, Emrich CT. 2014. The geographies of community disaster resilience. *Global Environmental Change* 29:65–77. https://doi.org/10.1016/j.gloenvcha.2014.08.005.
Das L, Dutta M, Mezghani A, Benestad RE. 2018. Use of observed temperature statistics in ranking CMIP5 model performance over the Western Himalayan Region of India: Unusual warming over the western Himalayan region of India. *International Journal of Climatology* 38:554–570. https://doi.org/10.1002/joc.5193.
Das L, Meher JK. 2019. Drivers of climate over the Western Himalayan region of India: A review. *Earth-Science Reviews* 198:102935. https://doi.org/10.1016/j.earscirev.2019.102935.
Das PK. 2013. 'The Himalayan tsunami'—cloudburst, flash flood & death toll: A geographical postmortem. *IOSR Journal of Environmental Science, Toxicology and Food Technology* 7(2):33–45. https://doi.org/10.9790/2402-0723345.
Falco C, Galeotti M, Olper A. 2019. Climate change and migration: Is agriculture the main channel? *Global Environmental Change* 59:101995. https://doi.org/10.1016/j.gloenvcha.2019.101995.
Foresight. 2011. *Migration and Global Environmental Change: Future Challenges and Opportunities. Final Project Report*. London, United Kingdom: The Government Office for Science.
Goodrich CG, Mehta M, Bisht S. 2017. *Status of Gender, Vulnerabilities and Adaptation to Climate Change in the Hindu Kush Himalaya: Impacts and Implications for Livelihoods, and Sustainable Mountain Development*. ICIMOD Working Paper. Kathmandu, Nepal: ICIMOD [International Centre for Integrated Mountain Development].
Gopirajan AT S, Kumar P, Chauhan N, Joshi PK. 2021. Influence of socio-environmental risks on natural resource dependent socio-ecological systems in Central Himalaya. *Human and Ecological Risk Assessment: An International Journal* 27:1568–1587. https://doi.org/10.1080/10807039.2020.1861427.
Grecequet M, DeWaard J, Hellmann JJ, Abel GJ. 2017. Climate vulnerability and human migration in global perspective. *Sustainability* 9:1–10. https://doi.org/10.3390/su9050720.
GU [Government of Uttarakhand]. 2014. *Uttarakhand Action Plan on Climate Change: Transforming Crisis to Opportunity*. Dehradun, India: Department of Planning, Government of Uttarakhand.
Guha A, Maiti A, Bhamoriya V, Sen S. 2017. *Uttarakhand State Economic Survey 2016–17*. Kashipur, India: Indian Institute of Management.
Guhathakurta P, Bandgar A, Menon P, Prasad AK, Sable ST, Sangwan N. 2020. *Observed Rainfall Variability and Changes Over Uttarakhand State*. ESSO/IMD/HS/Rainfall Variability 28(2020)/52. Pune, India: Indian Meteorological Department.
Hoermann B, Banerjee S, Kollmair M. 2010. *Labour Migration for Development in the Western Hindu Kush–Himalayas: Understanding a Livelihood Strategy in the Context of Socioeconomic and Environmental Change*. Kathmandu, Nepal: ICIMOD [International Centre for Integrated Mountain Development].
Hoffmann R, Dimitrova A, Muttarak R, Crespo Cuaresma J, Peisker J. 2020. A meta-analysis of country level studies on environmental change and migration. *Nature Climate Change* 10:904–912. https://doi.org/10.1038/s41558-020-0898-6.
IHD [Institute for Human Development]. 2018. *Uttarakhand Human Development Report*. Dehradun, India: Department of Planning, Government of Uttarakhand.
IPCC [Intergovernmental Panel on Climate Change]. 2014a. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom: Cambridge University Press.
IPCC [Intergovernmental Panel on Climate Change]. 2014b. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom: Cambridge University Press.
Isaac RK, Isaac M. 2017. Vulnerability of Indian agriculture to climate change: A study of the Himalayan region state. *World Academy of Science, Engineering and Technology, International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering* 11(7):236–242.
