Deciphering the nexus of climate change, agriculture, and migration: perspectives from African and Asian realms

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Abstract

Purpose – The present research attempts to delve into the climate-agriculture-migration nexus to ascertain whether the variation in agriculture output due to climatic factors has a significant influence on the emigration flows from the Asian and African continents.

Design/methodology/approach – The present study draws upon a rich panel of data from 27 countries (14 African and 13 Asian) between 1995 and 2020. The first stage least square, OLS and 2SLS techniques have been employed to examine the relationships between climatic factors and international migration, climatic factors and agriculture output, and agriculture output and international migration, respectively.

Findings – The results exhibit a positive relationship between temperature and international migration. The influence of temperature on agriculture output is negative but insignificant while precipitation promotes agriculture output. In addition, agriculture output negatively influences international migration, and these findings establish a climate-agriculture-migration relationship.

Practical implications – To counteract the climate-agriculture-migration nexus, it is incumbent upon governments to conduct extensive field trials and data collection exercises to assess the influence of climate in separate agro-ecological zones and devise policies accordingly.

Originality/value – The literature concerning the interrelationship between climatic factors, agriculture and migration is scarce and what is available pertains to different contexts. Moreover, no studies are based on Asia and Africa; the continents have a high dependence on agriculture and outmigration rates, and the present research covers this important gap in the literature.

Keywords Climate change, Agriculture, Migration, Diversification index, Average temperature

Paper type Research paper

1. Introduction

The earth has always witnessed climate change; however, its pace has multiplied over the past 100 years. Attributed mainly to anthropogenic activities, the temperature has consistently increased by 0.9℃ since the 1800s; however, by 2050, it will rise to 1.5 ℃ (Arora, 2019). The increase in greenhouse gas (GHG) emissions and pollution are the major contributors to climate change (Kaur and Kaur, 2023). Consequently, the occurrence and intensity of floods, heat waves, droughts, cyclones, and other natural disasters have increased manifold over the past few decades (Srivasatava and Srivasatava, 2020). The economic loss due to natural disasters has continuously risen; in 2022, it was \$313bn, while in 2018, it was \$225bn. Droughts, floods, and cyclones comprise 95% of natural disasters and are directly related to climate change factors (Lörinc *et al.*, 2023; Olper *et al.*, 2014). Similar to climate change, human migration has been witnessed since the start of civilisation; however,

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in the last few years, the pace of migration has surged, and as of 2020, 281 million people live in countries other than their country of origin (UNDESA, 2020). Many people use migration to escape adverse climatic conditions, and a World Bank report projected that climate change will force 30 to 143 million more people to migrate by 2050 (World Bank, 2023; Silva Rodríguez de San Miguel *et al.*, 2021). Droughts and wildfires have displaced more than 800,000 and 200,000 people, respectively, since 2017 (Cho, 2021). However, the underlying mechanism of the climate-migration connection remains an enigma even though vast literature substantiates this relationship.

Moreover, climate change may have significant adverse impact on agriculture production and output (Ritu and Kaur, 2023; Olper *et al.*, 2014). According to a report by the "Food and Agriculture Organisation (FAO)", if the current trend of climate change and GHG emissions continues, the production of major crops like wheat and rice will decline by 5–50% and 20–30%, respectively, by 2,100 (Arora, 2019; Olper *et al.*, 2014). Agriculture employs a major proportion of the population in low-income countries, and its employment share is 49% and 30% in Africa and Asia, respectively (ILOSTAT, 2023). Further, the variation in agriculture output due to climatic factors can significantly affect the decision-making of those dependent on agriculture for their livelihood. Moreover, the impact of changes in mean temperature and precipitation on agricultural output is well substantiated, which may act as a significant driver of migration (Cattaneo and Peri, 2016). Thus, the role of agriculture in the climate-migration relationship seems significant in Asia and Africa as these continents exhibit a high dependence on agriculture. However, literature focusing on this relationship is scarce, and what is available pertains to different contexts. The climate-agriculture-migration relationship for 1980–2010 was analysed by Cai *et al.* (2016) and for 1960–2010 for poor and middle-poor countries by Falco *et al.* (2019). The current research extracts data from 27 countries (14 African and 13 Asian) from 1995 to 2020 to examine the climate-agriculture-migration nexus.

