



# A combined cognitive and spatial model to map and understand climate-induced migration

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## Abstract

Climate change impacts on populations have increased the number of affected people and climate migrants worldwide. Although the nexus between climate change and migration is not monolithic, analyses of individual-level factors at the local scale that reveal the specific drivers of migration are lacking. Here, we show that people are motivated by individual calculations, prioritizing economic and social factors when deciding to migrate. We use data from 53 structured interviews to decompose the assessment of the decision-making process of people deciding to migrate from a region highly vulnerable to climate change, assessing the internal and external migratory potential. The assessment of migration potential evidenced that potential migrants react and make decisions based on perceptions and preferences among economic, social, environmental, and cultural factors when migrating and value these factors differently. Our spatial multi-criteria model reports disaggregation in that people prioritize economic factors, such as unemployment, job opportunities, and lack of income, over other migration-related factors, while environmental factors are generally considered underlying. Our results demonstrate that migration is not monolithic but a mixture and amalgam of multiple interacting factors, which causes people to migrate or stay in one place despite vulnerability and climate change impacts.

**Keywords** Climate migration · Climate change · Human mobility · Multi-criteria analysis · Migration · Decision-making process

## 1 Introduction

Climate change is considered one of the main drivers of temporary and permanent internal and cross-border migration (Ayales et al., 2019; Black et al., 2011; Casillas, 2020; Falco et al., 2019; Foresight, 2011; Wiegel et al., 2019). This is due to the impacts of changing

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weather patterns, which can directly and indirectly affect food security, livelihoods, and the habitability of human landscapes. These climate change impacts exacerbate established challenges, especially for those already vulnerable due to poverty, poor access to services, and social exclusion (Birkmann et al., 2022; Campbell et al., 2016; Hermans & McLeman, 2021). Recently, this connection has been demonstrated in West Africa, Latin America, and Central Asia, where the adverse effects of climate change have directly contributed to 18.8 million displaced people in 2017 (IOM & UN-OHRLS, 2019).

Additionally, climate refugees are receiving increasing international attention, and forecasts predict the diasporas of millions of climate migrants in the coming years (Hoffmann et al., 2020; IOM & UN-OHRLS, 2019; Muttarak, 2021). Particularly nowadays, due to efforts to meet sustainable development agendas such as the 2030 Agenda, migration has been recognized as a complex and multifaceted phenomenon affecting all social, economic, and environmental spheres, which must be addressed to achieve the SDGs, ensuring that they are carried out in an inclusive and recognized manner. With national climate change mitigation commitments set to overshoot the goal of keeping global temperatures below an increase of 1.5 °C, the issue of climate-driven human migration is becoming an increasingly pressing issue, both within and across national borders (IPCC, 2018).

Attempts to address connections between climate change and human migration have focused on identifying, first, how changes in one affect the other (Campbell et al., 2016; Casillas, 2020; Castelli, 2018; IOM & UN-OHRLS, 2019). Second is this interaction's magnitude (Boas et al., 2019; Chen & Mueller, 2019; Falco et al., 2019; Hoffmann et al., 2021). This has yielded precise empirical knowledge on the so-called 'nexus' between human mobility and climate change, known as climate migration. For example, agricultural disasters associated with extreme climate phenomena have strongly affected migration in developing countries (Falco et al., 2019). However, these efforts have focused on quantifying and estimating future environmental migrants and refugees rather than investigating *why* these people are moving. This reinforces assumptions about migration as a linear and massive process and further generalizes the idea that all those at risk in future will migrate (Chen & Mueller, 2019; Hoffmann et al., 2020).

Moreover, most research on climate phenomena, environmental change, and its impact on human migration focuses on national or international levels, and this often leads to predictions that do not consider local contexts and disaggregated factors affecting migration dynamics (Boas et al., 2019). Much research to date also assumes that all people at risk will migrate and disregards, in most cases, the possibility of climate change contributing to people's immobility, i.e., people deciding to stay where they are. We also recognize that not migrating can be a choice or the result of constraints on people; some authors have identified place attachment, strong social bonds, and property over land or houses as primary factors for people's decision of not to migrate (Blondin, 2021; Farbotko, 2018; Farbotko et al., 2020; Mallick & Mallick, 2021; Mallick et al., 2022; Schewel, 2020; Wiegel et al., 2021).

Although we acknowledge that non-migration/immobility/non-mobility is a possibility, we chose to focus on which are the most relevant factors people consider the most influential in their decision-making process on migration. To predict, reduce, and otherwise manage human migration, we need to understand the individual decisions and personal drivers behind migration: *we need to investigate how climate change and human mobility are related from the point of view of individuals and communities*. This points to the importance of understanding the decision-making of potential migrants on whether to migrate at the local scale, especially regarding the prevalence and significance of different environmental, social, and economic factors intertwined in these decisions.

There are numerous and diverse interactions between the impacts of climate change on communities' economic, cultural, and political contexts that can influence migration, making this analysis a challenging task (Bernzen et al., 2019; Gray & Bilsborrow, 2014; Laczko & Aghazarm, 2010). For instance, Koubi et al. (2016) conducted an economic-demographic analysis of climate migration and environmental indicators through surveys in Africa, Asia, and the Americas. Their results indicated that although gradual ecological and climatic events tend not to generate human migration, sudden and abrupt climatic events increase the likelihood of human displacement (Koubi et al., 2016). Moreover, Massey et al., 2010 examined the connections between environmental change and migration in Nepal using social and economic variables (Massey et al., 2010). They found that factors associated with low productivity of agricultural activities and land cover changes trigger migration trends in rural Nepal (Massey et al., 2010).

On the other hand, Gray and Bilsborrow (2014) conducted a survey-based analysis to address the potential impact of climate change on migration in three rural areas of Ecuador. Their findings suggest differentiated responses to ecological and climatic effects that depend on the intrinsic adaptive capacity of rural households, and adverse environmental conditions do not necessarily increase internal migration from rural to urban environments (Gray & Bilsborrow, 2014). Moreover, Gray & Bilsborrow also show that when precipitations increase, migration is reduced because water irrigates crops and allows people to escape poverty in rural Ecuador (Gray & Bilsborrow, 2014). These differing responses are based on the use of different options and resources available to rural households to cope with the effects of climate and weather, such as the use of government assistance, local migration in search of employment, the reliance on remittances, social capital, and technical skills (Jha et al., 2018).

These findings are consistent with several studies that demonstrate how responses to climate change vary across social categories, such as gender, which can impact an individual's vulnerability or resilience (Detraz, 2017; Dillon et al., 2011; Gray & Mueller, 2012; Henry et al., 2004). For instance, some of these studies have found that men are more likely to migrate in the face of drought events, while women's migration decreases in the face of the same phenomenon (Dillon et al., 2011; Gray & Mueller, 2012; Henry et al., 2004). This reveals the existence of disparities in how different groups—in this case, gender—cope with and respond to the effects of climate change and, as Detraz (2017) points out, the need to comprehend them as complex phenomena in which gender and other social structures, such as class, culture, and religion, play a direct role (Detraz, 2017).

While these efforts have started to decipher the nonlinearity of the climate–migration interaction, they do not capture the complexity of migration decision-making with the detail needed to disaggregate and individualize this information at the community scale. To understand the multidimensional nature of migration and its relationship with climate, it is necessary to investigate the rationale for different approaches to migration (Boas et al., 2019; Wiegel et al., 2019). In addition, it is necessary to assess how climate change and migration affect each other and the socioeconomic, cultural, and political factors at the local scale. This requires examining choice priorities used by communities and individuals who decide to migrate and the conditions and combinations of factors under which they make this decision.

Therefore, we use a combined spatial and cognitive multi-criteria analysis to understand the factors that impact the migrants' decision-making regarding whether to migrate. Their internal and external migratory potential in the Central American Dry corridor is in Nacaome, Honduras. The cognitive model is composed of a multi-criteria evaluation of all the factors that intervene in the migration decision-making process.

