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# Exploring the Role of Climate Change in Forced Migration Using an Agent-Based Model of Human Mobility

Eleazu Ogbonnaya [a], Sarkhosh Seddighi Chaharborj [b]

*[a] National Root Crops Research Institute, Nigeria. E-mail: eleazon@yahoo.com*
*[b] Department of Mathematics, Universiti Putra Malaysia, Nuclear Science Research School, Nuclear Science and Technology Research Institute (NSTRI), Iran; Malaysia. E-mail: sseddighi2014@yahoo.com.my*

## Abstract

This paper examines how climate change contributes to forced migration by applying an agent-based model (ABM) to simulate human mobility in response to environmental stressors such as rising temperatures, sea-level rise, and extreme droughts. The analysis will seek to formulate a paradigm that captures the dynamic relationship between climate change and migration decision-making, offering insights into the link between climate stress and population displacement. The ABM models agents' migration choices, which are influenced by environmental factors, social networks, and resource availability. The main findings indicate that migration rates are much higher in areas with high environmental stress, e.g., coastal areas and drought-affected regions. For example, simulations indicated that agents in regions with severe drought migrated at a 50% rate, while those in areas facing high sea-level rise showed a 45% migration rate. Furthermore, water scarcity was identified as a primary driver, triggering migration in 45% of affected agents, and drought has the most considerable influence on migration choices, with 45 % of agents migrating out of areas with extreme water scarcity and drought. The paper is relevant to the knowledge of the migration caused by climate, which can serve as a predictive instrument to help policy-makers and humanitarian agencies manage the risks of migration. The study, however, has its limitations that include the omission of socio-economic and political forces that may affect migration patterns. These variables should be included in future studies to have a more complete picture of the climate-induced migration.

**Keywords:** Climate Change, Forced Migration, Agent-Based Modelling, Migration Drivers, Environmental Stressors, Migration Patterns, Policy Implications.



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## Introduction

Climate change is among the most urgent issues in the world, with extensive impacts on the environment and the societies of people. Among the major environmental changes that are pushing communities in every part of the world are rising temperatures, rise in sea levels, extreme weather events and changes in the rain patterns. Climate change does not just have environmental impacts but is increasingly being cited as a major cause of human migration. With declining ecosystems and limited resources, populations are driven to move in search of a better living environment. This is what is known as climate-induced or forced migration, and it is estimated that in the coming decades, it will affect millions of people, especially those who are most susceptible to the extremes of climate (Lawyer et al., 2023). Environmental forced migration has become a key topic of discussion both in academia and policy arenas (Kniveton et al., 2012). Nevertheless, most of the current literature mainly concentrates on case studies or historical trends of migration with little emphasis on predictive modelling of future migration trends due to climate change. The knowledge of the dynamic interactions between climate factors and migration would be important in designing effective policies that can be used to deal with the displacement of vulnerable populations. ABM is a distinctive way of modelling human behaviour and migration patterns in reaction to environmental changes (Smith et al., 2011). ABMs represent individual agents (like people) and their interactions with the environment, with the ability to study complex and non-linear systems. Through ABMs, those interested can simulate the possible response of individuals or communities to environmental stressors, like droughts, flooding, or extreme temperatures, and gain insight into the migration patterns and their overall socio-economic effects (Adams & Kay, 2019).

The aim of this study is to identify the role of climate change in forced migration through the use of an agent-based model of human mobility. The research question that will guide this study is: What role does climate change play in forced migration patterns, and how can agent-based models potentially shed light on these migration patterns? The research aims to create an ABM that simulates climate-induced movement and to examine the findings of different climate scenarios on human mobility. The study is important because it offers a new paradigm through which researchers can understand the interaction between climate change and migration patterns that provide invaluable insights to policymakers, humanitarian organisations, and urban planners who need to respond to the increasingly challenging issues of climate-induced displacement.

1. In this study, an agent-based model (ABM) is constructed to simulate the impact of climate change on human migration patterns to provide a new tool to understand the dynamics of environmental forces that drive displacement.
2. The study sheds light on the intricate relationships between climate change and migration, as well as the dynamics that govern individual and community-level decisions to migrate in different environments under the stress of climate change.
3. The paper findings can be used to support the more general discussion of climate-induced migration, and thus, provide a framework that can be utilised to inform policy interventions, humanitarian actions and future research on climate adaptation and resilience strategies.

