*Original Research Article*

CLIMATE CHANGE, POVERTY MIGRATION AND SECURITY IN MEXICO

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ABSTRACT

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| The perception that migration will be the most likely and most serious consequence of climate change, with large numbers of people migrating long distances, has not been sustained. Various analyses suggest that, although climate impact can affect population movement, in addition to many other expulsion and pull factors, most migration is internal and not permanent. Various studies on migration suggest that, although climate change is not a direct cause of migration, it can be a variable that influences poverty, which would translate into the migration of people.The objective of this work was to develop a quantitative model to show the statistical significance of the links between climate change, poverty and migration. Methodology: An econometric Multinominal Logit Model (MLM) was developed that offers a platform to explore the impact of climate change on poverty and migration, with results at the national and regional levels using local climate and demographic data as key factors. This model is not intended to be a predictive tool that yields absolute numbers of poverty, migrants and their destinations. It represents a resource that econometrically shows the effect of both demographic and climatic variables on the decision to migrate both internally and externally.Results: The results of the MLM show that climate variables are key and statistically significant determinants in the decision to migrate. With the evidence shown here, it can be said that Mexico is going through notable climatic changes in the midst of a variety of climatic events, such as floods, droughts and hurricanes, whose intensity and frequency are showing an upward pattern. Some states and cities are more at risk than others. Thus, climate change in Mexico affects many sectors: industrial, agricultural, water, energy, health, security; and migration within and across borders. The quantitative results represent an advance in the identification of the complex relationship between the possible effects of climate change, the various productive activities, mainly in rural areas, and the decisions to migrate in Mexico. Conclusion: The results of the MLM model in Mexico show that temperature and precipitation are key and statistically significant factors in the decision to migrate. Decision-makers have in this analysis a first outline towards a quantitative understanding of the relationship between climate change, poverty, migration and security.  |

*Keywords: Climate change, Poverty, Migration, Security, Mexico, Econometric model.*

1. INTRODUCTION

Migration is a characteristic trait of human beings throughout history. It has been driven and influenced by a variety of factors: from collapses and social conflicts, to the search for less hostile environments and better economic conditions. People have also moved from one climate zone to another in search of stability, security, and prosperity. For several decades, natural variations in the environment and anthropogenic contributions to climate change have been correlated with the frequency, intensity, spatial and temporal extent of extreme weather events (Allen et al., 2012). Anthropogenic effects are typically related to rising temperatures and sea levels; and changes in precipitation patterns, and as a consequence, changes in migratory patterns and population displacement. If current patterns continue, and the estimates of the Intergovernmental Panel on Climate Change (IPCC) become reality, global temperature is expected to rise by at least 2°C by the end of the century, placing Climate-Induced Migration (CIM) at the top of the international agenda (de Sherbinin et al., 2011).

In addition to economic reasons, other factors are behind the decisions to migrate, such as the desire to improve education levels; finding better social and cultural environments; places with low levels of violence and political instability; family reunification; and recently environmental factors. In general, research on migration has highlighted social, economic, cultural and political aspects, leaving environmental factors aside, even in regions that are highly dependent on natural resources. Thus, it is important to consider how the environment brings a new dimension to the determinants of migration.

Rural areas in less developed countries have millions of households that depend daily on the natural resources of their local environment, such as raw materials for productive activities and for direct consumption and livelihoods. Therefore, the decrease in these resources, potentially derived from climate change, would have a direct impact on decisions to migrate. There is a growing consensus that Greenhouse Gases (GHG) emissions, caused by human activity, are altering the Earth's climate, with changes in temperatures, precipitation levels, sea level rise, and increased frequency and occurrence of extreme weather events. So, it is feasible that climate-related changes can accelerate migration.

Various factors have been proposed to determine the relationship between climate change and migration, these different perspectives include economic, demographic and social aspects. Thus, the lack of high-resolution climate data has limited the integration of the climate perspective, in fact, most migration-related research does not consider any environmental factors. Studies, such as the EACH-FOR project (European Union) affirm that there is a relationship between environmental degradation and migration in Mexico; for example, erosion and changing rainfall patterns were significant ejection factors for migrating (Warner et al., 2011).

The migratory phenomenon is complex and intertwines demographic, social, political, economic, and environmental expulsion and attraction factors, as shown in Figure 1 which shows that a person's decision to migrate is influenced by a wide and complex variety of issues at the macro, meso, and micro levels. Breaking down this complex process into the elements that constitute it, and quantifying its weighting in the decision to migrate, is not a simple process. A detailed quantitative analysis would confirm that environmental factors, such as precipitation and temperature changes, are determinants in the decision to migrate, providing the first steps towards a deeper understanding of the influence of environmental factors.

The challenge of this work is to develop a model with this complex scenario, in an adequate and comprehensive way, to determine the way in which these relationships occur at the time of making the decision to migrate. As shown in Figure 1, there are social, demographic, economic, political, and environmental factors involved in this decision. Ignoring any of these aspects could lead to erroneous results, when climatic variations mainly affect people where natural capital is one of the main sources of income

**Fig. 1 Conceptual framework of the determinants of migration**.

Spatial +/temporal variability & difference in source and destination.

The influence of environmental changes on drivers

**MACRO**

**MICRO**

Personal/household characteristics

Age, Sex, Education, Wealth, Marital Status, Preferences, Ethnicity, Religion, Language

DECISION

**MESO**

Intervening obstacles and facilitators

Political framework, Cost of Moving, Social networks, Diasponic links, Recrutement agences, Technolgy

Migrate

Stay

Gradual

Current

Sudden

Perceived

The concept of climate-induced migrants, originally called "environmental refugees," was introduced in the 1970s by Lester Brown of the World Watch Institute (Saunders 2000). For his part, Essam El-Hinnawi of the United Nations Environment Programme (UNEP) published in 1985 the first formal definition of the term "environmental refugee" (Essam El-Hinnawi, 1985). Jacobsen presented the first estimate of the number of "environmental refugees" and highlighted the potential role that climate change may play in the displacement of people in the future (Jacobsen, 1982).

In 1990, the IPCC indicated that the "greatest impact of climate change could be reflected in human migration, with millions of people displaced by natural disasters, coastal erosion, coastal flooding and disruptions to the agricultural industry" (Brown, 2008). Between 2007 and 2009, migration and displacement were recognized in UNFCCC process, which culminated in paragraph 14(f) in the 2010 Cancun Adaptation Framework, a call to "enhance understanding, coordination and cooperation with respect to climate change, induced displacement, migration and planned relocation". In 2014, the IPCC Special Report Controlling the risks of extreme events and disasters to improve adaptation to climate change, indicated that "disasters related to extreme weather influence the mobility and relocation of the population, which affects communities of origin and destination. The IPCC's fifth and sixth reports present a subchapter on CIM.

Consensus is beginning to be generated those changes in the climate are impacting human mobility and that this process will continue and increase in the future. However, the understanding of the magnitude of these effects is poor, probably due to the complexity of the process, the lack of reliable and complete data, and even the definitions of basic terminology. Estimates of the number of people globally affected by CIM vary greatly, ranging from 25 million to 200 million by 2050 (Izazola, 1997, Myers, 2002). These figures are in line with those of the International Organization for Migration (IOM) and the Stern Review (Stern, 2006). However, care should be taken with these figures, as some have described them as simplistic, and in addition, there is no general consensus on the categorization of the people affected. Some call them "climate refugees", while others call them "environmental migrants" or "environmentally motivated migrants" (Warner et al., 2009). IOM defines a climate change migrant as an environmentally displaced person or an environmental migrant as ‟persons or groups of persons who, for compelling reasons of sudden or progressive changes in the environment resulting from climate change that adversely affect their lives or living conditions, are forced to leave their usual homes, or choose to do so, either temporarily or permanently, and those who move, either within their country or abroad".

Some researchers reject the notion of CIM, describing the process instead as a "traditional coping strategy." For them, human mobility is a "response to spatio-temporal variations in climate and other conditions, and not a new phenomenon derived from having reached a physical limit" (Black, 2012). They propose that the root of displacement originates from the effects of human-induced environmental degradation derived from inadequate environmental management, lack of sustainable development and development inequities at the global level, and not from natural hazards and climate change. Although human mobility due to environmental changes is not new, anthropogenic climate change, together with extreme weather events, are aggravating the phenomenon, which is also affected by the inadequate and deficient management of natural resources, which induce migration.

Research on migration is not sufficient to support that climate change is a direct or exclusive cause of large-scale migration. Thus, it is necessary to identify the factors indirectly related to climate change capable of inducing the migration of people.

Based on the above, the climatic factors of human mobility are separated into environmental processes and events. Environmental events refer to rapidly developing climate-related natural disasters, such as hydrometeorological events and landslides where people are temporarily displaced, followed by a period of reconstruction and recovery, with eventual return to the point of origin. These natural disasters that trigger human displacement do not have a causal link to global warming and can occur independently of climate change. However, their frequency and intensity can be aggravated by environmental changes. The displacement of people due to social unrest, violence and conflict also falls into this category. In 2008 globally, 36 million people were displaced by rapidly developing natural disasters. Of these, more than 20 million were displaced [internally] due to climate-related disasters, and 16 million were displaced [internally] due to non-climate-related disasters (IDMC, 2009).