2. Review of literature

The review of the related literature revealed four types of studies, which are discussed as per their classification. Primarily, the studies concerning climate change-migration relationships were explored, and it was observed that the relationship is well-researched. The authors came across two types of studies based on macro and micro (unit-level) data. Carleton and Hsiang (2016) analysed data from 115 countries between 1960 and 2000 to find whether climate change affects intra and inter-country migration. The migration from middle-income countries to urban areas and other countries increased due to rising temperatures. However, in poor countries, liquidity constraints restrict migration trends. Beine and Parsons (2015) found that climatic factors did not directly impact international migration. However, there was an indirect impact operational via wages during 1960–2000. Maurel and Tuccio (2016) constructed a step model whereby climatic shocks promulgate a shift from traditional to modern sectors, and downward pressure on wages promotes emigration. The research employed a panel dataset of 222 countries from 1960–2000 and found that an 8.6–12.8% growth rate of climate-induced migration is likely to be observed. Gröschl and Steinwachs (2017) used a stylised theoretical gravity model on a panel dataset of 226 countries from 1980 to 2010. The results showcase little evidence of natural factors impacting medium and long-run emigration. Among the countries belonging to various income groups, middle-income countries are significantly impacted by natural hazards.

However, among the studies based on micro data, Kubik and Maurel (2016) used rural household data from Tanzania to elaborate on how weather shocks influence internal migration. The research revealed that the probability of migration increased due to a reduction in agricultural income attributed to climatic shocks. The impact is more prominent for households in the middle-income groups, signifying the importance of initial endowments in migration decisions. Furthermore, Gray and Mueller (2012) used 15-year longitudinal data of 1,700 rural households in Bangladesh and evidenced that the impact of flooding on mobility was modest, while crop failure had a substantial impact on the mobility of families. Mastrorillo *et al.* (2016) conducted a study based on South Africa and found that outmigration increased due to increased rainfall and temperature. However, the influence of these factors varies significantly across the types of migrants. Similarly, in the case of Bangladesh, climate change triggered natural disasters which led to a decrease in population growth by promulgating migration out of the coastal regions (Salauddin and Ashikuzzaman, 2012).

While exploring the mechanism of how climate change impacts migration, it emerged that this relationship operated from climate to agriculture and then agriculture and migration. Concerning the first relationship, Chandio *et al.* (2020) found that in the period 1982–2014, the CO2 emission level significantly impacted agriculture production. Schlenker and Roberts (2009) also assessed the impact of temperature on soybeans, corn and cotton yields in America. The study found that crop yields increase with the increase in temperature, but the rise above the threshold level induces a reduction in yield. Further, Guntukula (2020) assessed how primary food and non-food crops are affected by climate and found that climate variables have a substantial impact on crops. However, the extent of the impact may vary from crop to crop. Burke *et al.* (2015) showed that productivity increases with temperature up to 13 °C, and it starts to decline. Furthermore, review studies like Auffhammer and Vincent (2012), Arora (2019), and Malhi *et al.* (2021) also supported the influence of climatic change on agricultural productivity.

Furthermore, Feng *et al.* (2010) empirically investigated the association between agricultural productivity and net migration from 1970 to 2009. The results revealed that a reduction in crop yields caused a significant increase in migration, and 3.7% of the adult population will leave the corn belt of the USA in 2020–49. Goldsmith *et al.* (2004) explored how the productivity of agriculture and migration are linked and found that rural-urban migration positively depends on the ratio of urban to rural per capita income, implying the impact of low agricultural productivity. de Brauw (2015) conducted research based on Ethiopia, where regression analysis revealed that agriculture productivity significantly influenced outmigration.