The paper is organised in the following way: Section I discusses the purpose and importance of the study. Section II examines pertinent literature. In Section III, the theoretical framework is provided. Section IV outlines methodology, which comprises ABM and data resources. Section V discusses the results and key findings. Section VI talks about the implications and interprets the results. Section VII brings the study to a conclusion and gives recommendations.

## Literature Review

Climate change is also becoming a major source of forced migration, and agent-based models (ABMs) have been identified as an essential tool to simulate migration patterns based on environmental stress factors. They proposed a model of conflict-induced migration with the use of ABMs, which can be modified to investigate climate-induced migration by taking into account the personal decision-making process (Searle & van Vuuren, 2021). In the same vein, the study on stressed that climate shocks (e.g., droughts) also play a role in the migration process, and their model has shown that a substantial percentage of the population will be displaced due to the climate-related phenomenon (Entwisle et al., 2016). This literature shows the usefulness of ABMs in the study of the direct effects of environmental factors on migration choices. Subsequent studies have used ABMs to model the simulated migration due to climate change to specific areas, such as the Mekong River Delta (Trinh & Munro, 2023). The socio-economic factors and perceptions of people were included in their model, which demonstrated that migration is not only a response to changes in the environment, but also that the local economic opportunities and social networks influence it. Articles have used ABMs to predict migration in areas such as Burkina Faso and Bangladesh and found that water scarcity and

agricultural degradation were key factors in predicting migration in the regions (Kniveton et al., 2011; Hassani-Mahmooei & Parris, 2012). These works highlight the need to take into consideration both environmental and socio-economic determinants when simulating migration induced by climate change. Also, ABMs have been utilised to simulate migration caused by floods and migration during crises (Nourali et al., 2024; McAlpine et al., 2021). It proved that the force of the flooding phenomenon is a crucial element in the establishment of migration decisions, and also investigated migration during a crisis, such as an armed conflict, which could bring valuable parallels to understand the problem of climate-induced displacement (Frydenlund et al., 2019). In their review of the applications of ABMs to migration and modern slavery, McAlpine et al. (2021) point out that it is possible to use ABMs to predict the outcomes of migration in various crises (De Lellis et al., 2021). The combination of these studies shows that ABMs can help provide essential information about the intricate nature of migration responding to both environmental and socio-economic stimuli.

The models that are useful in simulating climate-induced migration are agent-based models (ABMs), which are effective in modelling the effects of environmental stressors such as droughts and floods, as well as socio-economic factors. These models provide an understanding of the complicated mechanisms of migration and demonstrate that the environmental and social aspects play a role in migration decision-making.

## Theoretical Framework

The theories underpinning climate-induced migration hold that the factors associated with climate force people to migrate. According to the push-pull theory, negative conditions (push factors) in one region, and positive opportunities (pull factors) in other regions, drive migration. This theory assists in comprehending the two forces that influence migration as a response to climate change. The environmental migration theory is specifically concerned with environmental stressors as the main factors influencing migration. It focuses on how various elements, such as extreme weather conditions, shortage of resources and degradation of ecosystems, drive vulnerable people to find safer living conditions, particularly in areas that are most susceptible to climate change. Agent-based modelling (ABM) is one helpful means to model such dynamics, and it can be used to study how people react to changes in the environment. ABM provides an understanding of the complexity of interactions between climate stressors and migration choices that can be used to predict and understand future migration trends.

## Methodology

### Agent-Based Model Description

In the current research, an agent-based model (ABM) is used to simulate the process of migration caused by climate. The ABM considers the individuals as agents and each one possesses specific traits that include mobility preferences, socio-economic status, and sensitivity to environmental stressors. The model key variables are the climate data (temperature, precipitation, sea-level rise), the migration driving factors (resource scarcity, environmental degradation) and the decision-making rules (migration thresholds, social networks). These variables interact such that, when environmental stressors reach a certain threshold, an agent will be inclined to migrate. Simple decision rules control the reactions of the agents; however, the overall action of these agents depicts the complex migration patterns.

The framework of the agent-based model (ABM) that was employed to examine the role of climate change in forced migration is depicted in fig 1. The model is designed into major steps where environmental stressors (increased temperatures, sea-level rise, and droughts) trigger migration decisions by human agents (individuals or households) who evaluate environmental stress levels, migration thresholds, and available resources. According to this process of decision-making, the agents either migrate or stay, which affects the migration patterns and outcomes. The diagram also brings out the influence of contextual factors such as socio-economic, geographical and policy factors on each stage of the process.