On the other hand, environmental processes refer to indirect and slow-developing events (changes in weather patterns) that contribute to sea level rise, salinization of agricultural land, droughts and desertification, water scarcity and food insecurity, among others, which gradually deteriorate the sustainability of goods related to the environment. Since the 1990s, migration has been considered to stem from a decline in agricultural production, water availability, and damage to physical infrastructure (Myers and Kent, 1995). In this case, the decision to migrate more permanently might not be made immediately; however, when in-situ adaptation becomes impossible and competition for natural resources intensifies, entire families and communities can relocate to safer and more productive areas, most likely at short distance, rather than long-distance migration across borders (White, 2010).

CIM has the potential to exacerbate challenges related to the vulnerability of populations in general and migration in particular. Alternatively, it can also be seen as an adaptive response and could present significant opportunities, such as income diversification and remittance flows (Kälin and Schrepfer, 2012). Migration as an adaptation to slow-developing disasters, or to sea-level rise, could be long-term or short-term, temporary or permanent, internal or transboundary (Penz, 2010). In the case of rapidly developing disasters, migration as an adaptation measure may be mainly seasonal or temporary. However, and contrary to the notion of migration as an adaptation measure, low-income communities (poverty) do not have the economic resources and tend to lose mobility. At best, low-income families can relocate locally, while people with greater economic resources are in a better position to migrate longer distances, including across borders. As mentioned above, migration is multi-causal, and many dynamics are a key element in the decision to migrate, including family ties, gender, religion, community aspects, household differences and land ownership.

Once migration has occurred, the relocation process is complex and difficult for migrants and hosts. The Impoverishment and Reconstruction Risks model highlights eight risks to consider when relocating; not owning land, unemployment, homelessness, marginalization, food security, increased incidence of disease and loss of access to resources (Cernea, 2000).

Rapid urbanization in densely populated areas can increase people's vulnerability by concentrating populations in higher-risk areas, such as coastal areas, areas exposed to drought or flooding, and overpopulated areas vulnerable to future environmental changes. The most exposed areas are occupied by the poorest in society who cannot afford housing in sheltered and properly maintained neighbourhoods, and they will bear most of the related risks. This situation is evident in the urban peripheries, which are increasingly occupied by legal and illegal settlements, commonly inhabited by migrants displaced to the peripheries of the city, very poor people who are displaced and people who moved due to rising rents. Higher levels of CIM could increase the number of informal or illegal settlements as people move from rural to urban areas in search of work.

It is important to consider that some people have the means, but not the desire to migrate (immobile), while others wish to migrate, but do not have the economic means (trapped). Many of the most affected people are immobile and simply do not migrate, even when their homes are seriously damaged or completely destroyed; Many will instead choose to rebuild their homes in the same location. Rural communities and indigenous populations are often more reluctant to migrate, since their lifestyle and roots in their place of origin are sometimes stronger than the desire to seek a better quality of life; They may consider what they already own to be a "good quality of life," not what they might get elsewhere.

Climate change can trap people who do not have the economic capacity to respond to environmental changes: by damaging certain goods, migration becomes difficult. For example, the reduction in land quality results in crop losses, less income, and the absence of capital needed to migrate. Thus, the poorest people (in rural areas and large cities), who are likely to be at risk from climate change, will have the least ability to migrate and will be trapped in potentially dangerous areas vulnerable to climate risks.

It has been suggested that climate-induced resource scarcity can lead to conflict, which indirectly causes CIM and aggravates tensions in destination communities. Other hypotheses suggest that CIM rarely leads to conflict; although "unstable urban and rural demographics are associated with increased risks of civil war, and low-level community conflicts are common during periods of environmental stress."

In 2003, a report predicted that, due to environmental degradation, the United States of America (USA). would have to strengthen its border controls to "stop the migration of people with dietary deficiencies from the Caribbean, Mexico, and South America" (Schwartz and Randall, 2003). Subsequent reports reported that climate change poses a threat to national security, and CIM is one of the most concerning issues related to temperature and sea level rise (Campbell et al. 2007). It also suggested that the migration of hundreds of millions of people could trigger significant security risks and increase regional tensions (Steiner, 2009). In 2010, the Pentagon identified climate change and the CIM as security threats to the USA. In 2009, the NATO Review predicted a bleak future regarding environmental degradation and its impact on migration. In 2010 an article published in Defence News, warned that "water and food shortages caused by climate change could lead to changes in migration patterns in areas where tensions are already high. With 600 million people in the world living within 10 meters above sea level, rising sea levels could cause mass displacement of people, and could devastate crops and property (Morisetti and Dory, 2010). In 2011, the Security Council discussed climate change and security, concluding that it could exacerbate existing international security threats. In addition, he indicated that environmental changes, such as sea level rise and related land loss, could have security implications.

Some authors suggest that climate change can aggravate existing tensions and contribute to new conflicts (Klare, 2000). A persuasive correlation has been found between civil conflicts and the global climate. Based on data between 1950 and 2004, climate change and civil instability were correlated, during the El Niño/Southern Oscillation (ENSO) years, the likelihood of civil conflict in the tropics doubled. ENSO may have played a role in more than 20% of all civil conflicts since 1950: not as the sole cause, but as a contributing factor (Hsiang et al., 2011). The effects of ENSO can be seen as climate change as a threat multiplier, as high temperatures and related droughts can lead to famine and damage to agricultural and non-agricultural economies. Other studies suggest that fluctuations in environmental conditions stress the human psyche, leading to aggressive behaviors and increasing the likelihood of conflict. Concurrent climate-related impacts can reinforce each other to generate "vicious cycles" of increasing vulnerability that can be difficult to predict and could create worsening challenges (Feakin and Depledge, 2010). Migration in general could increase existing social tensions, as local people may resent transient opportunistic migrants. This in turn can lead to greater border security and more rigid policies to prevent outside groups from accessing local resources. Underdeveloped countries are susceptible, due to their geography, agricultural dependence, high rates of population growth and urbanization that put more pressure on infrastructure and over-demanding resources (Stern, 2006).

Migration in Mexico

Migration is a feature of modern Mexico, and it seriously affects its stability, prosperity, and political relations with its neighbors. Migration flows to and through Mexico are not new; however, the expulsion and attraction factors that control these movements are becoming more and more complex. The migration of people can occur during periods of economic crisis, violence, persecution, natural disasters, and the depletion of natural resources that results in the loss of fertile land and livelihoods of communities (Herrera-Lasso and Artola, 2011).

Migration from Mexico, both legal and illegal, is related to people seeking opportunities to improve their economic situation and quality of life, and to sustain the well-being of families who remain in Mexico, protecting their property and mitigating the effects of unemployment (Yunez-Naude and Mora-Rivera, 2010). The USA has historically provided such opportunities, and continues to be the primary destination for Mexican migrants. As of 2010, 12 million Mexicans lived in the USA (Alba, Castillo, & Verduzco, 2010). Estimates for the year 2030 are 22 million Mexicans living in the USA (Corona and Tuirán, 2002). Migration tends to be seasonal (circular migration), with large flows to the USA in spring-summer, and large flows back to Mexico in fall-winter (PEW Research Centre, 2009).

Mexico has and will have internal migration as individuals, families, and entire communities move from rural to urban areas in search of a better quality of life, more job opportunities, social stability, and better security: all act as motivating factors. Large cities have been a magnet for migration during the twentieth century, but in the last 20 years, medium-sized cities in the center, west, and north of the country have received large flows of migrants from other parts of Mexico and from countries in Central and South America (Cruz Piñeiro, 2010).

Internal migrants to the northern border usually come from Jalisco, Michoacán, Guanajuato, and recently, from Chiapas, Veracruz, Oaxaca, and Guerrero. In 2008, 2.09 million people migrated to northern cities, but in 2008 and 2009, migration flows began to decline, from 2.08 million to 1.59 million. International migrants arriving in border cities decreased from 1.18 million to 735,000; and Mexican migrants from the south who arrived in the north decreased from 902000 to 835000 (Cruz Piñeiro, 2010).

According to statistics from the National Institute of Statistics and Geography and Informatics (INEGI) in 2023, 3 million people ≥ 5 years of age lived in different locations in June 2018. The data show a decrease in migration flows to the north of the country; however, many border cities are overcrowded and migrants face problems of housing and job opportunities, due to lower productivity in the maquiladoras (Cruz Piñeiro, 2010).

Finally, the CIM does not constitute a military threat, but depending on the reception of migrants in the destination areas, tensions could arise, or worsen, in the social or political systems; The most exposed systems are industry, water, food, energy supplies and health. If unemployment and hunger lead to temporary or permanent migration, wages in destination areas would be reduced, as undocumented migrants would accept lower wages.