Moreover, Falco *et al.* (2019) examined how the link between weather, agriculture and international migration were associated during 1960–2010. It was found that a fall in agricultural productivity due to climate change promotes migration, and the influence was more substantial in poor countries compared to middle-income countries. Similarly, Cai *et al.* (2016) examined the significance of agriculture in the climate-migration association for the years 1980–2010 and found that the influence of temperature on emigration was statistically significant only in agriculture-dependent countries. Viswanathan and Kumar (2015) used state and district levels to evaluate India's three-way relationship among climate, agriculture, and internal migration. It was revealed that a fall in agricultural output due to climatic factors led to an increase in migration; more precisely, a 1% fall in rice yield led to a 2% increase in outmigration. The magnitude of inter-district migration increases much more compared to intra-district. Thus, the literature points out the existence of an interrelationship between climatic factors, agriculture and migration, but no studies were based on Asia and Africa; the continents have a high dependence on agriculture and emigration. Moreover, a report by the United Nations revealed that the rise in temperature in Asia due to global warming is more than the worldwide average leading to an increase in the frequency and intensity of floods, storms, droughts and severe heatwaves (World Meteorological Organisation, 2024). Also, Africa, despite being the least contributor to global warming, bears its collateral damage as 95% of agriculture is rainfed (African Development Bank Group, 2024). Thus, it becomes incumbent to evaluate the existence of climate change, agriculture, and migration nexus in

Asian and African contexts. Besides, the studies comprehending these relationships are based on data before 2010 and there is a need to evaluate these relationships using the latest data to reveal the current picture.

3. Data and summary statistics

The study aims to investigate the climate agriculture migration nexus in a selected panel of 27 countries for two continents from 1995 to 2020. We use a distinctive dataset for outmigration from the OECD Yearbook of Migration 2020. The panel of 27 countries from two continents, i.e. Africa and Asia, has been selected; the choice of focus on these two continents stemmed from the notable patterns of emigration they exhibit, coupled with their significant dependence on agriculture. From Africa, 14 countries have been selected (Algeria, Burkina Faso, Central African Republic, Congo, Côte d'Ivoire, Egypt, Ethiopia, Ghana, Mali, Morocco, Nigeria, South Africa, Uganda and Zimbabwe). From Asia, 13 countries have been selected (Afghanistan, Bangladesh, China, India, Iraq, Indonesia, Kazakhstan, Malaysia, Pakistan, Philippines, Vietnam, Syria and Turkey). These countries have been selected on the basis of highest international migrant stock in 2020 in the two continents. The year 1995 has been chosen as the base year for this study because it marks the establishment of the World Trade Organisation (WTO). This significant development had profound implications for global trade patterns, particularly in agricultural trade, and it also impacted the migration of labour between countries. The creation of the WTO brought about reforms aimed at liberalising trade, reducing barriers, and promoting market-oriented policies, which in turn influenced economic conditions and labour movements worldwide (Huang *et al.*, 2000; Clapp, 2006). Moreover, the international migration data was available till 2020, thus, the time period 1995–2020 was selected. The variables, code and data sources taken to satisfy the objectives of the study are presented in Table 1.

The data for international migration was taken by summating all emigrants from each origin country and extracted from the OECD Yearbook of Migration 2020. The data for mean temperature and precipitation have been extracted from the "climate change knowledge portal of the World Bank". The agriculture output and "GDP per capita" data have been extracted from World Development Indicators (WDI). The data for the "export diversification index" has been extracted from UNCTAD. The data for the democracy index has been extracted from the Economist Intelligence Unit.

Variable name	Code	Unit of measurement	Source
International Migration	LM	Flows (in percentage)	Organisation of Economic Co-operation and Development (OECD)
Gross Domestic Product per Capita	LGDP	Constant 2015 (US $)	World Development Indicators (WDI)
Agriculture Output	LAO	Agriculture, forestry and fishing, and value-added (% of GDP)	World Development Indicators (WDI)
Average Temperature	LAT	Average annual temperature (°C)	Climate Change Knowledge Portal of the World Bank
Average Precipitation	LAP	Average annual precipitation (millimetres)	Climate Change Knowledge Portal of the World Bank
Diversification Index	LDI	Export diversification (Unit)	United Nations Conference on Trade and Development (UNCTAD)
Democracy Index	LDE	Unit (0–10)	Economist Intelligence Unit