This research sheds light on the potential of both internal and external migration phenomena in Nacaome from the individuals' perspectives, the factors they consider as drivers of migration, their relative weight, and the ranking of all the factors involved in the decision-making process. This approach helps develop policies to address the underlying problems associated with climate migration and its effects on individuals (McLeman, 2017, p. 334). The following section describes the study area and the methodology used in this study. We then present the results of the application of the interviews, the multi-criteria analysis using the BWM method, and, ultimately, the results of the spatialization of the model. Finally, we discuss the findings and highlight how this research's advances can help develop frameworks to better identify potential climate migrants.

## 2 Study area

We conducted this research in the municipality of Nacaome in the department of Valle, Honduras, which is in the Central American Dry Corridor. The Dry Corridor area comprises various ecosystems in the tropical dry forest ecoregion of Mesoamerica and spans from southern Mexico through Guatemala, El Salvador, Honduras, Nicaragua, and part of Costa Rica (van der Zee et al., 2012). Cyclical droughts and abnormal rainfall characterize the Dry Corridor during the rainy seasons, making the region prone to food insecurity due to crop failure (van der Zee et al., 2012).

Nacaome is composed of a predominantly agricultural landscape and a primarily rural population. It has a land area of 528 km<sup>2</sup> and consists of ten villages and 217 localities with 60,647 people (INE—Instituto Nacional de Estadística, 2018; Reyes, 2016). Nacaome's economy depends mainly on the agricultural and fish farming sectors. The most prominent are the shrimp industry, artisanal fishing, and cereal and fruit agriculture, including corn, beans, melon, and watermelon. The municipality's climate is warm, with marked rainy and dry seasons (INE - Instituto Nacional de Estadística, 2018).

Nacaome and the Valle department are experiencing a high migration rate, marked drought impacts, land degradation, and environmental degradation (Acuña et al. 2011; Hernández, 2016). Given its exposure, vulnerability, and capacity to respond to climate risk, Nacaome has been designated high risk due to climate change (INE—Instituto Nacional de Estadística, 2018; Observatorio Demográfico Universitario & UNAH, 2016). Figure 1 shows the geographic location of the study area. Moreover, climatic forecasts and predictions indicate a decline in agricultural commodity production and potential national labor shortages (Prager et al., 2020). The agricultural sector will face high risks to crop yields and overall economic performance of the agricultural sector due to its geographic location and high vulnerability to drought and tropical storm events (Prager et al., 2020).

## 3 Methods

To analyze and understand the migration decision-making process in the municipality and the migration potential of Nacaome, we divided the workflow into three steps (Fig. 2).

First, we conducted a literature review to inform the structured interview questions about factors that could contribute to the decision to migrate for Nacaome's residents and help understand the reasoning within the migration decision-making process. The literature review had a descriptive rather than systematic approach. It is intended to show a general

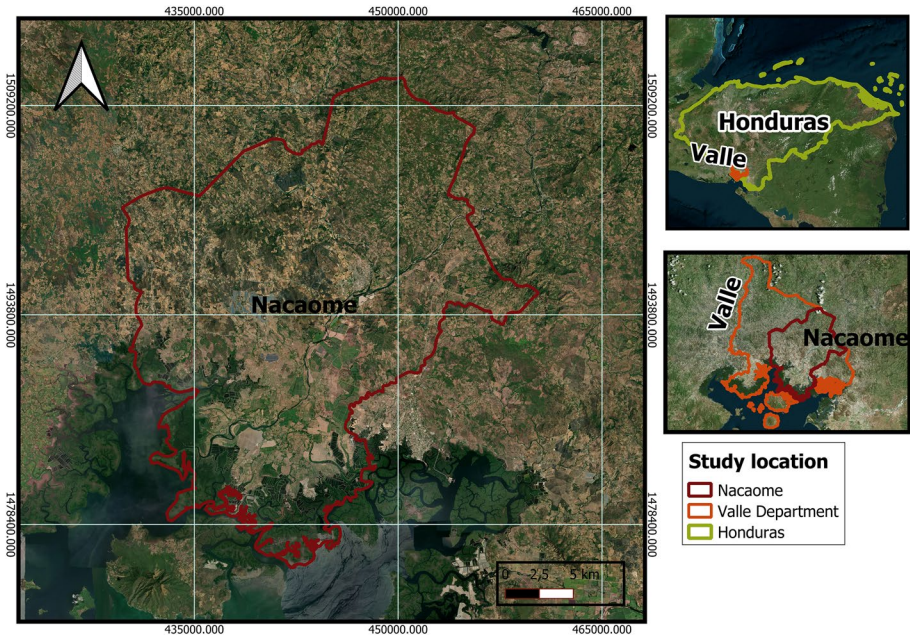


Fig. 1 The geographic location of the study area. Own development. Made using QGIS

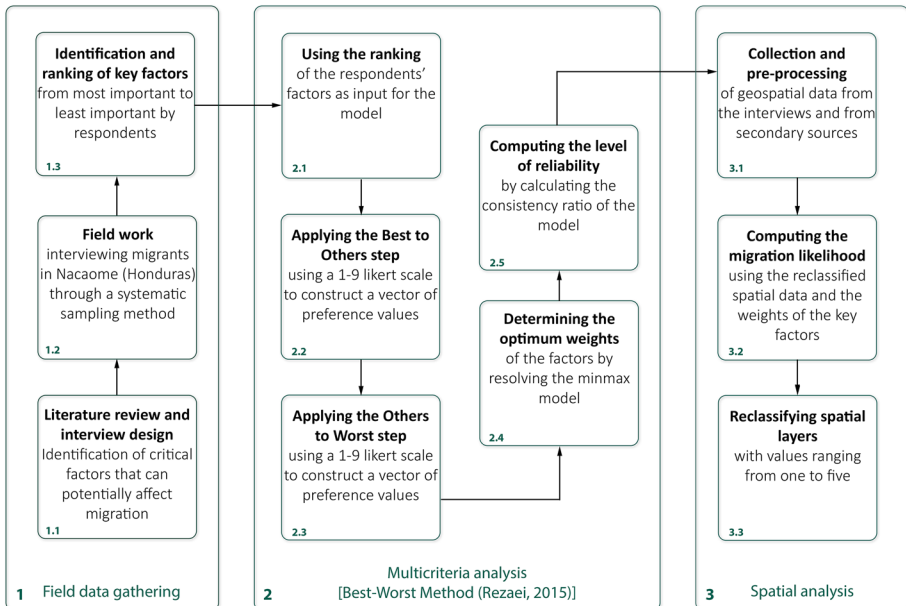


Fig. 2 Methodology workflow. Own development, based on Rezaei (Rezaei, 2015, 2016)

**Table 1** Migration-related factors retrieved from the literature review and added by the participants

Categories	Factors
1. Social factors	1.1 Marriage; 1.2 There are family/relatives in the new location; 1.3 I was facing discrimination; 1.4 Insecurity (physical &/or sexual); 1.5 To seek health care (inadequate health care in the area); 1.6 To seek schooling (e.g., no school in the area); 1.7 Violence; 1.8 Gender violence/segregation <sup>^</sup> ; 1.9 Changes in disease vectors (malaria, dengue, etc.) or Covid 19 <sup>^</sup> ; 1.10 Educational level <sup>^</sup> ; 1.11 Vacation
2. Economic factors	2.1 Not enough income from livelihood sources; 2.2 Unreliable harvest; 2.3 Crop failure; 2.4 No land available for farming/agriculture; 2.5 Unemployment in that location; 2.6 Job opportunity in a new place; 2.7 Higher income in a new place; 2.8 Lost land security; 2.9 Property sale 2.10 Living costs*; 2.11 Fuel costs*
3. Political factors	3.1 There was a political conflict; 3.2 To seek political freedom; 3.3 Government provided incentives for me to go <sup>^</sup> ; 3.4 Government forced me to move. 3.5 Corruption*
4. Environmental factors	4.1 Floods; 4.2 Droughts; 4.3 Temperature increase; 4.4 Precipitation increases; 4.5 Strong winds/Hurricanes/Tornadoes; 4.6 Erosion Process <sup>^</sup> ; 4.7 Water salinization <sup>^</sup> ; 4.8 Soil salinization; 4.9 Productive capacity (fertility); 4.10 Contamination by agricultural chemicals; 4.11 Few water sources and poor management; 4.12 Heavy rains/Storms; 4.13 Landslide/avalanche <sup>^</sup> ; 4.14 Water availability reduced; 4.15 Deforestation and forests fires; 4.16 Cold waves; 4.17 Heatwaves; 4.18 Increase in the intensity of adverse weather phenomena
5. Demographic factors	5.1 Food supply/food security; 5.2 Starvation and malnutrition; 5.3 Age; 5.4 High mortality rate <sup>^</sup> ; 5.5 Increase in sexually transmitted diseases <sup>^</sup> ; 5.6 Increase in vector-borne diseases; 5.7 Low percentage of women, men, youth, and elderly in the community <sup>^</sup>