**2. BACKGROUND**

The sixth IPCC report has concluded that GHGs contribute to and aggravate naturally occurring changes in climate. Over the past century, the Earth's average temperature has risen by 0.75°C, and over the past 25 years, the pace of global warming has accelerated by more than 0.18°C per decade. Calculations by Ramirez et al (2022a, 2022b) predict an average increase in temperature will be between 0.5-5°C in Mexico by the end of this century according to the SSP scenario, where the greatest warming will occur in the north, west and northwest of the country. It has been reported that rainfall could decrease by up to 20.3% during the same period. The effects of climate change are expected to vary from region to region. For example, the tropics are expected to experience more frequent rainfall, and deserts are expected to experience temperature increases while rainfall decreases. It is also reported that, by the 2090s, climate change is likely to expand the area affected by droughts, double the frequency of extreme droughts and last six times longer.

Severe weather conditions and natural hazards are not recent for Mexico, as it has been exposed to climate-related hazards and severe hydrological events throughout its history. Mexico was ranked 49th in the Germanwatch Global Climate Risk Index, 1991–2010 (Harmeling, 2012). It is known that natural hazards are aggravated during extreme weather events, such as those derived from the ENSO phenomenon that alters rainfall patterns, and that causes intense rains that produce landslides and floods. ENSO-related effects can also lead to severe droughts, shortfalls in dam levels, shortages of rainfed crops, water pollution, and poor water quality (Warner et al., 2009, 2011; Bates et al., 2008).

Mexico is exposed to hurricanes on both coasts. According to the Climate Change Vulnerability Index for 2011, most of Mexico (coastal regions) face high to extreme risks due to climate change (Maplecroft, 2011). Coastal states are vulnerable to coastal erosion, saltwater intrusion, storm surges, and sea-level rise in low-lying areas of the Gulf of Mexico and the Caribbean (Ortiz Pérez and Méndez Linares, 1999). Thus, climate change represents a risk for Mexico, since 60% of the population lives on the coasts (BBVA, 2010).

World Bank figures show that between 1997 and 2006, economic losses due to storms and floods averaged 0.17% of GDP, and 3.5 million people were directly affected by hurricanes (World Bank, 2010). By 2023, a total of more than 193000 people were affected by natural disasters in Mexico (ECLAC, 2010).

Rising sea levels could render coastlines uninhabitable, damage or destroy industrial infrastructure, or exceed the capacity of local authorities. The combination of these factors would contribute to the flows of displaced persons, and ultimately to the migration of people to places far from coastal regions. The Gulf of Mexico is a region at risk of rising sea levels, as eight of the ten most important fishing ports and two industrial ports are located there. On the Pacific coast, the port of Manzanillo handles more than 25 million tons of products annually (Statistical Yearbook of Ports of Mexico 2011) and faces the potentially highest economic losses due to rising sea levels. Other especially susceptible areas are the Yucatan Peninsula, Veracruz, Ixtapa and Cozumel.

It is estimated that the greater intensity and variability of rainfall will increase the risk of flooding. Flooding poses safety risks as it can cause drowning deaths and fatal injuries, contaminate clean water, and encourage vector-borne diseases. The Weather Service data across the country, not only in the arid and semi-arid regions of the north and northwest of the country, but also in the south, which has historically been wetter. Arid and semi-arid regions are more vulnerable to desertification, deforestation and land erosion, as the severity of droughts will increase with higher temperatures and more variations in rainfall. In 2024, 88% of the Mexican territory was affected by some type of drought, and 38% by severe droughts. The most affected states have been Durango, Chihuahua, Sonora and Coahuila, followed by Nuevo León, Zacatecas, San Luis Potosí, Aguascalientes and Guanajuato; considering the magnitude of the droughts, Baja California, Sinaloa, Querétaro, Hidalgo and Tlaxcala should also be included in this category (Gaceta Parlamentario, 2012).

The impact of climate change on agriculture and water-intensive industries is expected to be a determinant of climate-related migration, impacting the local economy and the livelihoods of farming families and their businesses. Extreme weather events can cause the sudden and collective displacement of people. This is an immediate, but temporary, response to preserve the well-being and survival of affected communities.

It has been suggested that in Mexico, climate change is affecting human mobility in both the hot and dry states of the north, and in the humid and tropical states of the south. Some already densely populated regions that are attractive to migrants have developed, or will develop, vulnerabilities related to climate change that could be exacerbated by the increased concentration of people with the arrival of migrants. The states of Baja California and Chihuahua stand out as the most vulnerable states due to their high temperatures, low rainfall and high consumption of water and energy. The states of Jalisco, Guanajuato, Michoacán, State of Mexico and Puebla, were also named vulnerable sites, but to a lesser extent. Veracruz and Chiapas are considered to have less exposure to climate change, and rainfall could increase, which would relieve pressure on the hydraulic, energy, and food sectors (Aguilar, 2003). In 2008, two communities in central Veracruz reported that 28% of the population had a household member who had migrated in the previous five years, which coincides with the coffee crisis (1999 to 2003); 61% emigrated to the USA and the rest to regional or national destinations (Tucker, Eakin, & Castellanos, 2010). In the areas of the Sierra and Soconusco in Chiapas there is growing competition and instability in consumer prices, which combined with the frequent passage of hurricanes and tropical storms (increased legal and illegal logging, and large-scale floods and landslides), are accelerating the decision of small farmers to migrate from the affected regions (EACH-FOR, 2012).

Temperature is one of the climate variables that correlates with socioeconomic problems related to climate change. A 2008 World Bank study (Yúnez Naude and Mora Riviera, 2008) found that people living in communities with higher-than-average temperatures during spring and fall are more likely to migrate. However, the likelihood of migrating within Mexico is lower for residents of communities subject to higher-than-average temperatures during the summer. Although tourism can benefit from slightly higher temperatures, the impact on the agricultural industry, which depends on stable environmental conditions, can be problematic. It is estimated that an increase in temperature that produces a 10% reduction in crop production will see a movement of about 2% of people from Mexico to the USA.

Environmental changes influence fundamental health conditions, such as clean air, clean water, sufficient food, and safe housing. The health consequences related to climate change are indirect and derive from the environmental, ecological and social impact of a changing climate (WHO, 2003, 2009). Climate fluctuations in Mexico impact food production, water supply, infection patterns, and vector-borne diseases, as well as the movement of people (WHO, 2003, Gage et al., 2008, McMichael and Lindgren, 2011). High temperatures combined with torrential rains provide the perfect environment for water and food contamination, which causes diarrheal diseases, such as cholera, which can be fatal in children and older adults (INE-INSP, 2006). Diarrhoeal diseases, malnutrition, malaria and dengue fever are very sensitive to climate (WHO, 2003) According to the WHO, in 2004, climate change caused 3% of deaths from diarrhoea, 3% from malaria and 3.8% from dengue worldwide. It attributes 0.2% of deaths in 2004 to climate change, 85% in children (WHO, 2009). Lack of access to drinking water is a cause of morbidity and disease. According to the WHO, 2.2 million people/year die from diarrhea, most of them young children.

Heat waves have a direct effect on health in Mexico, increasing vulnerability, especially in older adults, who are expected to represent 12% of the total population by 2025 (PAHO, 2010). Heat waves also pose a threat to the safety of individuals, as well as entire communities, by increasing the incidence of violent crime. Another effect is the emergence of mental health problems due to climate change in living conditions resulting from lower farm incomes, displacement, or post-traumatic effects when a disaster occurs (Butke and Sheridan, 2010). Thus, climate change will alter public health, disease and mortality patterns, social stability, and geopolitical security (McMichael, 2011).

Changing rainfall patterns are causing more frequent and severe droughts in Mexico. Small-scale farmers who rely on rainfed agriculture will be impacted by increasingly erratic rainfall. The World Bank concluded that communities that experience above-average rainfall during the summer and winter will most likely not migrate. However, if precipitation is above average in the fall, then the probability of migration will be higher. In Tlaxcala, with the onset of the rainy season a month and a half later than 20 years ago, many farmers have been forced to migrate. The decrease in land and desertification affects the agricultural sector in Tlaxcala, they are related to changes in rainfall patterns. In addition, the liberalization of markets in the 90's and less rainfall resulted in less agricultural income, which forced the poorest to migrate (Yunes-Naude and Mora-Riviera, 2010).

On the other hand, climate change may make other areas more attractive for human settlements. For example, some communities may benefit from altered rainfall patterns that cause higher volumes of precipitation to areas that were previously affected by water scarcity, assuming that the infrastructure is in place to manage it (Brown, 2008).

This would be a pull factor for communities seeking arable land and sufficient water supply (German Marshall Fund of the United States, 2010). Such a scenario is very likely in Mexico, currently most of the irrigation infrastructure is concentrated in the north, while the most suitable land for agriculture in the next 20 years is located in the south (Feakin and Depledge, 2010).