Table 1. Description of variables

4. Econometric approach

Some prerequisite tests have been applied before preceding the main methodological framework. The study employed cross-sectional dependence (CSD) and unit root tests to satisfy the data requirement. Panel data can be affected by CSD due to some external factors, economic and regional linkages and latent heterogeneity and if ignored, the panel data results lead to biased and unreliable estimates. Wang *et al.* (2014) gave the null hypothesis (H0) for the CSD test, asserting the absence of cross-sectional dependence in the dataset. We employed three tests namely Breusch-Pagan LM test (Breusch and Pagan, 1980), Pesaran scaled LM (Pesaran *et al.*, 2008), and Pesaran CD (Pesaran *et al.*, 2004) tests to identify CSD. By affirming the presence of CSD, the study has employed the cross-sectional LM Pesaran (CIPS) and cross-sectional Augmented Dickey-Fuller (CADF) tests, which are second-generation panel unit root tests. If the CSD is confirmed, these tests address the cross-sectional correlation. The equation of CADF is as follows:

$$\Delta Y_{i,t} = x_i + x_i Y_{i,t-1} + \gamma_i \overline{\gamma_{t-1}} + \sum_{I=0}^{P} \gamma_{iI} \Delta \overline{Y}_{t-1} + \sum_{I=1}^{P} \gamma_{iI} \Delta Y_{i,t-1} + \varepsilon_{it} \tag{1}$$

$$\widehat{CIPS} = \frac{1}{N} \sum_{i=1}^{n} CADF_i \tag{2}$$

Furthermore, the mainstream approach to methodologically studying the rapport between migration and weather events is as follows:

$$LM_{it} = W'_{it} b + K'_{it} d + F_t + C_i + u_{it} \tag{3}$$

Where LM_{it} is the log of international migration, i represents the country ($i = 1,..,n$), t represents the period T($t = 1, \ldots, $ T) and W'_{it} represents the climate variables. K'_{it} signifies the control variables. The equation comprises "a full set of year, F_t", and of country, "C_i, fixed effects". Finally, u_{it} is the "error term". Note that W'_{it} could include elements like the square of average temperature, accommodating for the effect of "weather on emigration" in a nonlinear way.

Our investigation relies on a "structural two-stage least squares (2SLS) approach", akin to Feng *et al.* (2010), but with some notable differences. 2SLS is an extension of Ordinary Least Squares (OLS) used when the dependent variable's errors correlate with independent variables. If OLS were used, estimated coefficients would be biased and unreliable. In our context, this two-stage method is essential because migration decisions often influence agricultural outcomes, creating an endogeneity issue. When migration shocks result from factors unrelated to agriculture, they directly impact agriculture output. "Standard OLS methods" become biased because the error term correlates with the variable of interest: agriculture outcomes. To tackle this, and to examine if climate shocks/weather shocks (extreme temperature and rainfall patterns) affect migration through the agricultural channel, we initially regress "climate variables" on "agriculture output". The forecasted "agriculture output" from this first stage regression acts as instruments in the second stage migration equation. In essence, our standard experiential model using 2SLS can be formally expressed as:

$$x_{it} = W'_{it} \gamma + K'_{it} \delta + f_t + c_i + v_{it} \tag{4}$$

$$LM_{it} = \alpha x_{it} + K'_{it} \delta + f_t + c_i + \varepsilon_{it} \tag{5}$$

Here, the logarithm of "agriculture output" is denoted as x_{it}. Our goal is to accurately estimate the unbiased α coefficient in Eq. (3), representing the elasticity of international migration concerning "agriculture output". However, any increase in rural migration due to factors unrelated to agricultural shocks (such as conflicts) directly impacts agriculture output. Thus, in our initial Eq. (2), the "agricultural variable" x_{it} is seen as endogenous and is assumed to depend on weather shocks, W'_{it}, which serve as our instruments. Essentially, in the "first stage", we explore how variations in "climate change" might influence agriculture and subsequently impact migration.

Both Eqs (2) and (3) incorporate a set of controls, K'_{it}, and include fixed effects for years, f_t, and countries, c_i. Finally, ε_{it} and v_{it} represent the error terms in the two equations, assumed to be uncorrelated. Building on Eqs (2) and (3), our objective is to test whether the impact of "climate change" on migration occurs indirectly through the agricultural channel. By substituting (2) into (3), we derive the "reduced-form relationship" between "weather and migration" as presented in (1), encapsulating the potentially crucial role of "agriculture".

Granger (1969) propositioned a causality test to define the "dependence relations" between "economic time series". According to this, if two variables $X_t, Y_t, t \geq 1$ are "strictly stationary", (Y_t) Granger causes X_t if past or current values of X contain additional information on future values of Y. The "Granger causality test" assumes "parametric and linearity" in the "time series model".