## Literature review sources

Alfaro Martínez et al. (2018), Alpízar et al. (2020), Ayales et al. (2019), Black et al. (2011), Boas et al. (2019), Casillas (2020), Dodd et al. (2020), Espósito and Torres Campubí (2011), Falco et al. (2019), Finch (2021), FAO (2019); Foresight (2011), IOM (2018); McCarney and Kent (2020); McLeman (2017) (McLeman, 2017), Narváez et al. (2009); Ortiz-Paniagua and Felipe Pérez (2017), The Nansen Initiative (2015); Vallejos (2020), van der Zee et al. (2012), Wrathall et al. (2014)

The symbol “<sup>^</sup>” at the end of the factors represents a factor that belonged to the initial literature review that the participants did not consider as influencing migration. The symbol “\*” means that the participants added the factor

picture of how migration has been studied concerning climate change and to get a sense of the relevant factors to have in mind for comprehending the relationship between climate and migration. Based on this literature review and the interviewees’ answers, we identified 49 factors that impact migration related to climate change. We categorized these factors

into five clusters organically by our criteria: *social* ( $n=11$ ), *environmental* ( $n=18$ ), *economic* ( $n=9$ ), *demographic* ( $n=7$ ), and *political* ( $n=5$ ) (Table 1).

Second, we collected field data through structured interviews to identify and rank all possible factors contributing to migration. Third, we conducted a multi-criteria analysis to choose the best alternatives based on the decision-maker's objectives and preferences, avoiding cultural, economic, or environmental biases (Zarghami & Szidarovszky, 2011). The approach we followed for it was the Best–Worst method (BWM). This method uses pairwise comparisons to discern the relative preferences of one factor over the others (Rezaei, 2015) and determine each factor's weight (level of importance). This method allowed us to understand and examine the multidimensional nature of migration, as well as to facilitate an assessment of the variety of perceptions, aspects, and patterns that demographic, economic, environmental, political, and social factors play in the decision-making process of potential internal (within Honduras) and external (outside Honduras) migrants (Rezaei, 2015).

Finally, we processed the related spatial information, developed spatial layers in a geographical information system, and undertook a cross-analysis of the spatial and cognitive data to produce a map of the likelihood of potential migration areas in Nacaome. By enabling the identification of variables that lead people to migrate and areas of high potential migration, our model can aid policymakers in undertaking targeted, tailored actions to cope with climate change-related migration effectively. Moreover, it can be applied and replicated elsewhere in Honduras or any region vulnerable to climate change.

### 3.1 Systematic sampling and interview overview

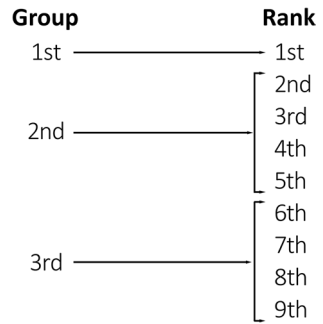
To analyze the decision-making process of migrants in Nacaome, we used individual interviews as data collection instruments (Gill et al., 2008). The interview protocol was based on Koubi et al. (2016) and Warner (2011). It consisted of 28 semi-structured questions that collected information about the households' composition, economic activity, livelihoods, demographic characteristics, and information associated with the historical migration dynamics of the people who compose it (including both internal (within Honduras) and external (international) migration).

Through the interview, we inquired about interviewees' perceptions of climate change and how it has positively and negatively affected them in their current or previous locations. This was done by exploring the climatic phenomena in the last 5 years and their influence on migration to better understand how climate change has impacted each household. We tested the interview with researchers from the National Autonomous University of Honduras before using it at scale for research to simplify its understanding. Their feedback from this piloting stage resulted in various changes, including familiar words used in the municipality of Nacaome and adjustments to ensure that no questions were closed-ended or prompted only yes or no answers.

Furthermore, to better understand their social context and adaptive capacity, we also inquired about the interviewees' transportation methods, the networks of people who helped them migrate, their age, and their gender. We also asked about household members' financial details, occupations, employment status, and primary sources of income.

Since our study area is entirely native Spanish-speaking, the interviews had to be translated into Spanish. Furthermore, our sample universe was geography-based and did not discriminate between migrants and non-migrants, i.e., who was interviewed depended on whether their household was selected. The interviews were conducted with residents of

**Fig. 3** Grouping of the ranks into three groups. Own development



the municipality of Nacaome to assess migration potential based on their current perceptions. Therefore, our interview lacked dependent or independent variables; instead, it was focused on the individual assessment of the possible factors that may impact a person's decision-making process on migration.

We conducted 53 interviews (accounting for 53 different households) from October 8th to October 10th, 2021; each interview had an average duration of 30 min. The interviews were conducted with the head of the household or another adult. We followed our research's (EDI) approach to ensure equity, diversity, and inclusion. All interviewed households were spatially registered using GPS. We used a systematic sampling method to minimize bias, wherein the first household interviewed was selected randomly within the municipality area, and interviews after that were conducted at a distance of six households from the first interviewed household. This six-household distance approach was applied to avoid possible judgments or biases due to the closeness or proximity of the inhabitants of each household, i.e., close relatives responding the same as any other home interviewed. Finally, based on Saunders et al. (2015) and to protect respondents' identity and maintain data integrity, we conducted an anonymization process, avoiding inquiries about the name, religion, and race that would compromise anonymity.

During the interviews, we used the list of factors developed via the literature review to specifically ask respondents to identify all the factors they considered to be involved in the decision to migrate—see step 1.3 in the methodology workflow (Fig. 2). Moreover, we provided respondents space to contribute additional, unforeseen factors if they did not find them in our list. We decided to offer as many factors as possible and the option for respondents to propose their factors. This helped to avoid (1) leading questions that would reinforce the multidimensionality of migration and (2) asking only about the adverse effects of migration climate change. Instead, we provided many factors and read them several times to choose which factors they considered crucial.

Interviewees ranked the selected factors using a 1–9 scale according to their relevance for migration decision-making. (Further details are explained in the following section.) In this scale, the factor ranked number one corresponds to the factor that has the most significant impact on the decision-making process of whether to migrate, while the factor ranked number nine corresponds to the factor with the lesser impact. To evaluate the rankings of the factors, we subdivided the ranks into three groups. Following our criteria, we organized the groups so that the first group corresponds to the factors ranked first, the second to those ranked 2nd–5th, and the third to the factors ranked 6–9th (Fig. 3). The factor groups were then analyzed according to their frequentist salience by the proportion of times each factor was selected in each group. For instance, suppose a factor  $x$  was not selected in the first position but was selected 9% of the time in positions 2–5 and 2% in positions 6–9.



Additionally, we examined the differences between the factors selected by men and women. Thus, we evaluated the proportion of factors selected by men and women, and the relevance and representativeness of each of the three factors groups, thereby reflecting the variation in prioritizing different factors when deciding to migrate.