A study by the Institute for the Study of International Migration assesses the connection between environmental changes and migration in semi-arid and traditionally emigrant states (Jalisco and Zacatecas). It concludes that migration, mainly to the USA, but also to Mexican urban areas, has been an adaptation mechanism of local communities and households to manage climate variability and to diversify income, which helps the rest of their families to remain in their place of residence. However, the direct causal links between climate change and migration are difficult to identify. Instead, environmental change is a factor in the decision to migrate (Martin & Escobar-Latapí, 2010). Thus, it is concluded that in Jalisco and Zacatecas population movements are caused by drought cycles; along with poor development planning that aggravates deforestation and poor water quality.

3. Material and methods

The model used to determine the link between climate change and migration is an econometric model (multinominal logit model MLM), employing demographic data from the 2020 national census in Mexico, together with detailed climate data provided by the CCKP (World Bank), with the aim of estimating the impacts that climate variables have on migration from Mexico. MLM identifies key variables and their ability to influence the decision to migrate, either within the country's borders (internal) or beyond them (international).

The analysis of the determinants of migration is based on the 2020 Population and Housing Census (INEGI, 2021), which provides a demographic and socioeconomic description of a representative sample of the population of Mexico at the municipal level, and, above all, the distribution of this sample within the country. In addition, atmospheric and data were used to relate changes in population distribution and changes in climate; and the influences of climate change on agriculture, which could be related to changes in population distribution.

The data were divided into population characteristics (sex, age, total, internal and international migration; education, socioeconomic characteristics, health, etc.); and poverty characteristics (type of construction, size and use of space, public services and sanitary facilities, among others). It is estimated that, in 2023, 3.3 of the Mexican population over five years of age had a different place of residence registered than in 2018 (Figure 2). During 2018, the most attractive states to migrate were Baja California Sur, Quintana Roo, Baja California, Querétaro and Aguascalientes; and the least attractive are Guerrero, Mexico City, Chiapas, Veracruz and Sinaloa with a reduction in their population from -2.8 to -1.5% (Figure 3).

**Fig. 2 Percentage of population aged ≥5 years according to the place of 5 years before (ENADID, 2018)**



**Fig. 3 Net migratory balance of ≥ 5 years by state 2018 (ENADID, 2018).**

Regarding international migration, 48.8% are young people of working age, between 20 and 34 years old; while 19.2% belong to a younger age range, from 15 to 19 years old. Migration among people aged 50 and over represents only 5.7% (Figure 4). An additional feature of this phenomenon is that the five states with the highest rate of external migration are Guerrero, Zacatecas, Chiapas, Oaxaca, and Sonora (Figure 5).



Fig. 4 Distribution of percentage of international migrants by age, 2020.



Fig. 5 Percentage of international emigrant population to the USA 2023

In addition to demographic data, atmospheric data (temperature and precipitation) at the municipal level were used. These variables contribute to characterizing the places of origin of migrants. Temperature and precipitation reflect the prevailing climatic conditions. While the characteristics of the land in each municipality, it allowed to consider the influence of climatic variables and evaluate the productivity of the different lands in the decision to migrate. The model seeks to calculate the influence of climate and land variables on a person's decision to migrate.

When using these variables in the model, it should be understood that the climate in any region of the world can be understood as the average climate condition that is observed over a certain period of time. Therefore, climatological normals (thirty-year period) are used to determine the average climate of a region, which includes the average monthly values of atmospheric variables, such as temperature and precipitation, among others. In climate change studies, the period from 1961 to 1990 (data available with the required level of resolution) is used as the base period to calculate the environmental changes in each variable.



**Fig 6 Internal migrants (2023) and internal displacement due to disasters (2008-2023)**

Because of their importance, climatological projections of temperature and precipitation are used in studies to assess the impact of climate change. This information becomes very valuable, as it provides the basis from which it is possible to quantify variations in both precipitation and temperature related to climate change. After selecting the geographical regions of Mexico, and with the base scenario established; The next step is the development of climate change scenarios, choosing the models to generate the information required for climate variables between now and the end of the century.

Considering the IPCC Working Group on Climate Assessment Scenarios and Impacts (IPCC-TGICA), a variety of models have been selected that represent the range of uncertainty, including the approximate range of possible increases in temperature, as well as increases and decreases in precipitation. Therefore, taking into account all the IPCC-TGICA criteria, in this study the CCKP models (World Bank) were used with the IPCC SSP 4.5 and SSP7.0 scenarios (Table 1) since they are the most likely scenarios for the end of this century. Climatologies of current and future average temperatures and precipitation were generated using the base period from 1961 to 1990 (all at the municipal level). In the aforementioned model, calculations were made up to the year 2100 using only the scenario that contains the necessary information resolution, the SSP4.5 emissions scenario (most likely scenario by the end of the century). This procedure is reported by Ramirez et al., in 2022a and b (Table 2).

The socio-demographic variables for the present study were generated from a random sample composed of 25% of the available data sample from the 2020 Population and Housing Census. For the purposes of this study, only people over 12 years of age were considered, since INEGI defines this age as the economically active population, omitting incomplete records. As mentioned above, the meteorological data were estimated by the author and reported in another article (Ramirez et al. 2022a and b).

Table 3 presents the descriptive statistics of the key variables used in this analysis. The data were divided into three categories: individual characteristics, family characteristics, and climatic characteristics generated at the municipal level. In the individual characteristics, it is concluded that gender does not present substantial differences since men represent 48% of the sample. The average age is 37.4 years, but it should be remembered that only people over 12 years of age were included. 35.1% were heads of households, and 53.5% were married.

**Table 1 Changes in global surface temperature. Temperature differences relative to the average global surface temperature of the period 1850–1900 are reported in °C.**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Near term, 2021-2040 | Mid-term, 2041-2060 | Long term, 2081-2100 |
| Scenario | Best estimate | Very likely range | Best estimate | Very likely range | Best estimate | Very likely range |
| SSP1-1.9 | 1.5 | 1.2 to 1.7 | 1.6 | 1.2 to 2.0 | 1.4 | 1.0 to 1.8 |
| SSP1-2.6 | 1.5 | 1.2 to 1.8 | 1.7 | 1.3 to 2.2 | 1.8 | 1.3 to 2.4 |
| SSP2-4.5 | 1.5 | 1.2 to 1.8 | 2.0 | 1.6 to 2.5 | 2.7 | 2.1 to 3.5 |
| SSP3-7.0 | 1.5 | 1.2 to 1.8 | 2.1 | 1.7 to 2.6 | 3.6 | 2.8 to 4.6 |
| SSP5-8.5 | 1.6 | 1.3 to 1.9 | 2.4 | 1.9 to 3.0 | 4.4 | 3.3 to 5.7 |

**Table 2. Anomalies of temperature, precipitation and change of % of precipitation for Mexico according to the different scenarios of the IPCC (2014) SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5 during the present century (regional models).**

|  |
| --- |
| Temperature anomalies in °C |
|   | 2020-2039 | 2040-2059 | 2060-2079 | 2080-2089 |
| SSP1-1.9 | 0.68±0.09 | 0.81±0.08 | 0.70±0.1 | 0.61±0.10 |
| SSP1-2.6 | 0.82±0.06 | 1.19+±0.07 | 1.32±0.06 | 1.25±0.09 |
| SSP2-4.5 | 0.83±0.06 | 1.46±0.06 | 1.96±0.09 | 2.35±0.12 |
| SSP3-7.0 | 0.75±.04 | 1.59±0.06 | 2.49±.11 | 3.49±0.14 |
| SSP5-8.5 | 0.94±0.04 | 1.93±0.05 | 3.14±.08 | 4.54±0.15 |
| Precipitation anomalies in mm |
|   | 2020-2039 | 2040-2059 | 2060-2079 | 2080-2089 |
| SSP1-1.9 | 1.57±5.41 | 2.58±5.83 | 2.27±5.98 | 1.58±5.28 |
| SSP1-2.6 | 1.12±3.39 | 0.28±3.75 | -0.65±3.38 | 0.08±3.75 |
| SSP2-4.5 | 0.12±3.71 | -0.93±4.45 | -2.12±5.00 | -3.40±6.31 |
| SSP3-7.0 | -0.97±2.13 | -3.51±4.64 | -5.92±8.35 | -7.77±11.18 |
| SSP5-8.5 | -1.78±2.56 | -3.32±5.82 | -5.63±8.49 | -9.38±14.07 |
| Changes in % precipitation in mm |
|   | 2020-2039 | 2040-2059 | 2060-2079 | 2080-2089 |
| SSP1-1.9 | -2.60±5.84 | -1.64±5.57 | -1.36±4.94 | -2.90±3.84 |
| SSP1-2.6 | 0.42±3.45 | -0.21±3.62 | -1.27±4.38 | -0.35±4.54 |
| SSP2-4.5 | -0.98±4.48 | -3.10±6.71 | -5.1±6.49 | -5.81±7.59 |
| SSP3-7.0 | -1.46±3.60 | -4.94±6.15 | -8.78±8.94 | -10.59±12.66 |
| SSP5-8.5 | -1.65±4.76 | -4.28±7.57 | -7.63±11.18 | -12.80±16.15 |

Family characteristics showed that the average years of schooling of household members over 12 years of age is 9.8 years. Access to education among Mexican households is very heterogeneous; with people without access to education, up to people with 24 years of schooling (higher education). On average, 3.6 household members are over the age of 15. Despite this, the number of bedrooms in each house is only 2.2 and 98% have access to sanitary services. However, 22% of households do not have drinking water available for domestic use, and on average, 2.2 out of 10 homes do not have a drainage system.