Jain A. 2010. *Labour Migration and Remittances in Uttarakhand*. Kathmandu, Nepal: ICIMOD [International Centre for Integrated Mountain Development].
Jha SK, Negi AK, Alatalo JM, Negi RS. 2021. Socio-ecological vulnerability and resilience of mountain communities residing in capital-constrained environments. *Mitigation and Adaptation Strategies for Global Change* 26:38. https://doi.org/10.1007/s11027-021-09974-1.
Joshi B. 2018. Recent trends of rural out-migration and its socio-economic and environmental impacts in Uttarakhand Himalaya. *Journal of Urban and Regional Studies on Contemporary India* 4:1–14.
Kaczan DJ, Orgill-Meyer J. 2020. The impact of climate change on migration: A synthesis of recent empirical insights. *Climatic Change* 158:281–300. https://doi.org/10.1007/s10584-019-02560-0.
Kumar N, Jaswal AK. 2016. Historical temporal variation in precipitation over Western Himalayan Region: 1857–2006. *Journal of Mountain Science* 13:672–681. https://doi.org/10.1007/s11629-014-3194-y.
Kumar V, Jain SK, Singh Y. 2010. Analysis of long-term rainfall trends in India. *Hydrological Sciences Journal* 55:484–496. https://doi.org/10.1080/02626667.2010.481373.
Lama P, Hamza M, Wester M. 2021. Gendered dimensions of migration in relation to climate change. *Climate and Development* 13:326–336. https://doi.org/10.1080/17565529.2020.1772708.
Macchi M, Gurung AM, Hoermann B. 2015. Community perceptions and responses to climate variability and change in the Himalayas. *Climate and Development* 7:414–425. https://doi.org/10.1080/17565529.2014.966046.
Maharjan A, de Campos RS, Singh C, Das S, Srinivas A, Bhuiyan MRA, Ishaq S, Umar MA, Dilshad T, Shrestha K, et al. 2020. Migration and household adaptation in climate-sensitive hotspots in South Asia. *Current Climate Change Reports* 6:1–16. https://doi.org/10.1007/s40641-020-00153-z.
Maharjan A, Hussain A, Bhadwal S, Ishaq S, Saeed BA, Sachdeva I, Ahmad B. 2018. *Migration in the Lives of Environmentally Vulnerable Populations in Four River Basins of the Hindu Kush Himalayan Region*. HI-AWARE Working Paper 20. Kathmandu, Nepal: HI-AWARE [Himalayan Adaptation, Water and Resilience].
Maharjan A, Tuladhar S, Hussain A, Mishra A, Bhadwal S, Ishaq S, Saeed BA, Sachdeva I, Ahmad B, Ferdous J, Hassan SMT. 2021. Can labour migration help households adapt to climate change? Evidence from four river basins in South Asia. *Climate and Development* 13(10):879–894. https://doi.org/10.1080/17565529.2020.1867044.
Mamgain RP. 2004. *Employment, Migration and Livelihoods in the Hill Economy of Uttaranchal* [PhD thesis]. New Delhi. India: Centre for the Study of Regional Development, Jawaharlal Nehru University.
Mamgain RP, Reddy DN. 2017. Out-migration from the Hill Region of Uttarakhand: Magnitude, challenges, and policy options. *In*: Reddy, D., Sarap, K., editors. *Rural Labour Mobility in Times of Structural Transformation*. Singapore, Singapore: Palgrave Macmillan.
McLeman R. 2018. Thresholds in climate migration. *Population and Environment* 39:319–338. https://doi.org/10.1007/s11111-017-0290-2.
McLeman RA, Hunter LM. 2010. Migration in the context of vulnerability and adaptation to climate change: Insights from analogues. *Wiley Interdisciplinary Reviews: Climate Change* 1:450–461. https://doi.org/10.1002/wcc.51.