Furthermore, we compared and evaluated whether there were significant differences between the responses of men and women concerning selecting factors that promote migration. For this, four samples were used. The first one included the total frequency of times the factors were selected and the three groups of classification of the factors (first group, second group, and third group). This indicated an analysis of eight samples, four for the women's responses and four for the men's responses.

We conducted Shapiro–Wilk tests to evaluate the distribution of the samples. However, none of the samples showed a normal distribution behavior. We also applied three types of transformations to the data, logarithmic transformation, square root transformation, and cube root transformation. Nevertheless, the data did not fit a normal distribution despite these transformations.

In this sense, we decided to employ the non-parametric Kruskal–Wallis test to compare the differences between two or more groups. It extends to the Mann–Whitney  $U$  test, which compares the medians of two groups and does it by not assuming a normal distribution for calculating test statistics and  $p$  values (Ostertagová et al., 2014). All statistical analyses were conducted using R 4.1.0 (R Core Team, 2022).

Finally, we performed an epsilon-squared method of choice for effect size measurement. The method ranges from 0 to 1, as shown in the following scale displaying the strength of the effect or difference between two variables (Tomczak & Tomczak, 2014):

0.00 < 0.01—Negligible.

0.01 < 0.04—Weak.

0.04 < 0.16—Moderate.

0.16 < 0.36—Relatively strong.

0.64—Strong

0.64 < 1.00—Very strong.

### 3.2 Multi-criteria analysis

We used the Best–Worst method (BWM) developed by Rezaei (2015) to identify the factors that have the most significant potential to influence people's migration in the municipality of Nacaome (Li et al., 2020; Rezaei, 2015). The Best–Worst method (BWM) is a multi-criteria and individual decision-making approach that employs pairwise comparison to solve problems of discrete multi-attribute decision-making (MADM). We decided to apply the BWM because it captures the decision-maker's preferences better than other methods. BWM has shown significantly better ordinal consistency, which means it provides better consistency in preserving the best-to-worst order. The BWM also produces a closer weighting relationship based on the Euclidean distance between the weights and their corresponding pairwise comparisons (Li et al., 2020; Rezaei, 2015).

We identified the main factors involved in the decision-making process of migration through the interviews' ranking (step 1.3 in the methodology workflow); afterward, we assessed the priority of the factors in the migration process using a pairwise comparison

**Table 2** An example of the identification of critical factors. Based on Rezaei (2015)

Interviewee	Factors
Interviewee #1	Unemployment Droughts Job opportunity Insecurity Deforestation
Interviewee #2	Unreliable harvest Sexual insecurity Droughts Political conflict Age

**Table 3** An example of identifying the best and worst factors

Interviewee	Best factor	Worst factor
Interviewee #1	Unemployment	Deforestation
Interviewee #2	Sexual insecurity	Droughts

approach from the method Solver Linear BWM, developed by Rezaei (Rezaei, 2016).<sup>1</sup> The five-step Best–Worst multi-criteria method (Rezaei, 2016) is explained below.

### 3.2.1 Step 1: identification of critical factors

We introduced the ranking of factors made by the interviewees in step 1.3 into the model  $\{f_1, f_2, f_3, f_4, \dots, f_n\}$  (Table 2). This step focused on identifying the factors rather than classifying them or assessing their importance.

### 3.2.2 Step 2: determining the best and worst key factors

From the set of factors identified by the interviewees and presented in step 1, the interviewees chose the ‘best’ and ‘worst’ key factors. The ‘best’ key factor is the factor that most strongly influences the decision-making process on migration. The ‘worst’ key factor is the least influential factor in the decision to migrate (Table 3).

### 3.2.3 Step 3: determining the best factor over the other factors (Best-to-Others)

We asked the respondents to determine the preference values of the best factor over the other factors based on a one-to-nine Likert scale (Table 4). This results in the Best-to-Other (BO) vector, which is calculated as  $A_B = (a_{B1}, a_{B2}, a_{B3}, \dots, a_{Bn})$  where  $a_{Bj}$  shows the preference of the best criterion B over the other criterion  $j$  (Tables 4 and 5).

<sup>1</sup> <https://bestworstmethod.com/software/>.

**Table 4** BWM's Likert scale

Value	Meaning
1st	Equal importance
2nd	Somewhat between equal and moderate
3rd	Moderately more important than
4th	Somewhat between moderate and strong
5th	Strongly more important than
6th	Somewhat between strong and very strong
7th	Very strongly important than
8th	Somewhat between very strong and absolute
9th	Absolutely more important than

Based on Rezaei (2015)

**Table 5** An example of determining the best-to-others

Interviewee	Best factor	Ranking by factors				
		Unemployment	Droughts	Job opportunity	...	[Other factors]
Interviewee #1	Unemployment	1	4	2	...	6
Interviewee #2	Sexual insecurity	8	9	6	...	7

Based on Rezaei (2015)

**Table 6** An example of determining the others-to-worst

Interviewee	Worst factor	Ranking by factors				
		Unemployment	Droughts	Job opportunity	...	[Other factors]
Interviewee #1	Deforestation	5	3	5	...	1
Interviewee #2	Droughts	4	2	6	...	2

Based on Rezaei (2015)

### 3.2.4 Step 4: determining the preference of all factors over the worst factor (Others-to-Worst)

We asked the respondent to assess the preference value of the worst factor over the other factors. The ranking of all factors over the worst criterion is expressed using the same one-to-nine Likert scale. This process results in the Other-to-Worst (OW) vector, which is written as  $A_W = (a_{1W}, a_{2W}, a_{3W}, \dots, a_{nW})^T$  where  $a_{jW}$  shows the rank of the preference of the worst factor  $j$  over factor  $W$  (Table 6).

**Table 7** An example of optimum weights computation

	Unemployment	Droughts	Job opportunity	Insecurity	Deforestation
Weights	0,38,793,103	0,12,931,034	0,25,862,069	0,17,241,379	0,05,172,414
Consistency Ratio	0,12,931,034				

Based on Rezaei (2015) and the data of this research

### 3.2.5 Step 5: determining the optimum weights

Finally, for the optimal weights  $(w_1^*, w_2^*, w_3^*, \dots, w_n^*)$ , the optimal weighting of the factors is the one in which, for each pair of  $w_B/w_j$  and  $w_j/w_w$  we have that  $w_B/w_j = a_{Bj}$  and  $w_j/w_w = a_{jw}$  (Table 7).

It must be satisfied that, for all  $j$ , the solution must have been found where the absolute maximum differences  $\left| \frac{w_B}{w_j} - a_{Bj} \right|$  and  $\left| \frac{w_j}{w_w} - a_{jw} \right|$  For all  $j$  is minimized.

The BWM allowed us to calculate the Consistency Ratio  $\in [0,1]$ , which expresses the model's consistency level. The lower the Consistency Ratio, the more robust the comparisons will be and, therefore, the more reliable the results. The Consistency Ratio checks the reliability of the optimal weights calculated with the BWM and expresses the level of accuracy between the pairwise input comparisons and the calculated weights.

Based on work by Mohammadi and Rezaei (2020), we employed the geometric mean to integrate the overall global weight preferences of the 53 respondents. To construct the final ranking of the global weights, we only selected factors with a frequency of at least one-fifth of the total. This process avoided the overestimation of the rankings by factors selected too infrequently. For example, suppose we would consider a factor  $x$  selected only once in the 53 interviews and ranked as the most critical factor. In that case, it could be ranked as the most critical factor overall for all 53 interviewees when calculating the global weights. Thus, by removing this factor  $x$ , we ensure that we include the factors with the greatest representativeness and relevance for the respondents.