Regarding the climate database, and considering the data at the municipal level of the model used CCKP, the following analysis arises. In the model CCKP for 2023, the average annual temperature is 21.4°C. Regarding the accumulated annual rainfall, the model indicates an average of 763.1 mm/year. The average monthly rainfall is 105.3 mm.

Table 4 presents the socio-demographic characteristics of the sample used, grouped into: 1) non-migrating persons, 2) Persons who have joined the national migratory flow (internal migration), defined as those persons who changed their residence from one state to another between 2005 and 2010, and 3) persons who joined the international migratory flow during the same period.

The average age of non-migrants is higher than those who migrate internally, which, in turn, is higher than those who migrate internationally. A slight majority of non-migrants are women; In contrast, slightly more than 50% of internal and international migrants are men. Households with international migrants have less schooling compared to non-migrants and internal migrants; and they are more proportionally composed of members of working age, as indicated by the number of people over 15 years of age. Indicators of poverty and economic activity were evaluated through variables, such as the number of rooms in the home, and the presence or absence of basic services (water and drainage).

**Table 3** Descriptive statistics of key variables

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Individual features** | **Mean** | **σ** | **Min.** | **Max.** |
| Gender (Dummy, 1 = male) | 0.48 | 0.5 | 0 | 1 |
| Age | 37.41 | 18.525 | 13 | 130 |
| Head of Household (Dummy) | 0.351 | 0.482 | 0 | 1 |
| Marital status of the head of the household (1 = married) | 0.535 | 0.501 | 0 | 1 |
| **Family characteristics** |  |  |  |  |
| Average household schooling | 9.84 | 3.567 | 0 | 24 |
| Number of family members over the age of 15 | 3.578 | 1.752 | 0 | 21 |
| Number of rooms per house | 2.151 | 1.25 | 1 | 12 |
| Sanitary services | 0.981 | 0.425 | 0 | 9 |
| Access to clean water (Dummy) | 0.776 | 0.385 | 0 | 1 |
| Drainage System (Dummy) | 0.777 | 0.425 | 0 | 1 |
| **Climatic characteristics** |  |  |  |  |
| Average Annual Temperature (CCKP World Bank) | 21.4 | 3.527 | 15.03 | 27.8 |
| Total annual precipitation (CCKP World Bank) | 763.1 | 375.3 | 150.2 | 2200.5 |
| Average annual rainfall (CCKP World Bank) | 105.325 | 25.35 | 10.95 | 190.33 |

Simple statistical analysis does not provide clear and precise information on the influence of variables on the decision to migrate. Thus, it is necessary to implement an appropriate method to identify which variables influence the decision to migrate. Therefore, a multivariate regression method, multinominal logit, was used, which controls these correlations in order to obtain the effects of the different characteristics of people, families and their migration.

Table 4 Demographic characteristics of the 2020 census sample.

|  |  |
| --- | --- |
|  | **Fate of migrants** |
| **Individual features** | **No migration** | **Internal migration** | **International migration** |
| Gender (Dummy, 1 = male) | 0.485 | 0.505 | 0.51 |
| Age | 38.225 | 30.43 | 25.27 |
| **Family characteristics** |  |  |  |
| Average household schooling | 7.58 | 8.875 | 6.384 |
| Number of family members > 15 years | 3.578 | 3.276 | 4.698 |
| Number of rooms per house | 2.152 | 1.991 | 2.2 |
| Sanitary services | 0.981 | 0.973 | 0.953 |
| Access to clean water (Dummy) | 0.776 | 0.85 | 0.89 |
| Drainage System (Dummy) | 0.777 | 0.89 | 0.783 |

4. Results

The results of the Multinominal Logit Model (MLM) used to measure the impact of climate variables on the decision to migrate of the inhabitants of Mexico were associated in two parts. First, decisions to migrate are evaluated using a simple logit model with two possible outcomes: non-migrant and migrant (both internally and internationally). Second, the results of MLM are presented in terms of three types of migration: non-migration, internal migration, and international migration.

The coefficients for the key variables are shown in Table 5, which shows the coefficients of total, internal, and international migration using the logit model. The table presents the coefficients of influence of both climatic variables (average temperature and precipitation) and sociodemographic variables (individual, family and household). The coefficients show that both sets of variables play an important role in the decision to migrate. However, in some cases, the effects of these variables differ among the various types of migration.

Total migration

Total migration includes a heterogeneous mix of internal and international migration. The objective was to identify the key variables in the decision that people make when changing residence, regardless of the final destination. Total migration coefficients reveal that, despite this heterogeneity, almost all sociodemographic and climatic variables are important in explaining the movement of people. The following characteristic features were identified: Males show a greater tendency to migrate than females; the probability of people migrating increases with age, but at a decreasing rate, which means that migration is being concentrated in the working-age population; The likelihood for people to migrate increases significantly with the average schooling of family members, the number of people in the household over 15 years of age, and poverty indicators such as access to basic drinking water services and drainage systems; And high temperatures have a positive effect on the decision to migrate, which means: in those places where the temperature is extremely high, there is statistical evidence that a person has a greater reason to migrate.

Internal migration

The coefficients corresponding to internal migration highlight the impact of key variables, and in particular, climate variables, is not uniform among migrants destinations; due to the existence of a huge variety of climates and microclimates throughout Mexico. The results of the Multinomial Logit Model show the following differences in internal migration decisions: Internal migration shows that men are more likely to migrate internally; internal migrants are preferably young and economically productive; higher levels of schooling in a family have a positive and significant effect on internal migration; the variables of poverty levels show that people with the highest poverty levels are more likely to migrate internally; higher average temperatures have a significant positive impact on the decision to migrate; and higher average rainfall has a significant negative impact on the decision to migrate.

International migration

With regard to international migration, the coefficients obtained by the MLM showed the following characteristics: International migrants are preferably male of working age; there is a notable difference in the relationship between education levels and types of migration (internal and international), since unlike domestic migration, higher average levels of schooling in a family have a negative and significant effect on international migration; the number of household members of working age has a negative effect on internal migration, however, the impact is positive in the case of international migration; The decision to migrate internationally increases with household poverty rates, which has a negative and significant effect on international migration. The variables of temperature and precipitation related to international migration are related by more than coincidence. The MLM showed sufficient evidence to suggest that studies attempting to determine the variables that influence the decision to migrate should consider environmental or climatic context variables.

**Table 5 Logit and multi-nominal logit/CCKP models with one and two destinations (SSP4.5)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Total migration** | **Internal migration** | **International migration** |
| Average annual temperature | -0.0464 | 0.082 | -0.315 |
| Average annual temperature (squared) | 0.0008 | -0.0021 | 0.008 |
| Average annual rainfall  | 0.003 | -0.007 | 0.035 |
| Average annual precipitation (squared) | -7.85E-06 | 3.21E-05 | -0.0001 |
| Gender (Dummy, 1 = male) | 0.425 | 0.028 | 1.263 |
| Age | 0.035 | 0.0241 | 0.095 |
| Age (squared) | -0.0007 | -0.0005 | -0.0021 |
| Average household schooling (years) | 0.055 | 0.1211 | -0.1329 |
| Number of members over 15 years old | 0.0634 | -0.125 | 0.3321 |
| Number of rooms per house | -0.25 | -0.3321 | 0.253 |
| Number of rooms per house (squared) | 0.0223 | 0.0334 | -0.065 |
| Access to clean water (Dummy) | 0.0702 | 0.0293 | 0.1539 |
| Drainage System (Dummy) | 0.2599 | 0.361 | 0.152 |
| Constant | -3.756 | -4.52 | -5.354 |

Marginal effects

Using the coefficients in Table 5, and keeping all the independent variables constant at their average value, it is possible to study the marginal effects of each variable in isolation and individually. Marginal effects are a fundamental tool in the representation of the direct impact of each independent variable on the decision to migrate and are expressed in probabilities. One interpretation of the results is to take each variable, increase it by one unit, and observe the potential effect associated with the change in the probability of migrating (Table 6).