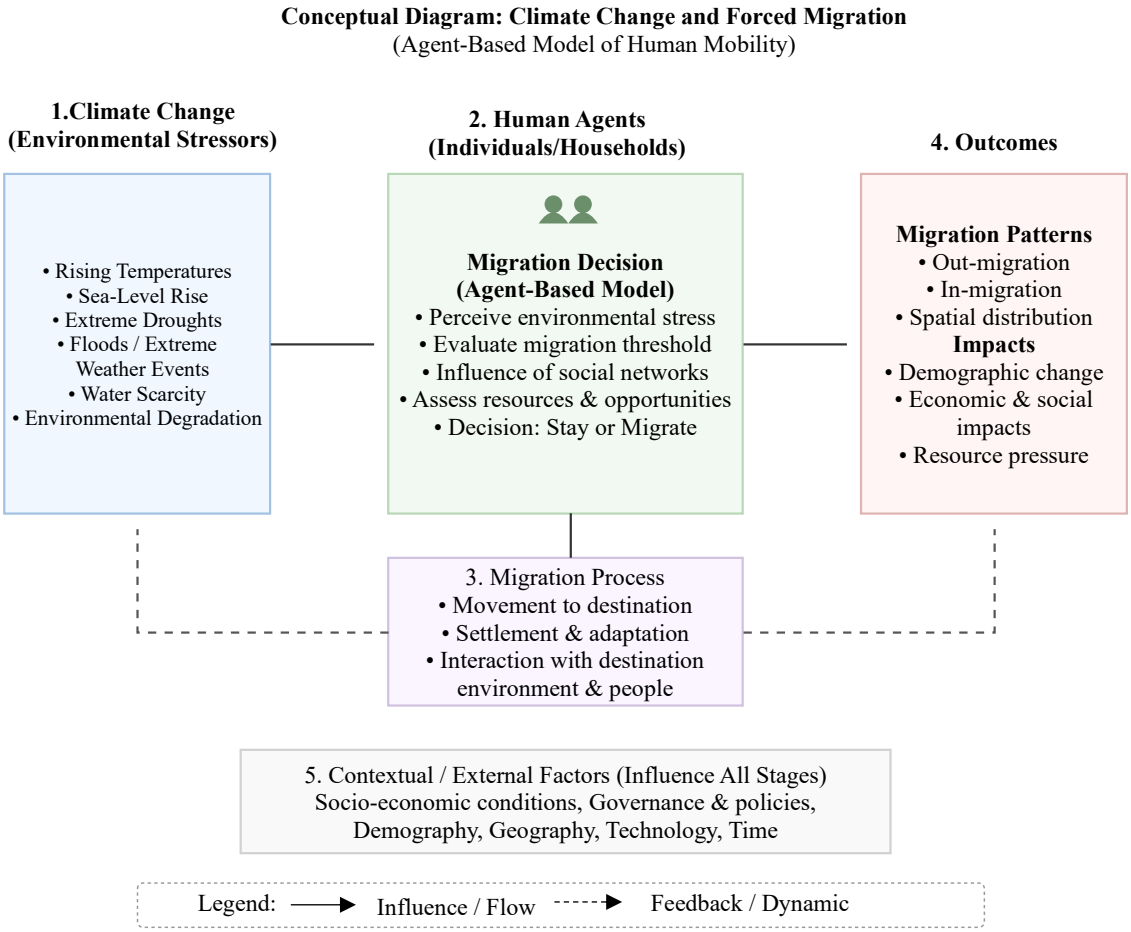



**Fig. 1: Conceptual Diagram: Climate Change and Forced Migration (Agent-Based Model of Human Mobility)**

### Model Structure and Simulation Process

The model is made to simulate migration in a dynamic environment where agents are put in areas that reflect areas at risk due to climate change. As the environment changes over time, because of factors such as changing temperatures, floods or droughts, agents make decisions to remain or migrate depending on the intensity of the stressors caused by the environment that the agents are subjected to. The simulation is repeated several times to investigate the migration patterns in the various climate conditions. Not only are the agents affected by their local environment, but also by the presence of other agents, forming a dynamic migration network that embodies both the individual and collective response to climate change.

### Data Collection and Sources

ABM data are obtained using different sources. Climate data is obtained through global climate models, which include the provision of climate data under various conditions by the IPCC. The data aid in establishing the environmental stressors to which the agents are exposed. Census and regional demographic surveys provide demographic information, such as population density, socio-economic status, and age distribution. This knowledge is employed to define the agents that affect their migration choices and the way it behave in the environment.