### 3.3 Spatial analysis

Given the scale of the analysis and to better understand the context in which people live, we collected secondary information on environmental, biophysical, social, and economic factors of the municipality of Nacaome. We compiled the spatial data from OCHA: The Humanitarian Data Exchange,<sup>2</sup> the Geoportal of the Forestry Sector of Honduras,<sup>3</sup> the Geoportal of Demographic Indicators of the National Autonomous University of Honduras,<sup>4</sup> and the Geoportal of Territories at Risk<sup>5</sup> (Gobierno de la Republica de Honduras, 2021; Observatorio Demográfico Universitario & UNAH, 2016; OCHA Services, 2021; Universidad Nacional Autonoma de Honduras, 2021) (Table 8). We subsequently reprojected all spatial layers to the Coordinate Reference System

<sup>2</sup> [https://data.humdata.org/group/hnd?ext\\_geodata=1&page=2&q=&ext\\_page\\_size=25#datasets-section](https://data.humdata.org/group/hnd?ext_geodata=1&page=2&q=&ext_page_size=25#datasets-section).

<sup>3</sup> <http://geoportal.icf.gob.hn/geoportal/main>.

<sup>4</sup> <https://geoportal-odu.unah.edu.hn/>.

<sup>5</sup> <https://territorioseriesgo.unah.edu.hn/>.

**Table 8** Sources of spatial information used for this research

Data repositories	Data used
The humanitarian data exchange	Health indicators; Gender equality; Conflict events; Development indicators; climate change, Poverty; Environment, Agriculture, Displacement indicators, Population Density; Food insecurity; Flood vulnerability, Drought vulnerability; Climate change vulnerability
Geoportal of the forestry sector of Honduras	Vegetation Cover; Forest Fire; National, Departmental, and municipal boundaries; Livelihood zones; Hydrology; Deforestation
Geoportal of demographic indicators of the national autonomous University of Honduras	Population structure; Migration rates; Poverty; Education
Geoportal of territories at risk	Sub-villages administrative boundaries

‘EPSG:32,616-WGS 84 coordinates system/UTM zone 16N’ in QGIS version 3.16 for integrating and harmonizing the data so that queries can result in the exact location on the earth’s surface (ESRI, 2021; QGIS.org, 2021). We used the ‘Correct geometries’ tool for cases where the layers had topographic errors (QGIS.org, 2021). GPS data for the interviewed households’ locations were imported using the QGIS plug-in ‘GPS Tool’ (QGIS.org, 2021).

Additionally, we created a spatial database containing all the reprojected spatial layers representing the factors identified by the respondents as influencing migration (Table 2) and the spatial location of the households interviewed. Each spatial layer was reclassified using QGIS 3.16 (QGIS.org, 2021) on a scale from 1 to 5, where one codes for “very low,” two for “low,” three for “medium,” four is “high” and five, “very high.” Thus, we produced layers with vector information for each factor involved in migration. For instance, we used the Unemployment layer and reclassified it according to the previously proposed scale, where a value of 5 pictures very high Unemployment rates, and areas with a value of one register low Unemployment rates.

Finally, we used the “Field Calculator” tool of QGIS to calculate the migration potential in the municipality. For this purpose, we used the reclassified factor values and the weight of each factor obtained through the BW. Equation 1 shows the procedure for calculating the migration potential:

$$\sum_{i=1}^n K = k_i \cdot n_i \quad (1)$$

where  $K$  represents the migration’s potential value,  $k_i$  is the reclassified value of each migration factor, and  $n_i$  refers to the weight of each factor calculated with the BW. Finally, to spatially represent the model, we conducted an inverse distance weighted (IDW) interpolation on QGIS using a pixel size of 30 m to estimate the spatial values of migration potential in the areas where no interviews were conducted based on the values of the factors’ weights of the 53 interviewees’ migration potential.

The zones with the greatest likelihood of migration in the municipality of Nacaome were generated by integrating 43 vector layers of the municipality’s biophysical, economic, and social factors. We constructed a Geodatabase that included all the factors identified by the interviewees as potentially influencing migration. The resulting vector layer was

classified into five classes, namely: (i) very low potential, (ii) low potential, (iii) medium potential, (iv) high potential, and (v) very high potential.

## 4 Results

### 4.1 Overview of household-level analysis and migration trends

From the 53 interviews conducted in the municipality of Nacaome, 73% percent of the people interviewed were women, and the remaining 27% were men. The interviews were conducted uniquely with the head of household (63%), while 20% included their partner and 17% included their children. In general, respondents consider themselves to be in a situation of medium (42%), high (21%), and abysmal poverty (30%), the remaining percentage of interviewees did not respond. Moreover, our findings reveal low educational levels and high unemployment rates in the interviewed households.

The type and number of livelihood activities vary significantly across the interviewed households. On the one side, 45% are dedicated to activities associated with agriculture on a permanent and occasional basis, and 10% to artisanal mining. Also, 25% reported that they depend exclusively on remittances sent by their families, 15% stated they are engaged in non-agricultural sales, and 5% in construction. Across all the households, only 6% reported traveling outside the municipality to work in agricultural and sales activities.

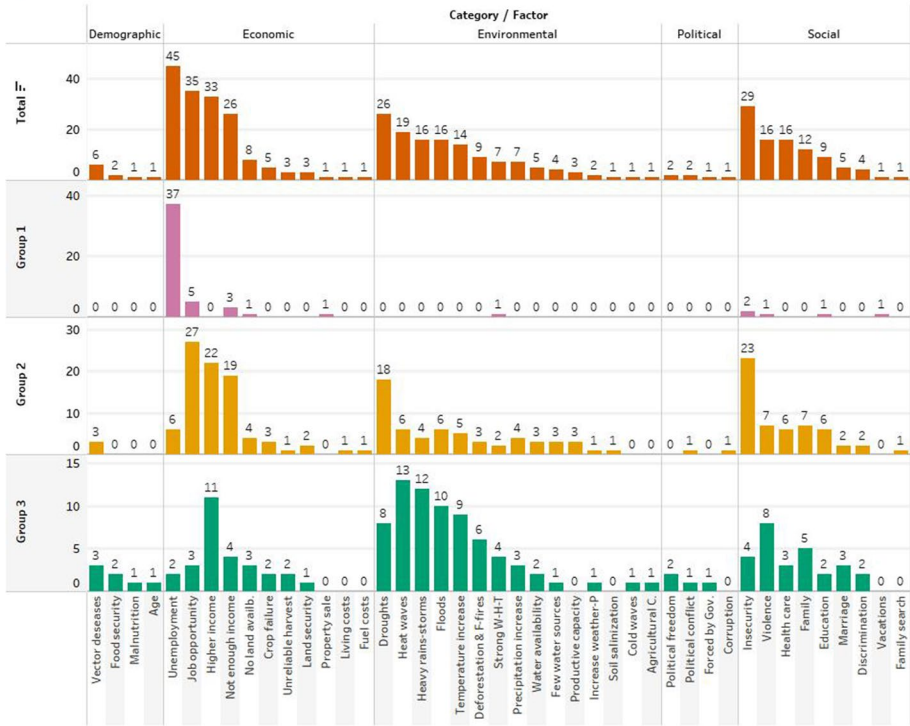
Our analysis reveals that most respondents (62%) had neither migrated nor considered it a possibility. However, the remaining 38% indicated that they had considered migrating. This was mainly due to economic factors such as *Unemployment*, *Not enough income*, and the search for *opportunities* and a *better quality of life*. Only 5% of those interviewed stated that they had known people who had migrated because of droughts, desertification, and hurricanes. Regarding the latter, they highlighted the role of Hurricane Mitch in 1998, which is considered a significant driver of migration in Honduras.

We found that 34% ( $n = 18$ ) of the respondents had migrated. Of this total, 16% had moved abroad and returned to Nacaome, with the United States, El Salvador, and Guatemala being their main destinations abroad. They reported using family and friendship networks to facilitate settlement in their destinations and used illegal means of transportation to cross international borders. The main destinations of respondents who have emigrated internally (84% of the 34% who have migrated) are other municipalities within the Valle, southern Honduran departments such as Choluteca and Paraíso, and the country's capital, Tegucigalpa. Like international migrants, internal migrants employed family networks to facilitate temporary and seasonal labor migration. Furthermore, they argued that the specific reasons for migration were motivated by economic and social factors associated with *Unemployment*, *a better quality of life*, *Not enough income*, and *Job opportunities*.