5. Results and discussion

5.1 Cross-sectional dependence (CSD) test

The CSD test has been used to check the interdependence between the countries through various channels and mechanisms. The finding in Table 2 depicts the presence of cross-sectional dependence among the countries as the null hypothesis of no cross-sectional dependence has been rejected at a 1% significance level for all the tests namely the Breusch-Pagan LM, Pesaran scaled LM and Pesaran CD tests. Continuing with the prerequisite tests, the study checks the stationarity among the variables as the cross-sectional dependence has been confirmed and the first-generation unit root test cannot be applied because it would lead to biased results. The second-generation panel unit root tests (PURT) namely CIPS and CADF

Test	Test statistics	p-value
Breusch-Pagan LM	1695.507	0.000***
Pesaran scaled LM	50.74516	0.000***
Pesaran CD	11.81342	0.000***

Second-generation unit root tests

Variables	CADF Level	CADF First difference	Decision	CIPS Level	CIPS First difference	Decision
LM	−1.990	−3.192***	1st difference	−2.493	−4.355***	1st difference
LGDP	−2.510	−3.185***	1st difference	−2.071***	–	Level
LAO	−2.311**	–	Level	−3.159***	–	Level
LAT	−3.810**	–	Level	−2.332***	–	Level
LAP	−2.428**	–	Level	−4.331***	–	Level
LDI	−3.212**	–	Level	−4.584***	–	Level
LDE	−1.584	−2.626***	1st difference	−1.694	−4.025***	1st difference

Note(s): *, **, ***: significance at 1%, 5% and 10% level, respectively; LM: International Migration; LGDP: Gross Domestic Product per Capita; LAO: Agriculture Output; LAT: Average Temperature; LAP: Average Precipitation; LDI: Diversification Index; LDE: Democracy Index

Source(s): Authors' calculation

Table 2. Cross-sectional dependence test and second-generation unit root test

have been employed. The findings have been depicted in Table 3 and show that in the case of CADF, all the variables are significant at level except LM, LGDP and LDE. The findings for CIPS show that all the variables are significant at levels except LM and LDE. The results provide the mix of I(0) and I(1) levels of stationarity (see Table 2).

5.2 Descriptive statistics

Table 3 showcases the descriptive statistics of the data, namely “mean values, standard deviation, skewness, and kurtosis values”. Most importantly, the “Jarque Bera” test has been used to check the normal distribution in the dataset. The “mean and median values” in the series are related and have very little difference. In the case of “skewness” all the variables are “negatively skewed” except LAO and LGDP, which are “positively skewed”. In the case of “kurtosis”, all the variables show platykurtic curve patterns except for LAP and LAO, as these show leptokurtic curve patterns. The J – B statistic values for LAT show normal distribution, and the rest of the variables are not normally distributed as their probability values are less than 5% significance level.

5.3 Climate and migration

The initial step in our approach involves estimating an equation where the “logarithm of the international migration” is directly regressed against “weather variables” while “controlling for year and country-fixed effects”. The initial Eq. (1), serves as a foundational representation in the “migration-weather research landscape”. This establishes a consistent relationship to support our subsequent 2SLS approach, as emphasised by Angrist and Pischke (2008).

Across the overall sample, we observe that international migration tends to increase due to rise in temperature, which is “statistically significant at a 5% level” (see Table 4). One per cent increase in temperature results in a 0.13% increase in international migration, unlike the effect of precipitation, which is statistically insignificant. The results align closely with previous research by Feng *et al.* (2010) examining Mexican migration to the U.S. and Beine and Parsons (2015) exploring impact of rise in temperature on migration. These results are coherently in line with earlier findings, demonstrating that temperature, in a nonlinear fashion, notably influences emigration, while precipitation holds lesser significance (Cattaneo and Peri, 2016; Olper *et al.*, 2014). Extreme temperatures and extended heatwave periods make certain regions unsuitable for living or farming and push individuals to leave areas facing these conditions, causing environmental displacement (Carleton and Hsiang, 2016;