For example, with the CCKP model and the SSP4.5 scenario, it is possible to observe that the increase in the average annual temperature of 1°C leads to an increase in the probability of internal migration by 0.0018. The effect is negative for international migration with a change of 0.0008. If we consider the influence of the average annual temperature on any type of migration, the net effect would be positive and equivalent to an increase of 0.001 in the probability of migrating. In the case of precipitation, an increase in precipitation would decrease internal migration by -0.0018, while it would increase international migration by 0.0005 and the net effect on any migration would be -0.0013, in practical terms if rainfall increases, migration in Mexico decreases, but if precipitation decreases, migration will increase regardless of the destination. These coefficients might seem insignificant, but the importance lies in the statistical significance and the sign associated with the coefficients, which show that the relationship between climatic variables and decisions to migrate is not null and is statistically significant.

To understand the practical meaning of these indices, a hypothetical and practical example can be given. In the IPCC's SSP4.5 scenario, an increase in global temperature of between 2.1 and 3.5°C is estimated for Mexico by 2100 and INEGI reports that, in 2024, the economically active population in Mexico is 61 million people. Using this data, the model could predict that internal migration would increase between 230580 and 384300 people by the end of the century as a direct result of rising temperatures. On the other hand, the decrease in precipitation would increase internal migration between 109800 and 219600 people by the end of the century, associated with the decrease in rainfall. The combined effect between temperature and precipitation would estimate an internal migration between 340380 and 603900 people. It must be remembered that these levels of migration assume constant temperature increase, and that Mexico's population will not increase, regardless of all the other contributions of other environmental, social, or economic factors. Therefore, based on these estimates, the relationship between climate change and migration is evident and statistically significant. It should be noted that migration is a multi-causal phenomenon and that climatic variables are only one component of migration. Equally important is the comparison of the influence of temperature with the influence of variables, such as sex, which show significant influence on the decision to migrate. As shown in Table 6, being male increases the probability of national and international migration by 0.00045 and 0.00654, respectively. Therefore, the effects associated with temperature have a greater influence than sex on the decision to migrate internally, while international migration is the other way around.

**Table 6 Marginal Effects of a Two-Destination Multinominal/CCKP Logit Model (SSP4.5)**

|  |  |  |
| --- | --- | --- |
| **Variable** | **Internal Migration** | **International****Migration** |
| Average annual temperature | 0.0018 | -0.00079 |
| Average annual rainfall  | -0.00018 | 0.00005 |
| Gender (Dummy, 1 = male) | 0.00045 | 0.00654 |
| Age | 0.00045 | 0.00015 |
| Average household schooling (years) | 0.0025 | -0.00055 |
| Number of members over 15 years old | -0.00299 | 0.00132 |
| Number of rooms per house | -0.00552 | 0.00028 |
| Access to clean water (Dummy) | 0.0006 | 0.00069 |
| Drainage System (Dummy) | 0.00656 | 0.0006 |

The impact of schooling is positive for internal migration and negative for international migration. International migrants come from households with lower poverty rates, as indicated by the marginal effect calculated for the variable of the number of rooms in the household; The effect is negative for domestic migration, indicating that destinations within the country can be reached at a lower cost, and are therefore more accessible to the poorest people.

Regional effects

Given the diversity of climates and microclimates; and the demographic characteristics of Mexico, it is important to analyze in detail the effects that we find to be statistically significant at the national level with respect to the influence that climatic variables have on decisions to migrate at the regional level.

There is regional heterogeneity in Mexico in terms of access to natural resources, economic capabilities, cultural diversity, and infrastructure. The combination of these factors has different effects on the migratory flow. Considering previous studies on migration, the typical characterization of regional classification based on the flow of remittances from the USA was used. This allows migration flows to be quantified and provides a relative distribution of remittances sent by migrants. In this regard, with reference to the National Survey on Migration on the Northern Border of Mexico (EMIF), the country was grouped into four regions (Ávila et al., 2011):

1. Region traditionally with the highest international migration: Aguascalientes, Colima, Durango, Guanajuato, Jalisco, Michoacán, Nayarit, San Luis Potosí and Zacatecas.
2. Northern Region: Baja California, Baja California Sur, Coahuila, Chihuahua, Nuevo León, Sinaloa, Sonora and Tamaulipas.
3. Central Region: Mexico City, Hidalgo, State of Mexico, Morelos, Puebla, Querétaro and Tlaxcala.
4. South-Southeast Region: Campeche, Chiapas, Guerrero, Oaxaca, Quintana Roo, Tabasco, Veracruz and Yucatán.

Table 7 presents the coefficients for MLM developed for the four regions. According to data from the CCKP climate model (SSP4.5), the average annual temperature is statistically significant for internal migration; negative in the North region and positive in the Central region. In the case of international migration, this variable is positive and statistically significant in the Central, Traditional and Southern regions, while it is also negative for the North region.

The average annual rainfall has a positive impact on the probability of internal migration in the Traditional and South-Southeast regions, and a negative impact in the North and Central regions. With respect to international migration, the impact of average annual rainfall is negative and statistically significant in all regions.

Considering the marginal effects at the regional level (Table 8), it is possible to show that the impact of an increase in the average annual temperature of 1°C would cause different effects on internal migration in the different regions, a positive impact of 0.16 in the Central region, 0.2379 in the South-Southeast. In the North and Traditional regions, the impact would be -0.653 and -0.185, respectively. The impact on international migration would be different: positive in the Traditional and Central regions (0.0061 and 0.0282), and negative in the North and South-Southeast (-0.0015 and -0.000015). On the other hand, the increase in average annual precipitation by one unit has a negative impact on internal migration in the North and Central regions, of 0.0501 and 0.0336, respectively; and a positive impact in the Traditional and South-Southeast regions, of 0.113 and 0.0403.

Based on the results of the MLM, it is possible to indicate that, in the present study, evidence has been found to suggest that climate variables are key and statistically significant determinants in the decision to migrate.

With the evidence shown in the present study, it can be concluded that Mexico is going through notable climatic changes in the midst of a variety of events such as floods, droughts, hurricanes, whose intensity and frequency are showing an upward pattern. Some states and cities are at greater risk than others, this situation is emphasized by the impact of climate change that is affecting many sectors such as industry, agriculture, water, energy, health and as a consequence the displacement of people within and beyond borders.

**Table 7 Multinominal logit/CCKP two-destination model (SSP4.5) at the regional scale**.

|  |  |  |
| --- | --- | --- |
|  | Internal migration | International migration |
| Variable | Traditional | North | Center | South | Traditional | North | Center | South |
| Average annual temperature | -0.100 | -0.423 | 8.521 | 0.140 | 0.351 | -0.095 | 1.935 | 0.006 |
| Average annual temperature (squared) | 0.001 | 0.009 | -0.250 | -0.007 | -0.008 | 0.006 | -0.043 | -0.003 |
| Average annual rainfall | 0.059 | -0.035 | -0.022 | 0.021 | -0.060 | -0.028 | -0.250 | -0.006 |
| Average annual precipitation (squared) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 |
| Gender (Dummy, 1 = male) | 1.441 | 0.786 | 1.610 | 1.630 | 0.032 | -0.021 | -0.025 | 0.130 |
| Age | 0.058 | 0.088 | 0.15 | 0.17 | 0.025 | 0.02 | 0.0135 | 0.05 |
| Age (squared) | -0.001 | -0.002 | -0.003 | -0.003 | 0.000 | 0.000 | 0.000 | -0.001 |
| Average schooling (years) | -0.091 | -0.001 | -0.13 | -0.15 | 0.13 | 0.065 | 0.098 | 0.11 |
| Number of members over 15 years old | 0.35 | 0.475 | 0.295 | 0.275 | -0.115 | 0.001 | -0.175 | -0.15 |
| Number of Rooms/House | -0.0125 | -0.04 | 0.15 | 0.45 | -0.377 | -0.605 | -0.315 | -0.252 |
| Number of Rooms/House (squared) | -0.041 | -0.032 | -0.045 | -0.07 | 0.033 | 0.055 | 0.031 | 0.03 |
| Access to clean water (Dummy) | 0.19 | 0.575 | -0.0125 | 0.225 | 0.075 | -0.234 | -0.18 | 0.075 |
| Drainage System (Dummy) | 0.31 | 0.45 | 0.162 | 0.097 | 0.35 | 0.333 | 0.333 | 0.33 |
| Constant | -533 | -4.51 | -80.4 | -10.332 | -4.003 | -1.957 | -2.27 | -2.251 |

Table 8 Marginal effects in two-destination multinominal/CCKP logit models (SSP4.5).