### 4.2 Ranking factors influencing internal and external migration

Based on the information collected, we determined 43 factors that could impact the decision-making process on the migration of people living in the municipality of Nacaome. Participants recognized 15 environmental, 11 economic, nine social, four political, and four demographic factors, meaning that out of the 49 factors retrieved from the literature, the participants removed and included various factors that influence and do not influence migration (see Table 1). From this selection, the economic factors were the most selected

Hoja 2



Suma de Total, suma de Positon 1, suma de Positon 2-5, suma de Positon 6-9 para cada Factor desglosado por Category.

**Fig. 4** Frequencies of each factor by different groups (1st position, 2–5 position, and 6–9 position). Full bar in orange displays the number of times the participants selected a factor. Purple bars display the percentage of times that a factor was selected in the first group (position 1), and Yellow and Green bars represent the percentage of times a particular factor was selected in the second (position 2–5) or third group (positions 6–9), respectively. Own development. Meaning of the abbreviations: No land availib. = No land available; Agricultural C. = Agricultural contamination; Deforestation & F-fir. = Deforestation and forests fires; Increase weather-p. = Increased adverse weather phenomena; Strong W–H–T. = Strong winds, hurricanes, and tornados; Forced by gov. = Forced by government

by respondents, with a total frequency of 161 selections, followed by environmental factors (131 selections), social factors (93 selections), and demographic and political factors (10 and 6 selections, respectively).

Similarly, economic and social factors were consistently and strongly represented in individual frequency selection. The factors most frequently identified by interviewees were *Unemployment* ( $n=45$ ), *Job opportunity* ( $n=35$ ), *Higher Income* ( $n=33$ ), *Insecurity* ( $n=29$ ), and *Not enough income* and *Droughts* ( $n=26$  for both) (please to the top orange bars in Fig. 4).

We found that only ten factors in the first group were chosen at least once as the most critical factor for their potential influence on migration. The factor with the highest number of times selected in this position is *Unemployment*, with 70% ( $n=37$ ). It is followed by *Job opportunity* with 9% ( $n=5$ ), *Not enough income* with 6% ( $n=3$ ), *Insecurity* with 4% ( $n=2$ ), and the factors of *Violence*, *Education*, and *Strong winds, hurricanes and tornados*, *No land available*, *Vacations*, and *Property sale* with 2% each ( $n=1$ ).

**Table 9** Frequency of environmental factors in the second group 2 (factors in positions 2–5) and in the third group (factors in positions 6–9) when Unemployment, Job Opportunity, and Not enough income were ranked in the first position (first group)

Factors	Frequency of economic factors in position 1	Environmental factors in positions 2–5	Environmental factors in positions 6–9
Unemployment	37	25	24
Job opportunity	5	4	4
Not enough income	3	1	1

Concerning the second group (factors in positions 2–5), we found a predominance of economic factors at 42% of the total factors identified, followed by environmental factors at 29% and social factors at 26%. Specifically, the top five factors with the highest frequency identified in this group were *Job opportunity* with 13% ( $n=27$ ), *Insecurity* with 11% ( $n=23$ ), *Higher income* with 11% ( $n=22$ ), *Not enough income* with 9% ( $n=19$ ), as well as *Droughts* with 9% ( $n=18$ ).

Finally, the factors located in the third group (factors in positions 6–9)—with the minor influence on migration decision-making—presented more equitable patterns in the selection. For this group, environmental factors such as *Heatwaves* stand out as the one with the highest number of times selected with 9% ( $n=13$ ), followed by *Heavy rains and storms* 8% ( $n=12$ ), *Higher income* 8% ( $n=11$ ), and *Floods* 7% ( $n=10$ ) (for more detailed information see Fig. 4).

Additionally, the results show that 67% of the people who selected economic factors such as *Unemployment*, *Job opportunities*, and *Not enough income* as their first choice, also selected at least one environmental factor (67%) in positions 2–5, and 64% of the time at least one environmental factor was selected in positions 6–9. For a detailed explanation, see Table 9.

### 4.3 Factors analysis by gender

Findings reveal that both Women and Men identified *Unemployment* as the most critical factor (68%,  $n=26$ , 73%,  $n=11$ , respectively) in deciding to migrate. However, in the first group (position 1), women tend to select factors such as *Not enough income* (8%,  $n=3$ ), *Job opportunity* (8%,  $n=3$ ), *Insecurity* (5%,  $n=2$ ), and *Strong winds, hurricanes, and tornados* (3%,  $n=1$ ), *Education* (3%,  $n=1$ ), and *Not land available* (3%,  $n=1$ ). In comparison, Men only selected *Job Opportunity* (13%,  $n=2$ ), *Property sale* (7%,  $n=1$ ), and *Violence* (7%,  $n=1$ ) as other factors in the same group (further detail in Table 10).

As for the second group of factors (position 2–5), whereas both men and women showed a more diverse and broader selection of factors, emphasizing economic and social factors, women differed by including *Family in the new location* (5%,  $n=7$ ), *Health care* (4%,  $n=6$ ), *Marriage* (1%,  $n=2$ ), *Discrimination* (1%,  $n=2$ ), and *Corruption* (1%,  $n=1$ ). In contrast, men selected *Living costs* (2%,  $n=1$ ) and *Fuel costs* (2%,  $n=1$ ) as factors that women did not select. Furthermore, factors of the third group (position 6–9) reflect several similarities as having selected an appropriate portion of environmental and social factors.



**Table 10** Factors analysis by gender

	Factor	Women	Percentage of women	Men	Percentage of men
First group	Unemployment	26	68%	11	73%
	Not enough income	3	8%	–	–
	Job opportunity	3	8%	2	13%
	Insecurity	2	5%	–	–
	Strong winds, hurricanes, and tornados	1	3%	–	–
	No land available	1	3%	–	–
	Education	1	3%	–	–
	Vacations	1	3%	–	–
	Property sale	–	–	1	7%
	Violence	–	–	1	7%
	Second group	Unemployment	30	21%	2
Job opportunity		19	13%	8	14%
Insecurity		16	11%	7	12%
Higher income		14	10%	8	14%
Not enough income		12	8%	6	10%
Droughts		10	7%	5	9%
Family in the new location		7	5%	–	–
Third group	Floods	12	10%	1	2%
	Heatwaves	12	10%	4	9%
	Higher income	7	8%	4	9%
	Temperature increase	6	6%	3	7%
	Violence	6	6%	2	3%
	Heavy rains and storms	6	6%	6	13%
	Droughts	–	–	4	9%

Own development. The values in the Women and Men columns denote the frequency with which they selected a factor in a given position. The percentage represents the proportion of Women and Men who selected a specified factor at any given position out of the number of times that factor could be chosen

**Table 11** Results of the Kruskal–Wallis statistical test

Samples assessed	Kruskal–Wallis Chi-squared and <i>p</i> value	Epsilon-squared
Women total–Men total	chi-squared = 28.819, <i>df</i> = 10, <i>p</i> value = 0.001333	0.686
Women 1G–Men 1G	chi-squared = 12.137, <i>df</i> = 3, <i>p</i> value = 0.00693	0.289
Women 2G–Men 2G	chi-squared = 19.484, <i>df</i> = 7, <i>p</i> value = 0.006798	0.464
Women 3G–Men 3G	chi-squared = 18.764, <i>df</i> = 5, <i>p</i> value = 0.002126	0.447

Women Total and Men Total refer to the number of times a factor was selected among the three groups. 1G, 2G, and 3G indicate the factors groups: first group, second group, and third group

However, the statistical analysis showed significant differences between all four samples assessed, revealing that the factors determining the decision to migrate among men and women are different, as shown in Table 11.