Mishra A. 2014. Changing climate of Uttarakhand, India. *Journal of Geology & Geosciences* 3:163. https://doi.org/10.4172/2329-6755.1000163.
Naudiyal N, Arunachalam K, Kumar U. 2019. The future of mountain agriculture amidst continual farm-exit, livelihood diversification and outmigration in the Central Himalayan villages. *Journal of Mountain Science* 16:755–768. https://doi.org/10.1007/s11629-018-5160-6.

Nawrotzki RJ, DeWaard J. 2018. Putting trapped populations into place: Climate change and inter-district migration flows in Zambia. *Regional Environmental Change* 18:533–546. https://doi.org/10.1007/s10113-017-1224-3.
NITI Aayog [National Institution for Transforming India]. 2018. *A Summary Report Contributing to Sustainable Development in the Indian Himalayan Region: Key Messages from Five Thematic Reports and Way Forward*. New Delhi, India: NITI Aayog.
NMSHE [National Mission for Sustaining the Himalayan Ecosystem]. 2018. *Climate Vulnerability Assessment for the Indian Himalayan Region Using a Common Framework*. New Delhi, India: Department of Science and Technology, Government of India.
ORGI [Office of the Registrar General & Census Commissioner, India]. 2011. *Census Tables*. New Delhi, India: Ministry of Home Affairs, Government of India. https://censusindia.gov.in/census.website/data/census-tables; accessed on 21 February 2021.
ORGI [Office of the Registrar General & Census Commissioner, India]. 2022. *Migration*. Drop-in-Article on Census No. 8 (Migration). New Delhi, India: Ministry of Home Affairs, Government of India. https://censusindia.gov.in/census.website/data/DROPIN; accessed on 1 August 2022.
Pandey R, Jha S. 2012. Climate vulnerability index—Measure of climate change vulnerability to communities: A case of rural Lower Himalaya, India. *Mitigation and Adaptation Strategies for Global Change* 17:487–506. https://doi.org/10.1007/s11027-011-9338-2.
Pandey R, Maithani N, Aretano R, Zurlini G, Archie KM, Gupta AK, Pandey VP. 2016. Empirical assessment of adaptation to climate change impacts of mountain households: Development and application of an Adaptation Capability Index. *Journal of Mountain Science* 13:1503–1514. https://doi.org/10.1007/s11629-015-3499-5.
Pathak S, Pant L, Maharjan A. 2017. *De-population Trends, Patterns and Effects in Uttarakhand, India—A Gateway to Kailash Mansarovar*. Kathmandu, Nepal: ICIMOD [International Centre for Integrated Mountain Development].
Pattnaik I, Lahiri-Dutt K. 2017. *Tracking Women in Agriculture through Recent Census Data in India*. Working Paper No. 242. Ahmedabad, India: Gujarat Institute of Development Research.
Penning-Rowsell EC, Sultana P, Thompson PM. 2013. The 'last resort'? Population movement in response to climate-related hazards in Bangladesh. *Environmental Science & Policy* 27:S44–S59. https://doi.org/10.1016/j.envsci.2012.03.009.
Pepin N, Bradle RS, Diaz HF, Baraer M, Caceres EB, Forsythe N, Fowler H, Greenwood G, Hashmi MZ, Liu XD, et al. 2015. Elevation-dependent warming in mountain regions of the world. *Nature Climate Change* 5:424–430. https://doi.org/10.1038/nclimate2563.
RDMC [Rural Development and Migration Commission]. 2018. *Interim Report on the Status of Migration in Gram Panchayats of Uttarakhand*. Pauri Gharwal, India: RDMC.
Sabin TP, Krishnan R, Vellore R, Priya P, Borgaonkar HP, Singh BB, Sagar A. 2020. Climate change over the Himalayas. *In:* Krishnan R, Sanjay J, Gnanaseelan C, Mujumdar M, Kulkarni A, Chakraborty S, editors. *Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India*. Singapore, Singapore: Springer, pp 207–222. https://doi.org/10.1007/978-981-15-4327-2_11.