|  |  |  |
| --- | --- | --- |
|  | Internal migration | International migration |
| Variable | Traditional | North | Center | South | Traditional | North | Center | South |
| Average annual temperature | -0.185 | -0.653 | 0.16 | 0.2379 | 0.0061 | -0.0015 | 0.0282 | -1E-05 |
| Average annual rainfall  | 0.113 | -0.0501 | -0.0336 | 0.0403 | -0.0009 | -0.0004 | -0.004 | -0.0001 |
| Gender (Dummy, 1 = male) | 0.014 | 0.0025 | 0.0058 | 0.0048 | 0.00029 | -0.00045 | -0.0008 | 0.0019 |
| Age | 0.1152 | 0.157 | 0.292 | 0.3245 | 0.00033 | 0.00018 | 0.00023 | 0.00075 |
| Average household schooling (years) | -0.00065 | -4.5E-06 | -0.00024 | -0.0003 | 0.0019 | 0.0018 | 0.0028 | 0.0019 |
| Number of members over 15 years old | 0.0032 | 0.0018 | 0.0009 | 0.0007 | -0.0025 | -5E-06 | -0.004 | -0.0018 |
| Number of Bedrooms/House | -0.1605 | -0.2003 | 0.057 | 0.5013 | -0.0042 | -0.0078 | -0.0035 | -0.003 |
| Access to clean water (Dummy) | 0.0018 | 0.0017 | -2.2E-05 | 0.00058 | 0.0012 | -0.0059 | -0.0051 | 0.00101 |
| Drainage System (Dummy) | 0.0027 | 0.00099 | 0.00045 | 0.00015 | 0.0048 | 0.0066 | 0.0079 | 0.0048 |

It is important to highlight that the quantitative results of this research should be taken as a first step in the identification of the complex relationship between the possible effects of climate change on productive activities, mainly in rural areas, and that influence decisions to migrate. In this quantitative analysis, the climatic variables are generated with the CCKP model and the SSP4.5 scenario (most likely scenario at the end of the century) in the base period from 1960 to 1991. However, it is suggested to perform the analysis for all SSP scenarios.

With data from the 2020 Population and Housing Census, climatic variables at the municipal level, the econometric results of the present research show that climatic variables (temperature and precipitation) are key and statistically significant factors in the decision to migrate for the population of Mexico.

A limitation of the model is that it is not possible to predict absolute numbers of migrants, as any calculation depends on the probability that this will be true, which may not be the case. However, the main contribution of the model is to have detected effects on the probability of migrating that are statistically significant and non-zero, which demonstrates the statistical significance of the variables associated with climate change used and therefore it is possible to conclude an existing relationship between climate variables and the decision to migrate.

1. **DISCUSSION AND CONCLUSIONS**

In Mexico, climate-induced migration is a complex issue, with a lot of uncertainty about its future impact. The emission of greenhouse gases caused by human activity is generating changes in temperature, precipitation, sea level rise and a number of extreme weather events. Estimates such as Ramirez et al (2022a and b) predict an average increase in temperature of up to 4.5°C in Mexico by the end of this century, and that the greatest increase will occur in the north, west and northwest of the country. Rainfall could decrease by up to 20% during the same period. It is clear that the climate is changing and will continue to do so between now and the end of the century.

The present research showed an analysis of the correlation between climate, poverty and migration, since the factors behind the decisions to migrate are not only economic, but can include the search for better social and cultural environments; places with lower levels of violence and political instability; family reunification; and for this study the changes in the environment. In recent years, it has been proposed that changes in climate could accelerate migration; however, the mechanisms by which a changing climate will affect migration are still debated.

The complexity of migratory movements shows that the decision to migrate is influenced by a wide and complex variety of issues at the macro, meso and micro levels. Breaking down this complex process into its constituent elements, and quantifying its weighting in the decision to migrate, is not a simple process. Debate ranges from experts interested in the actual quantification of the CIM and the possibility of massive flows of refugees crossing borders, to those who criticize these calculations and label them as exaggerations. The CIM does not constitute a direct and severe threat to poverty, migration and security, but depending on them, tensions could arise, or worsen, in social or political systems; Among the most exposed are labor, water, food, energy and health systems. The MIC can also be a flexible response and could present opportunities, such as income diversification. Migration as an adaptation to slow-developing disasters, or to sea-level rise, could be long-term or short-term, temporary or permanent, internal or transboundary.

The phenomenon of migration to the United States of America has been part of the Mexican way of life for a century, with persistently high levels, as well as large movements within the country. Traditionally, the decision to migrate stems from social or economic factors, but there is growing evidence on the relationship between climate change, extreme weather events, increased poverty and the decision to migrate. In general, the impact of climate change on these events can be described by means of two environmental parameters: temperature and precipitation. Despite this apparent simplicity, the decision to migrate is multi-causal, and isolating the effects of climate change in this decision from the effects of economic, social or political issues would be very simplistic.

The results of the econometric model show that climate variability in temperature and precipitation is a determinant in the decision to migrate both internally and internationally. It is possible to interpret the results of the model, such as the impact of an increase in the average annual temperature (increase in probability of 0.0018) on internal migration is greater than the influence of the gender variable (increase in probability of 0.00045). In terms of net migration, an increase in the average annual temperature of 1°C results in an increase in the probability of migrating of 0.001, with an increase in the probability of internal migration of 0.0018. The combined effect between temperature and precipitation would estimate an internal migration between 340380 and 603900 people by the end of the century, regardless of other variables that affect migration in Mexico.

The results at the regional level indicate that the effects of climate variables are not homogeneous, with differential impact of climate variables in the different regions of the country, but in all cases, they are statistically significant with migration.

Based on these quantitative observations, competition and security of natural resources should be considered as key elements in Mexico in the context of environmental and migratory changes. Climate change is a risk to resource conservation and should be considered in future plans at the municipal, state, and national levels. The impact of climate change on poverty, migration and security is expected to be wide-ranging. Competition for key resources, such as water, food, land, and energy, can arise in places of origin and reception areas that are also vulnerable to overpopulation, resulting in resource scarcity, poverty, increased tensions, and potentially conflict, with the consequent growth of marginal societies. Potential competition may also arise between farmers, industries and trade for key resources such as water and energy, which are critical in production, manufacturing and marketing processes.

Water is a crucial resource in Mexico; of the total water extracted in Mexico, 77% is destined for agricultural activities, 14% for public supply, and 9% for industry, agribusiness, services, companies, and thermoelectric plants. The demand for water has increased in proportion to economic growth, and 104 of the 653 aquifers in Mexico have been classified as overexploited. In addition, droughts in some areas of northern Mexico are expected to be prolonged and intensified. In terms of migration, some northern states (Baja California Sur, Chihuahua, and Coahuila) consume large amounts of water, which increases pressure and could decrease population density in these regions. The quantitative model showed that if the average rainfall increases (it would alleviate water stress), then migration to these northern regions would decrease. There is a lower pressure on water availability in the southern region of Mexico. Therefore, an increase in precipitation does not have the same palliative effects as in the north.

It is considered that more than 27 million Mexicans live under circumstances of food insecurity, so greater irregularities in the rainfall season caused by climate change will have an impact on groundwater levels, and will have a detrimental effect on food production; it is estimated that Mexico is losing 1,036 km2 of agricultural land per year to desertification, which will have an impact on worsening poverty rates. Disruptions to farmland can lead to malnutrition among the population, increasing susceptibility to infections, fostering poverty, displacement, and could eventually lead to permanent migration. It has been estimated that 80000 farmers have migrated to other destinations, as droughts have seriously affected their primary source of income. The quantitative analysis of this research shows that a gradual increase in the average annual temperature has a positive impact on the decision to migrate both internally and internationally. Those communities that do not migrate as an adaptive response will have to establish resilient practices to cope with climate change and degradation.

Electricity production often requires high volumes of water to generate steam and cool. Therefore, a reduction in the amount of water available in Mexico would affect energy production, which represents a challenge for other sectors that depend heavily on water, with the likelihood that different sectors will compete for this resource.

When analyzing the quantitative model for the southern region, it is evident that the gradual increase in average annual precipitation will positively impact the decision to migrate, which means that people are expected to move to another region. This result could be an indication that, although economic pull factors have so far determined migration patterns, this pattern could be affected by climatic forces; In such a case, migration could increase in response to the expulsion factors implicit in climate variability.