**Table 12** Global weight factors influencing migration

Factor	Global weight	Factor	Global weight
Vacations ( $n = 1$ )	0,255,681,818	Cold waves ( $n = 1$ )	0,096,256,684
Property sale ( $n = 1$ )	0,24,380,805	Discrimination ( $n = 2$ )	0,095,395,192
Unemployment* ( $n = 44$ )	0,22,566,673	Violence* ( $n = 18$ )	0,095,090,401
Crop failure ( $n = 5$ )	0,175,434,977	Deforestation ( $n = 9$ )	0,094,797,619
Job opportunity* ( $n = 32$ )	0,167,978,851	Insecurity* ( $n = 31$ )	0,092,354,593
Higher income* ( $n = 30$ )	0,159,819,265	Health care ( $n = 9$ )	0,081,419,434
Water availability ( $n = 6$ )	0,14,883,082	Heatwaves* ( $n = 19$ )	0,078,685,091
Not enough income* ( $n = 26$ )	0,14,359,652	Heavy rains-storms* ( $n = 15$ )	0,076,860,603
Productive capacity (soil) ( $n = 3$ )	0,141,030,644	Temperature increase* ( $n = 13$ )	0,074,098,558
Few water sources ( $n = 4$ )	0,139,543,221	Increase extreme weather phenomena ( $n = 2$ )	0,073,328,814
Unreliable harvest ( $n = 3$ )	0,138,507,508	Forced by government ( $n = 2$ )	0,063,043,985
No land available ( $n = 7$ )	0,135,382,794	Family in the new location* ( $n = 13$ )	0,056,492,999
Soil salinization ( $n = 1$ )	0,129,032,258	Political conflict ( $n = 2$ )	0,052,825,007
Strong winds, hurricanes, and tornados ( $n = 8$ )	0,117,139,927	Agricultural contamination ( $n = 1$ )	0,045,045,045
Marriage ( $n = 4$ )	0,116,844,582	Food security ( $n = 2$ )	0,041,792,534
Education ( $n = 9$ )	0,114,718,651	Vector-borne diseases ( $n = 6$ )	0,035,020,483
Floods* ( $n = 17$ )	0,112,120,209	Age ( $n = 1$ )	0,034,090,909
Land security ( $n = 2$ )	0,111,496,896	Corruption ( $n = 1$ )	0,032,051,282
Droughts* ( $n = 26$ )	0,110,052,552	Fuel costs ( $n = 1$ )	0,027,472,527
Malnutrition ( $n = 1$ )	0,102,564,103	Political freedom ( $n =$ )	0,026,062,138
Living costs ( $n = 1$ )	0,098,901,099	Relative's search ( $n = 1$ )	0,01,843,318
Precipitation increases ( $n = 7$ )	0,098,585,363		

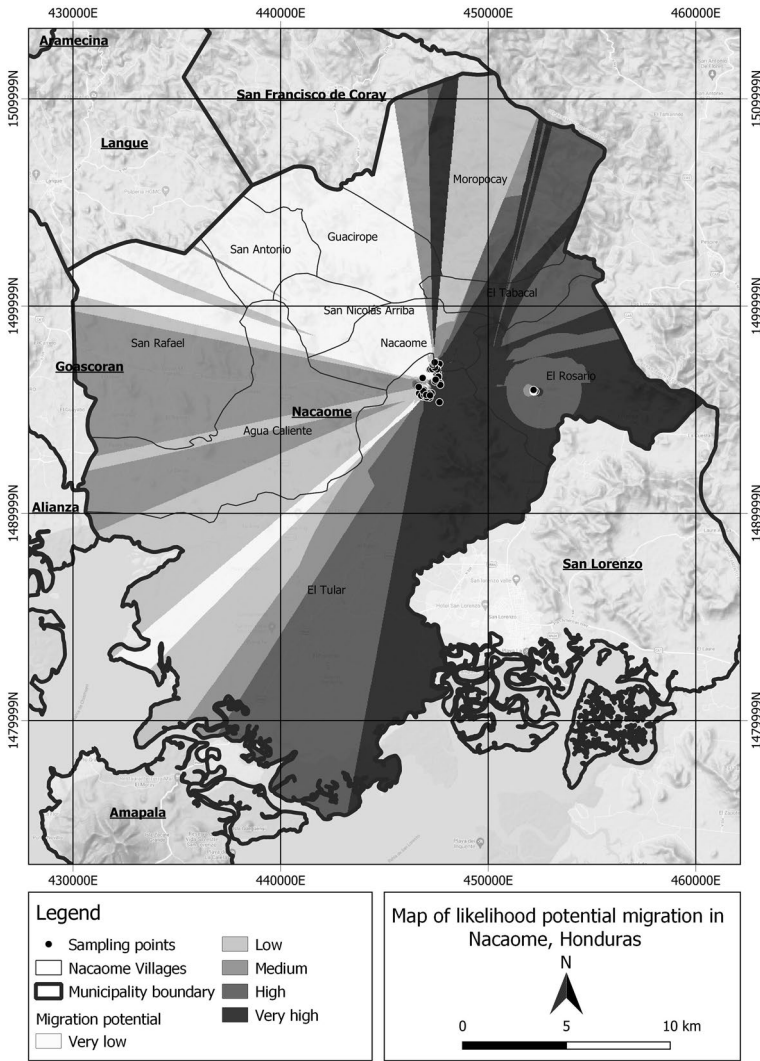
The higher the value, the greater the importance of a given factor in deciding whether to migrate for Nacaome's residents. The factors with '\*' passed the minimum one-fifth threshold, the 'n' values represent the frequency

#### 4.4 Determining factor weights using BWM

The analysis of the factors pairwise comparison of the BWM method indicates that the factor that was most frequently identified in the "Best" position (factor with the highest potential for leading to migration) is the factor *Unemployment* ( $n = 34$ ). On the contrary, the factor that the interviewees most frequently identified as "Worst" (factor with the lowest overall migration potential) is the factor *Heatwaves* ( $n = 8$ ) (Table 12).

The BWM results indicate that the factor with the highest weight value of all the factors corresponds to *Vacations* (weight: 0.255), followed by *Property Sales* (weight: 0.243), while *Unemployment* (weight: 0.225) appears in third place (Table 11).

However, many factors did not pass the threshold of one-fifth, indicating a frequency of selection greater than  $n \geq 11$  and yet appear with substantial weights, such as *Vacation*. Based on this threshold, in descending order, are the factors with the highest level of importance given their weight within the BWM. Following *Unemployment*, we found *Job opportunity* (weight: 0.167), followed by the factor *Higher income* (weight: 0.159), in the fourth position is located *Not enough income* (weight: 0.143). In position number five is



**Fig. 5** Map of the likelihood of potential migration in Nacaome, Honduras. The five-color scale represents the likelihood of migration potential. Own development

the factor *Floods* (weight: 0.112), then the sixth factor with the highest potential to induce migration is *Droughts* (weight: 0.110), followed by *Violence* (weight: 0.095), and finally, *Insecurity* (weight: 0.092) and *Heat waves* (weight: 0.078) (Table 12).

Considering that the Consistency Ratio ranges from 0 to 1, where 0 represents maximum consistency, the overall performance of the models assessed through this ratio showed a high level of reliability and very high consistency with an overall average value of 0.09, a maximum value of 0.45 and a minimum value of 0.03. This indicates that the model notably captures the decision-making process of individuals, reflecting the excellent performance of the BWM for the evaluation and calculation of the factors weights.

#### 4.5 Likelihood of internal and external potential migration in Nacaome

The likelihood map presents a color scale from blue to red, where red represents very high migration potential values. Conversely, green gives medium values of potential migration, and blue displays low potential. Thus, the map shows that within the municipality of Nacaome, there are various levels of migratory potential. Despite this, certain zones tend to be relatively evenly distributed. For instance, the eastern region of the municipality has high levels of migration potential that overlap with the predominant agricultural production areas. In contrast, lower levels of migration potential characterize the western part, which is distinguished by having fewer cultivated areas and more forest cover (Fig. 5).