	LM	LGDP	LAO	LAT	LAP	LDI	LDE
Mean	9.910541	7.857803	2.889916	2.910726	6.483035	−0.370922	−1.091219
Median	10.01301	7.866568	2.852737	2.911042	6.705313	−0.283972	−1.041287
Maximum	13.25683	8.190945	3.151966	2.934369	8.183177	−0.103643	−0.243346
Minimum	4.543295	7.508964	2.758404	2.887961	2.386926	−0.953742	−2.631089
Std. dev.	1.612398	0.216607	0.111612	0.011538	1.135047	0.211223	0.555789
Skewness	−0.375561	0.030606	1.052141	−0.006377	−1.179836	−0.821453	−0.594512
Kurtosis	2.978357	1.580573	3.052006	2.753758	4.854933	2.429228	2.828532
Jarque – Bera	16.51605	59.04170	129.5981	1.778342	263.5082	88.47888	42.21303
p-value	0.000259	0.000000	0.000000	0.410996[nd]	0.000000	0.000000	0.000000

Note(s): [nd]: normal distribution; LM: International Migration; LGDP: Gross Domestic Product per Capita; LAO: Agriculture Output; LAT: Average Temperature; LAP: Average Precipitation; LDI: Diversification Index; LDE: Democracy Index
Source(s): Authors’ calculation

Table 3.
Descriptive statistics

Table 4.
Regression analyses

Relationship	Climate and migration			Agriculture and migration			Climate and agriculture		
Dependent variable	International migration (LM)			International migration (LM)			Agricultural output (LAO)		
Technique	First stage least square			Two stage least square			First stage least square		
	Co-efficient	Standard error	Probability value	Co-efficient	Standard error	Probability value	Co-efficient	Standard error	Probability value
LAT	0.132	0.138	0.086**	–	–	–	−0.121	0.121	0.316^{ns}
LAP	0.028	0.015	0.598^{ns}	–	–	–	0.015	0.017	0.008*
LAO	–	–	–	−2.465	0.502	0.000*	–	–	–
LGDP	−0.433	0.024	0.000*	−0.515	0.203	0.011**	0.433	0.012	0.000*
LDI	−0.039	0.025	0.001*	−0.191	0.266	0.036**	0.024	0.010	0.014**
LDE	0.022	0.035	0.014*	−0.649	0.090	0.014**	0.028	0.008	0.001*
R^2		0.698			0.926			0.775	
F statistic		74.577			274.64			74.498	
Probability value		0.000*			0.000*			0.000*	

Note(s): *, **, ***: significance at 1%, 5% and 10% level, respectively; ^{ns}: non-significant; LM: International Migration; LAT: Average Temperature; LAP: Average Precipitation; LAO: Agriculture Output; LGDP: Gross Domestic Product per Capita; LDI: Diversification Index; LDE: Democracy Index
Source(s): Authors' calculation

Beine and Parsons, 2015. Furthermore, temperature changes can impact jobs reliant on specific environmental conditions, like farming or fishing, disturbing conventional farming methods, resulting in income loss and motivating people to migrate (Bylander, 2015; Warner *et al.*, 2010).

Another finding reveals that an increase in GDP reduces international migration; a one per cent increase in LGDP results in a 0.43% decrease in international migration. It highlights that the nations with higher GDP provide increased economic prospects, improved living standards, diverse job prospects and a favourable job landscape with higher pay, enhanced conditions, and secure employment, potentially decreasing emigration incentives (Olper *et al.*, 2014; Cattaneo and Peri, 2016). The relationship between the "export diversification index" and international migration is negative, showing that a 1% increase in export diversification leads to a 0.03% decrease in international migration. As the export diversification increases, there tends to be a decrease in the international migration. This correlation implies that when a country has a more diverse range of economic opportunities across various sectors, it might reduce the incentive for people to abscond from the country in search of better possibilities elsewhere (Carleton and Hsiang, 2016; Cattaneo and Peri, 2016). The relationship between the democracy index and emigration is positive and significant, revealing that a more stable country politically leads to lesser migration of people (Arora, 2019; Cai *et al.*, 2016).

5.4 Agriculture and migration

The calculated influence of "agriculture on international migration" might be skewed due to potential "reverse causality issues". Any international migration changes unrelated to "agricultural shocks" could directly impact agricultural production and efficiency. Furthermore, the OLS estimates could suffer from biases stemming from unaccounted-for variables, such as international price fluctuations and governmental responses through "agricultural protection policies" (Cai *et al.*, 2016). These factors have the potential to either amplify or counteract migration trends. Transitioning from basic OLS regressions to the more complex 2SLS regressions allows us to address these concerns meticulously. So, the subsequent analysis delves into the correlation between "migration and agriculture", detailed in Table 4, using the 2SLS estimation technique. Here, we regress the "migration" against "agriculture output" variable. To assess the relevance of the agricultural sector in influencing migration, we aim to maintain consistency in the primary drivers of migration. When gauged by production output, agriculture exhibits a significantly negative impact on migration (at the 1% significance level) in selected groups of countries.