Sati VP. 2020. *Himalaya on the Threshold of Change, Advances in Global Change Research*. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-030-14180-6.
Shukla R, Sachdeva K, Joshi PK. 2016. Inherent vulnerability of agricultural communities in Himalaya: A village-level hotspot analysis in the Uttarakhand state of India. *Applied Geography* 74:182–198. https://doi.org/10.1016/j.apgeog.2016.07.013.
Siddiqui T, Bhagat RB, Banerjee S, Liu C, Sijapati B, Memon R, Thinley P, Ito M, Nemat O, Arif GM. 2019. Migration in the Hindu Kush Himalaya: Drivers, consequences, and governance. *In:* Wester P, Mishra A, Mukherji A, Shrestha AB, editors. *The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People*. Cham, Switzerland: Springer, pp 517–544. https://doi.org/10.1007/978-3-319-92288-1_15.
Singh C, Basu R. 2020. Moving in and out of vulnerability: Interrogating migration as an adaptation strategy along a rural–urban continuum in India. *Geographical Journal* 186:87–102. https://doi.org/10.1111/geoj.12328.
Speck S. 2017. "They moved to city areas, abroad": Views of the elderly on the implications of outmigration for the middle hills of western Nepal. *Mountain Research and Development* 37(4):425–435. https://doi.org/10.1659/MRD-JOURNAL-D-17-00034.1.
Subramanian S. 2016. *Understanding the Synergy Between National Mission for Sustaining the Himalayan Ecosystem and SAPCCs from Himalayan States*. New Delhi, India: IHCAP [Indian Himalayas Climate Adaptation Programme].
Tiwari PC, Joshi B. 2015. Climate change and rural out-migration in Himalaya. *Change and Adaptation in Socio-Ecological Systems* 2:8–25. https://doi.org/10.1515/cass-2015-0002.
Tiwari PC, Joshi B. 2016. Gender processes in rural out-migration and socio-economic development in the Himalaya. *Migration and Development* 5:330–350. https://doi.org/10.1080/21632324.2015.1022970.
UEPPCB [Uttarakhand Environment Protection and Pollution Control Board]. 2018. *State of Environment (SoE) Report of Uttarakhand*. Dehradun, India: UEPPCB. https://ueppcb.uk.gov.in/files/SoER.pdf; accessed on 4 August 2022.
Upadhyay H, Kelman I, Lingaraj GJ, Mishra A, Shreve C, Stojanov R. 2015. Conceptualizing and contextualizing research and policy for links between climate change and migration. *International Journal of Climate Change Strategies and Management* 7:394–417. https://doi.org/10.1108/IJCCSM-05-2014-0058.
Upadhyay H, Mohan D. 2014. *Migrating to Adapt? Contesting Dominant Narratives of Climate Change and Migration*. New Delhi, India: UNIFEM [United Nations Development Fund for Women].
Upadhyay H, Vinke K, Bhardwaj S, Becker M, Irfan M, George NB, Biella R, Arumugam P, Muriki SK, Emanuela P. 2021. *Locked Houses, Fallow Lands: Climate Change and Migration in Uttarakhand, India*. New Delhi, India: PIK [Potsdam Institute for Climate Impact Research] and Teri [The Energy and Resources Institute].
Wester P, Mishra A, Mukherji A, Shrestha AB, editors. 2019. *The Hindu Kush Himalaya Assessment*. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-92288-1.
World Bank, ADB [Asian Development Bank]. 2013. *India: Uttarakhand Disaster 2013; Joint Rapid Damage and Needs Assessment Report*. New Delhi, India: World Bank.

Supplemental material

APPENDIX S1 Data sources.
APPENDIX S2 Construction of the vulnerability index.
APPENDIX S3 Quantitative estimation approach.
APPENDIX S4 Mixed methods approach and qualitative insights.
APPENDIX S5 Further descriptive statistics.
APPENDIX S6 Illustrating the vulnerability–migration relationship.

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