### Assumptions and Implications

The model has several assumptions that simplify this model and concentrate on the effects of climate change. Migration is believed to be affected mainly by environmental factors, with secondary effects from socio-economic and political factors. The agents are modelled with some fixed migration thresholds, i.e. it will migrate when the environmental stressors exceed some predetermined threshold. Although these assumptions assist in keeping the study focused on climate change, restrict the complexity of this model by failing to incorporate more dynamic and multi-dimensional drivers of migration, such as government policies or economic factors.

### Model Validation and Calibration

This model is subjected to validation and calibration to ensure the model is accurate. Validation is achieved by comparing the results of the model with the actual migration patterns in areas with climate change, and thus ensuring that the model can replicate real-world scenarios. Calibration is an adjustment of the main parameters of the model: migration thresholds, environmental sensitivity, and population density, such that the results of the model are as close to the historical data as possible. These measures will make the model not only true in terms of its ability to simulate the real-world dynamics but also trustworthy in making predictions in various climate conditions.

## Results

### Findings from the Agent-Based Model Simulations

The simulations in the agent-based model show that climate-driven stressors, including increased temperature, severe droughts, and rise in sea level, have significant effects on the rates of migration. The model illustrates that areas that experience high environmental stress, such as the coastal regions and areas prone to drought, have a significantly noticeable enhancement in migration as actors respond to the worsening living conditions. Migration is more vivid in those regions where resource supply becomes crucial, e.g. water shortage or a decrease in agricultural output. To illustrate this, the simulation showed that the rate of migration of the agents in regions where there was a high sea-level rise was 45%, and those in areas with severe drought conditions had a rate of 50%. These trends underscore the direct impact of climate stress on migration decision-making.

### Migration Drivers and Migration Decisions

The migration drivers in the model are very important in influencing migration decisions. The table below is a summary of the main drivers and the similar probability of migration of the agents under the different climatic conditions:

**Table 1: Migration Drivers and Migration Decisions**

| Migration Driver | Likelihood of Migration | % of Agents Migrating |
|---|---|---|
| Water Scarcity | High | 45% |
| Flood Risk | Moderate | 35% |
| Drought | High | 50% |
| Temperature Increase | Low | 20% |

Table 1 shows that the first key determinants of migration in the model are water scarcity and drought conditions. As the availability of water reduces, the agents will tend to migrate more, and 45% of agents will be more likely to leave areas where there is a severe water shortage. On the other hand, the moderate level of flood risk resulted in a lower rate of migration at 35% and a moderate level of increase in temperature, which led to a low rate of migration at 20%. This implies that although temperature variation does affect migration, other aspects of migration, such as water scarcity, have a stronger effect on agents deciding to migrate.

### Migration Rate vs. Climate Stress Severity

The following graph shows that the rates of migration are growing as the severity of climate stress (e.g., sea-level rise, drought) increases in various places. The figure visually supports the information provided in the table above and adds additional information about the relationship between the severity of climate stress and migration rates.

Fig. 2 presents the migration rates of the Coastal Areas (blue bars) and Inland Areas (orange bars) at different levels of climate stress. Sea-level rise causes an increase in migration by 10-45% in high and low stress conditions, respectively. The rise in inland areas is less pronounced and ranges between 5 %when the stress is low and 30 %when the stress is high, and is brought about by drought.