Finally, based on the conclusions and the evaluation of Mexico's current strategy, its strengths and opportunities, the following recommendations are suggested: Greater awareness and recognition of the CIM in Mexico; enabling the more effective coordination and management of climate change initiatives through a collaborative network of institutions; Strengthen the analysis and generation of higher-resolution demographic and climate data, as well as data on ecological degradation and resource depletion, which would increase the databases that are currently available. Integrate these data into a publicly available national database; establish annual vulnerability assessments; standardizing the vulnerability indicators of the CIM, in conjunction with formal evaluations at the national, state, and municipal levels; manage migration opportunities as a potential and flexible coping mechanism; and to promote the dissemination of climate change information, so that people are aware of the dangers where they live and improve their capacity to respond and adapt.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

References

1. Aguilar, A. G. (2003). Human Settlements and Climate Change in Mexico: A Future Scenario of Regional Vulnerability. In C. Gay García (Ed.), Mexico: a vision towards the XXI century. Climate Change in Mexico. National Autonomous University of Mexico.
2. Alba, F., Castillo, M. Á., & Verduzco, G. (2010). General Introduction. In J. L. Lezama & B. Graizbord (Eds.), The Great Problems of Mexico: Environment (p. 12). El Colegio de México.
3. Allen, S. K., et al. (2012). Managing the risks of extreme events and disasters to advance climate change: Summary for policymakers. Special report of working groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, 3-21.
4. Statistical Yearbook of Ports of Mexico. (2011). National Cargo Movement.
5. Ávila, J. L., et al. (2000). Remittances: amount and regional distribution in Mexico. In R. Tuirán (Ed.), Migración México-Estados Unidos Presente y Futuro (pp. 155-165). National Population Council.
6. World Bank. (2009). Climate change aspects in agriculture: Mexico note.
7. Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008: Climate Change and Water. Intergovernmental Panel on Climate Change Technical Paper, IPCC Secretariat, Geneva, 224 pp.
8. BBVA Bancomer Foundation. (2010). Mexico: Migration Situation, 11-17.
9. Black, R. (2001). Environmental refugees: Myth or reality. UNHCR Working Paper No. 34, New Issues in Refugee Research.
10. Brown, O. (2008). Migration and climate change. IOM Migration Research Series, No. 31.
11. Butke, P. S., & Sheridan, S. C. (2010). An analysis of the relationship between weather and aggressive crime in Cleveland, Ohio. Weather, Climate and Society, 2(2).
12. Campbell, K. M., et al. (2007). The age of consequences: The foreign policy and national security implications of global climate change. Center for a New American Security, 9.
13. Cernea, M. M. (2000). Risks, safeguards and reconstruction: A model for population displacement and resettlement. In M. M. Cernea & C. McDowell (Eds.), Risks and reconstruction: The experiences of resettles and refugees (pp. 1–30). World Bank.
14. Economic Commission for Latin America and the Caribbean. (2010). Disasters and Development: The Impact in 2010. ECLAC Bulletin No. 2, 4.
15. Corona, R., & Tuirán, R. (1997). International migration in the demographic situation of Mexico. National Population Council.
16. Cruz Piñeiro, R. (2010). Migratory flows on the northern border: dynamism and social change. In J. L. Lezama & B. Graizbord (Eds.), The Great Problems of Mexico: Environment (p. 408). El Colegio de México.
17. de Sherbinin, A., et al. (2011). Preparing for resettlement associated with climate change. Science Magazine, 334(6055).
18. EACH-FOR. (2009). Environmental Changes and Forced Migration Scenarios: Mexico Case Study Report.
19. El-Hinnawi, E. (1985). Environmental refugees. United Nations Environment Programme.
20. Feakin, T., & Depledge, D. (2010). Climate related impacts on national security in Mexico and Central America. RUSI Report, 10.
21. Parliamentary Gazette. (2012). Communication, No. 3422-I.
22. Gage, K. L., et al. (2008). Climate and vectorborne diseases. American Journal of Preventive Medicine, 35(5), 436.
23. German Marshall Fund of the United States. (2010). Climate change and migration: Report of the Transatlantic Study Team. Climate Change and Migration.
24. Harmeling, S. (2012). Who suffers most from extreme weather events? Weather-related loss events in 2010 and 1991 to 2010. Global Climate Risk Index Report.
25. Herrera-Lasso, L., & Artola, J. B. (2011). Migration and security: dilemmas and questions. In N. Armijo Canto (Ed.), Migration and Security: New Challenge in Mexico (p. 12). Colectivo de Análisis de la Seguridad con Democracia A.C.
26. Hsiang, S. M., et al. (2011). Civil conflicts are associated with the global climate. Nature, 476(7361), 438.
27. National Institute of Ecology, & National Institute of Public Health. (2006). Diagnostic study on the effects of climate change on the human health of the population in Mexico. Final Report.
28. National Institute of Statistics and Geography. (2011). Topographic and Natural Resources Series Vector Dataset, 1:1,000,000 Scale.
29. National Institute of Statistics and Geography. (2021). Sociodemographic panorama of Mexico: Population and Housing Census 2020. INEGI.
30. Internal Displacement Monitoring Centre. (2012). Global overview 2011: People internally displaced by conflict and violence, 55-59.
31. Internal Displacement Monitoring Centre. (2024). People internally displaced by disasters
32. Izazola, H. (1997). Some considerations regarding the study of the environmental dimension of migration. Economy, Society and Territory, 1(1), 120.
33. Jacobsen, K. (1982). Refugees and asylum seekers in urban areas: A livelihoods perspective. Journal of Refugee Studies, 19(3).
34. Kälin, W., & Schrepfer, N. (2012). Protecting people crossing borders in the context of climate change: Normative gaps and possible approaches. UNHCR Legal and Protection Policy Research Series, 10–14.
35. Klare, M. T. (2000). Resource competition in the 21st century. Global Trends, 99(641).
36. Maplecroft. (2011). Climate change vulnerability index.
37. Martin, S. F., & Escobar Latapí, A. (2010). Jalisco and Zacatecas, Mexico: On-site visit from February 24 to 27, 2010. Institute for the Study of International Migration.
38. McMichael, A. (2011). Climate change and health: Policy priorities and perspectives. Chatham House Report, 3.
39. McMichael, A. J., & Lindgren, E. (2011). Climate change: present and future risks to health, and necessary responses. Journal of Internal Medicine, 270(5), 401.
40. Morisetti, N., & Dory, A. (2010). The climate variable: World militaries grapple with new security calculus. Defense News, 29.
41. Myers, N. (2002). Environmental refugees: A growing phenomenon of the 21st century. Philosophical Transactions of the Royal Society B, 357(1420), 609-613.
42. Myers, N., & Kent, J. (1995). Environmental exodus: An emergent crisis in the global arena. The Climate Institute.
43. World Health Organization. (2009). Global health risks: mortality and burden of disease attributable to selected major risks, 24.
44. World Health Organization. (2003). Climate Change and Human Health – Risks and Responses
45. Pan American Health Organization, & National Institute on Aging. (n.d.). Aging in the Americas. Projections for the 21st Century. U.S. Census Bureau. CONAPO. (2010). Main causes of mortality in Mexico 1980-2007. Working Paper for the XLIII Session of the Commission on Population and Development: Health, Morbidity, Mortality and Development, New York, 16 April 2010, 42.
46. Ortiz Pérez, M. A., & Méndez Linares, A. P. (1999). Scenarios of vulnerability due to sea level rise on the Mexican coast of the Gulf of Mexico and the Caribbean Sea. Investigaciones Geográficas, 39.
47. Penz, P. (2010). International ethical responsibilities to 'climate change refugees'. In J. McAdam (Ed.), Climate Change and Displacement, Multidisciplinary Perspectives (pp. 154-155). Hart Publishing.
48. Pew Research Center. (2009). Mexican immigrants: How many come? How many leave?
49. Ramírez Sánchez, H. U., Fajardo Montiel, A. L., Ortiz Bañuelos, A. D., & De la Torre Villaseñor, O. (2022a). Impacts of climate change on the water sector in Mexico. Asian Journal of Environment & Ecology, 17(2), 37–57. https://doi.org/10.9734/AJEE/2022/v17i23084600.
50. Ramírez Sánchez, H. U., Fajardo Montiel, A. L., Ortiz Bañuelos, A. D., & De la Torre Villaseñor, O. (2022). The agricultural sector and climate change in Mexico. Journal of Agriculture and Ecology Research International, 23(3), 19–44. https://doi.org/10.9734/JAERI/2022/v23i33086644
51. Saunders, P. (2000). Environmental refugees: the origins of a construct. In P. Stott & S. Sullivan (eds.), Political Ecology: Science, Myth and Power (pp. 42-56). Arnold.
52. Schwartz, P., & Randall, D. (2003). An abrupt climate change scenario and its implications for United States national security. Global Business Network, 18.
53. Steiner, A. (2009). Environment as a peace policy. NATO Review.
54. Stern, N. (2006). The economic effects of climate change: The Stern review. Cambridge University Press, 111.
55. Tucker, C. M., Eakin, H., & Castellanos, E. (2010). Perceptions of risk and adaptation: Coffee producers, market shocks, and extreme weather in Central America and Mexico. Global Environmental Change.
56. Warner, K. (2009). In search of shelter: Mapping the effects of climate change on human migration and displacement.
57. de Sherbinin A. Warner, K., & Ehrhart, C. (2011). Casualties of climate change. Scientific American, 304(1), 64–71.
58. White, G. (2011). Security and borders in a warming world: Climate change and migration. Oxford University Press, 128.
59. Yunez Naude, A., & Mora Rivera, J. J. (2008). Climate Change and Migration in Rural Mexico. World Bank Report.
60. Yunez Naude, A., & Mora Rivera, J. J. (2010). International rural emigration and development. In J. L. Lezama & B. Graizbord (Eds.), The Great Problems of Mexico: Environment (p. 148). El Colegio de México