The likelihood map of potential migration in Nacaome using the Best–Worst method (BWM) and a combined spatial-cognitive individual decision-making model displays findings on individual-level factors' preferences to help us understand and assess what currently and potentially promotes human migration in areas highly vulnerable to climate change. The data reveal the spatial disaggregation of different responses to the myriad of factors involved in the migration decision-making process and reveal that not all individuals or communities at risk tend to migrate, even at the municipal scale.

### 5 Discussion

We analyzed the key factors driving internal and external migration decision-making in Nacaome, thus displaying the potential that people can migrate from Nacaome internally (to other parts of Honduras) and externally (to outside of Honduras). The findings point to economic and social factors as key determinants of migration. Conversely, environmental and climate change-related effects are only considered tertiary elements in the decision process. These findings indicate that, for Nacaome, climate change and migration do not appear to have a cause-and-effect relationship in which climate generates vulnerability and people move to avoid and cope with these impacts. On the contrary, the complexity of climate change-related migration means that approaches looking for causality and correlations alone cannot unravel and explain this nexus. Hence, approaches like ours are needed to capture the different factors influencing migration, determine their influence, and capture the diversity of people's decision-making processes considering whether to migrate. Our work contributes a novel approach to understanding the drivers of migration and the relative roles of climate and environmental change and social-economic development factors in migration decision-making.

Our analysis encountered high poverty levels, low education rates, and unemployment. Family networks and social capital motivated by economic factors mainly supported international and domestic migration patterns. Similarly, studies suggest that the preponderance of social and economic factors mainly affects and delimits migration patterns in the Dry Corridor (Reichman, 2022). These results are consistent with studies suggesting that social and economic factors' preponderance mainly affects and delimits Dry Corridor's migration patterns (Reichman, 2022). The Corridor has been negatively affected by the development and implementation of large agricultural and shrimp enterprises that have affected rural land use and household decision-making (Reichman, 2022). Analyses indicate that changes in rural livelihoods and the loss of land security and tenure, together with these agribusinesses' appropriation of land and natural resources, pushed poor farmers and villagers into

landlessness or marginal lands (Quijada & Sierra, 2019). Exacerbating structural inequalities leading to more precarious living situations and living with high economic, social, and environmental vulnerability possess incentives to migrate since they have limited capacity to employ in situ adaptation capacities (Delazeri et al., 2022).

Our study points to heterogeneous responses between climate and migration, demonstrating no linearities in the nexus but rather a loop of multiple interactions that underlie it. The influence of economic and social factors such as unemployment, low income, and insecurity on migration is far less novel (de Haas, 2011; Haas, 2021a, 2021b). However, our case study in Nacaome contributes by illustrating how environmental factors are not considered essential and can be classified as underlying the influence of migration. One reason could be that economic asset deterioration due to environmental changes is not perceived as detrimental but beneficial. For instance, increased rainfall can improve crops, promote yield generation and induce water stress due to excess rainfall (Gray & Bilbrow, 2014).

Our results have important implications for migration and non-migration associated with climate change studies. They highlight the significance of economic factors in the decision to migrate due to the “feedback loop of capital accumulation, impoverishment, and environmental degradation” (Biel, 2006). We illustrate the need to understand the process and ranking of the factors involved in the decision to migrate to climate change; expanding the analysis to factors beyond environmental ones is necessary, considering local realities, their relationship with their natural environment, and the process of how people make decisions (Mallick & Mallick, 2021; Mallick et al., 2022; Wiegel et al., 2019, 2021).

Our analysis also reported significant differences in the factors that may promote migration between men and women. Studies indicate that women migrate more for environmental factors than men (Awiti, 2022; Bleeker et al., 2021; Evertsen & van der Geest, 2020). It has also been found that the effect of crop failure tends to reduce household mobility, and indirect exposure increases it in women. Birk and Rasmussen (2014) argue that women are more likely to use their family networks and other social capital coping strategies to mitigate their exit from poverty to reduce climate vulnerability. The main differences in the decision to migrate between these groups are due to a lack of property rights and domestic and reproductive roles that impose time constraints on women’s participation in non-agricultural employment. Women often lack equitable access to land, credit, financial assets, information, and agricultural technologies, and their ability to diversify options to cope with the adverse impacts of climate change (Ratha et al., 2011). Therefore, our results can contribute to the debate and formulate connections between the dynamics of climate risks and gender-differentiated impacts and the development of gender-differentiated asset or capital poverty traps that may affect women more and thus promote differentiated ideas of migration factors (Awiti, 2022; Farbotko et al., 2020; Parsons, 2019; Parsons & Nielsen, 2021).

This research provides the first multi-criteria analysis of the decision-making process of potential migrants at the local scale in an area highly vulnerable to the effects of climate change, thus allowing us to deepen the debate and understand the link between climate change and migration. The model’s main advantage is that it allows a spatially explicit representation of the variation in migration potential within the municipality. It also demonstrates that there is no single driver of migration but rather a myriad of multiplicative and interacting factors that can influence the cause of migration, challenging the dichotomous understanding of climate migration and non-migration in areas highly vulnerable to this phenomenon. Stressing the multiplicity and diversity of responses and perceptions to climate impacts by local communities and how people experience these

impacts at the individual level and make decisions to cope with them. While the prevalence of one factor over another is relative and depends on each individual's assessment and preference, migration is always the result of a complex combination of macro- and micro-factors acting on each other at different scales and processes (Castelli, 2018; Parsons & Nielsen, 2021; Till et al., 2018).

Our spatially explicit model reveals that high migration potential is consistent with areas with a more significant presence of crop and fish farming activities and where agricultural activity is a critical economic activity for household sustenance in the municipality (Birk & Rasmussen, 2014; Black et al., 2011). The use of multi-criteria analysis in assessing climate change mitigation policies has shown that it is a tool that can potentially support community participation and transparency in climate change adaptation policy (Konidari & Mavrakakis, 2007; Malczewski & Rinner, 2015). More generally, our results are consistent with suggestions made in previous studies, based on different gravity models, of the effects that specific economic, social, climatic, or other factors may have on future migration. It thus leaves implicit that people are motivated by individual cost-benefit calculations to maximize income or utility and will therefore react instinctively and predictably to external stimuli or factors. They operate through perceptions and preferences and choose between different options. Furthermore, our research addresses how people's perceptions of economic, social, and cultural resources determine their ability to move or stay (de Haas, 2021a, 2021b; Streimikiene & Balezentis, 2013).

## 6 Conclusion

Migration decision-making dynamics are characterized by social, economic, environmental, political, and demographic factors. This study assessed how various factors affect and influence the decision-making process of potential migrants due to climate change, as well as how people prioritize and value them when deciding whether to move. In order to do this, we designed a spatially explicit multi-criteria model that enabled us to assess the variables that impact an individual's choice to move and to spatialize the regions with the most significant potential for migration. Our findings and model also clarified this link at the local scale and individual level, potentially offering launching pads for creating public policies on social, economic, and environmental vulnerability and aiding in achieving the SDGs. The knowledge gathered using this method can help with program creation, priority setting, and policy formulation to lessen the underlying vulnerabilities of local populations. Furthermore, we contend that it is essential to encourage academics and decision-makers to concentrate on identifying the elements that influence climate migration at the local scale in order to prevent the loss of specificity of indicators assessed at the regional or national level, such as personal circumstances, local networks, mobility capacity, and resources. Hence, our research highlights that local characterization of potential climate migrants and resulting nodes of changing vulnerability can inform the development of targeted policy interventions to reduce climate-induced migration.

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**Author contributions** MC-V was involved in conceptualization, methodology, and formal analysis and investigation; MC-V, JCBJ, and JB contributed to writing—original draft preparation; MC-V, JB, JCBJ, EH-O, DM-M, IL-A were involved in writing—review and editing; IL-A contributed to funding acquisition; IL-A, MC-V was involved in supervision.

**Data availability** The data that support the findings of this study are available from the corresponding author, upon reasonable request.

## Declarations

**Conflict of interest** The authors declare no competing nor potential financial conflicts of interest regarding this article's research, authorship, and publication.

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