Earlier studies stated that when "agriculture output" increases, it creates jobs and stabilises livelihoods, reducing the immediate need for migration. Conversely, declines in agriculture, caused by factors like land degradation, climate fluctuations, or economic policies, drive individuals to seek better prospects elsewhere (Cai *et al.*, 2016; Cattaneo and Peri, 2016). GDP per capita inversely and significantly impacts the "emigration" as lower GDP or economic instability prompts emigration due to hardships and limited prospects, while booms attract immigrants eyeing opportunities. Policies and global economic ties also affect migration. Ultimately, a country's GDP significantly shapes migration by influencing economic incentives and opportunities (Carleton and Hsiang, 2016; Falco *et al.*, 2019; Cai *et al.*, 2016). On the other hand, the "export diversification index" negatively impacts "international migration" at a 1% significance level by boosting domestic employment and enhancing economic stability. Expanding the range of its exports, a country broadens its economic foundation, generating jobs across multiple sectors. This lessens the economic pressure for individuals to migrate for better job opportunities. Additionally, a diversified and resilient economy, less susceptible to external shocks, leads to improved living conditions and higher domestic wages. Consequently, the factors that push people to seek opportunities abroad are diminished, leading to a decrease in international migration (Lee *et al.*, 2022; Agosin, 2008).

5.5 Climate and agriculture

The rapport between "agriculture and climate" has been depicted in Table 4, showing that precipitation positively and significantly impacts the agriculture output in the selected group of countries. A 1% increase in precipitation leads to a 0.01% increase in agriculture output whereas the impact of "temperature" on "agricultural output" is negative and insignificant as also substantiated by Warner *et al.* (2010) and Bylander (2015). The GDP per capita positively and significantly impacts agriculture output. A higher "GDP per capita" generally indicates increased purchasing power and potentially greater investment in agricultural technologies, infrastructure, and practices, which can boost "agriculture output".

Additionally, "higher GDP per capita" often correlates with better access to resources like fertilisers, machinery, and education, which can further enhance "agriculture output" (Cai *et al.*, 2016; Cattaneo and Peri, 2016). However, while there might be a correlation between "GDP per capita and agricultural output", other factors like climate, technology, government policies, and land fertility also play crucial roles in determining agricultural output (Mozumdar, 2012). The "export diversification index" (LDI) positively and significantly impacts "agriculture output". Export diversification enhances agriculture output by attracting investment, promoting innovation, and reducing risk. Both domestic and foreign investments improve agricultural infrastructure and technology, boosting productivity. New international markets offer farmers better prices, encouraging increased production. Innovation and technology transfer from diverse markets result in improved farming practices and higher crop yields. Diversification decreases reliance on single commodities, reducing vulnerability to price fluctuations (Jiang *et al.*, 2022).

In a nutshell, it is concluded that the significant involvement of the agricultural sector in influencing the relationship between "climate and migration" seems to withstand different viewpoints or interpretations. The negative relationship between temperature and agriculture leads to the cross-border movement of people seeking better opportunities and outcomes. The findings show climate impact migration via agriculture and establish the climate-agriculture – migration nexus.

5.6 Causality analysis

"Granger causality relationships" have been probed among the selected variables. The "null hypothesis" asserts that there is no "Granger causality"; thus, there is no linear "causal relationship" between the "mentioned variables" in Table 5 below, whereas the alternative hypothesis suggests "the existence of Granger causality" between the variables. Table 5 presents the causal relationship between "agriculture output (LAO), migration (LM), temperature (LAT), precipitation (LAP)". LAT and LM show a bi-directional causal relationship, and the results are significant at a one per cent level. In contrast, no causality relationship is confirmed between LAP, LM, and LAP and LAT. A unidirectional causal relationship is analysed running from LM to LAO and LAT to LAO; the results are significant at 5 and 10% levels, respectively. The one-way causal relationship has also been observed between LAO and LAP, and results are significant at a 10% level.