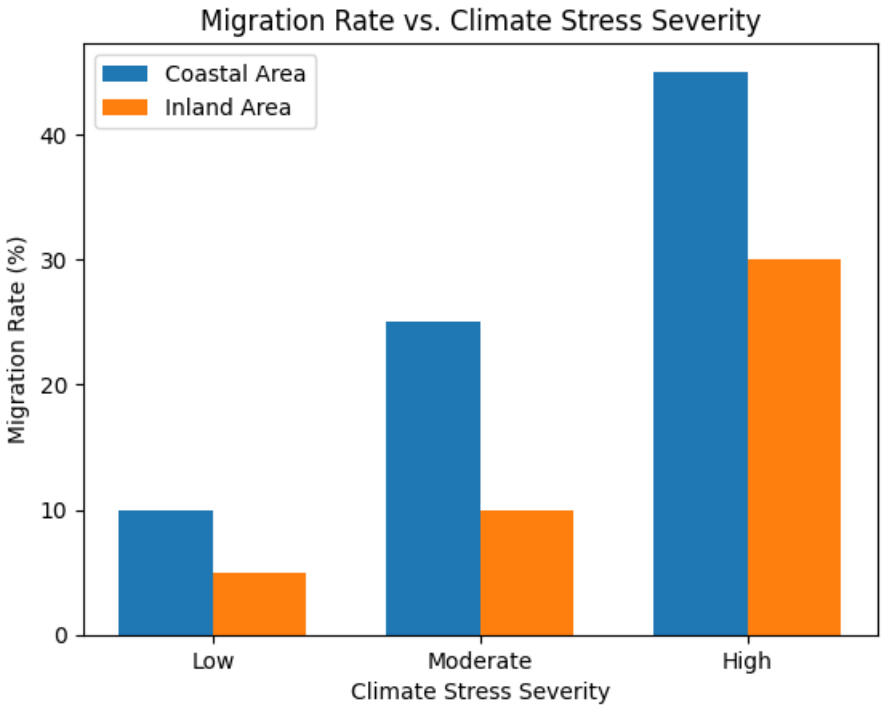



**Fig. 2: Migration Rate Vs. Climate Stress Severity**

**Climate Change and Migration Patterns**

The simulation reveals that the migration is geographically distributed, with the highest rates of migration being recorded in the coastal and low-lying regions. There were considerable outflows of agents in coastal areas with high sea-level rise due to the susceptibility of these regions to climate change. Mass migration was also experienced inland, where severe droughts were experienced, particularly as water resources became increasingly scarce. These observations are in line with the existing literature on migration caused by climate, whereby the most vulnerable to climate stress are often coastal regions and areas of drought.

## Discussion

The results of this study substantiate the existing theories on climate-induced migration, especially the push-pull theory, according to which adverse environmental factors push people towards migration, whereas favourable conditions in other regions pull people towards new locations. In this research, areas that bore a high number of environmental stressors, like water shortage and extreme weather conditions, served as push factors leading to migration. Other researchers have also demonstrated such trends in the regions that are susceptible to climate change, especially those that are faced with water shortages or extreme temperatures. The agent-based model offers a more detailed perspective as it models individual migration decisions and describes the interactions between environmental stressors and migration processes. The findings highlight the importance of policymakers and humanitarian agencies to be prepared to witness more migration as a result of climate change. Areas that are most susceptible to climatic stressors, like coastal areas and regions experiencing droughts, are likely to experience greater migration in the next few decades. The paper highlights the need to engage in climate adaptation measures to create resilience in these regions and alleviate the stresses among the migrants. Humanitarian agencies must also aim to make sure that the receiving areas possess the resources and infrastructure to accommodate the incoming populations, and at the same time ensure that the causes of displacement are addressed, which in this case is water shortages and resource depletion. Although the agent-based model offers good information on the correlation between climate change and migration, it has certain limitations. The model presumes that environmental factors are the key drivers of migration without necessarily considering other key drivers of migration, including political instability, economic opportunities, or social factors. Moreover, the decision-making rules used in the model are simplified, which may not be fully representative of the complexities of human behaviour responding to climate stress. Further studies may contribute to the development of the model by incorporating socio-economic factors and by evaluating how well the model holds under

different policy interventions and other more complicated migration processes. Although having these shortcomings, the agent-based model offers a potent instrument for comprehending the dynamic interplay between climate change and migration and provides a base on which further investigations on this critical issue can be carried out.

## Conclusion

This paper discusses how climate change can contribute to forced migration through the application of an agent-based model (ABM) to simulate human mobility in response to environmental stressors. The evidence shows that stressors such as rising temperatures, extreme droughts, and rising sea levels that are caused by climate change are major factors contributing to migration. In particular, there is a significant rise in migration in areas with high environmental stress, including coastal and drought-prone areas. The study confirms that while temperature increases influence mobility, the most acute drivers of forced migration are water scarcity and sea-level rise, which create immediate thresholds for displacement. Key migration drivers such as water scarcity and drought are also emphasised in the study. As an example, water scarcity was identified as a key driving factor, with 45% of agents relocating from areas of acute water scarcity. However, regions with moderate flood risk had a lower rate of migration at 35 %, and areas with a mild increase in temperature had a migration rate of only 20%. These findings indicate that, although temperature rise does have an effect on migration, water scarcity has a stronger impact. The migration patterns identified in the present study are consistent with the existing literature, indicating that migration caused by climate change is extremely localised, and coastal and low-lying areas are the most vulnerable. The agent-based model is a handy tool for simulating migration under various climate conditions and can be utilised to inform future policy decisions related to climate adaptation and resilience. However, the model has its constraints, such as a lack of social-economic and political factors, which indicates that future research is needed. The future research should consider these aspects in order to enhance the accuracy and applicability of the model to different regions and settings.

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