6. Conclusion, policy implications and limitations

6.1 Conclusion and policy implications

This study is driven by the expanding research on how climate variability influences migration, mainly focusing on the connection between weather patterns and migration

Table 5.
Pairwise Granger causality test

Null hypothesis	*F* statistic	*p*-value	Causality
LAT ↔ LM	9.35143	0.0001*	Bi-directional causality
LM ↔ LAT	4.63377	0.0100*	
LAP ↔ LM	0.28436	0.7526	No causality
LM ↔ LAP	0.16339	0.8493	
LAO ↔ LM	12.7586	4.E−06	One way causality
LM ↔ LAO	5.83825	0.0031**	
LAP ↔ LAT	1.60829	0.2010	No causality
LAT ↔ LAP	2.02239	0.1332	
LAO ↔ LAT	247.075	2E−80	One way causality
LAT↔ LAO	102.878	0.0810***	
LAO ↔ LAP	2.85568	0.0582***	One way causality
LAP ↔ LAO	1.01121	0.3644	

Note(s): *, **, ***: significance at 1%, 5 and 10% level, respectively; LM: International Migration; LAO: Agriculture Output; LAT: Average Temperature; LAP: Average Precipitation
Source(s): Authors' calculation

decisions at a larger scale. Previous research has established a correlation between weather factors like temperature and precipitation and migration patterns. The agricultural sector is a significant mediator in how climate change impacts migration. Nevertheless, there needs to be more exploration into the structural link connecting climate-driven shifts in agricultural outcomes to migration decisions, especially at a broader level. The present study sought to explicitly test if variations in agricultural outcomes caused by changes in temperature and precipitation over decades are fundamental to international migration decisions influenced by climate. The results of both OLS and 2SLS approaches strongly support this idea. The primary findings reveal that a 1% decrease in climate-driven agricultural output increases the international migration by approximately 2.4% in the selected countries. Furthermore, the 2SLS approach is better than the OLS one, indicating that overlooking the endogeneity of agricultural variables in migration decisions significantly underestimates this relationship, underscoring the potential importance of our study's results.

Furthermore, understanding the causality between climate-induced alterations in agricultural outcomes and migration is crucial for informed policy interventions addressing climate-induced migration flows. Moreover, future impacts of global warming, especially on agriculture and economies heavily reliant on the agriculture sector, will be critical to devise effective climate change mitigation and adaptation policies. The results highlight that agriculture is more susceptible to climate shocks, exhibiting a strong connection between climate-induced agricultural changes and migration, which necessitates the governments to undertake extensive field trials and data collection exercises to perform computational simulations which help to assess the influence of climate in separate agro-ecological zones. Also, satellite imaging and remote sensing can predict vulnerable agro-ecosystems, and timely responses can be developed in case of extreme events of water scarcity, floods, heat waves, etc. Moreover, the adoption of sustainable technologies by farmers is divisive in building resilience of the agricultural sector for which spreading awareness regarding sustainable technology and making it available at affordable rates are important. Besides, efforts should be devoted towards building efficient irrigation systems to tackle extreme climatic events.

Furthermore, the impact of GDP was negative on migration signifying that the need for provision of better employment opportunities and higher wage, and improvement in public services and infrastructure which could potentially decelerate the incentives to migrate. Also, given the positive impact of the "export diversification index" on agriculture output, a number of initiatives can be undertaken to promote export diversification by the government like investing in research and development for new products and crop varieties, improving infrastructure, and providing access to finance. Moreover, market access should be enhanced through trade agreements and quality certification, and support with government incentives and public-private partnerships. Also, farmers can be trained in cultivation of diversified high valued crops in demand in international markets which will not only reduce risk but also promote their earnings.

6.2 Limitations and scope for future studies

It is important to acknowledge the limitations of our analysis. The authors do not claim that climate-driven changes in agriculture are the sole factor influencing migration decisions; other determinants may play crucial roles, as existing literature suggests. Additionally, while our study emphasises direct income effects in the agricultural sector, the pathway from agricultural income shocks to migration is likely multifaceted, varying across countries and involving factors like food security, vulnerability, resource conflicts, and farm diversity, which requires further exploration. Future research should delve deeper into these mechanisms in developing countries to understand how weather-induced agricultural income changes influence migration decisions. Moreover, micro-level studies can further supplement the present study's findings.

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