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Human migration on a heating planet: A scoping review

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Abstract

Whilst people's migration outcomes may be influenced by climate change, the interaction of heat with migration and migrants is little understood. This scoping review explores the relationship between heat and human migration, focusing on i) whether and how heat functions as a driver of migration, and ii) how migrants are impacted by heat across the migratory journey. Four databases were searched for peer-reviewed literature to identify studies reporting on the heat-migration nexus through 18 June 2021, alongside a grey literature search. Of 12,149 peer-reviewed and 476 grey literature records, 187 articles were screened in full, resulting in the inclusion of 50 records (47 peer-reviewed, 3 grey). Publications assessed the impact of heat on human migration (n = 32), or the experience of heat among migrants (n = 18). In the former, 16/32 report a significant positive association where exposure to heat increases the likelihood of migration or intention to migrate. Moderating factors in the heat-migration pathway include other climatic factors, agricultural productivity, economic opportunities, age, and gender. The vast majority of studies assessing the impact of heat on migrants reported negative impacts of heat (such as heat related illness, heat stress and premature mortality) among migrants compared to non-migrants. Heat impacts were aggravated by poor infrastructure, insufficient workplace adaptations, lower educational level, and socio-economic factors. Findings suggest heat may influence migratory patterns in terms of people's intention to move, risk when on the move, and consequences of heat for settled migrants. However, the heterogeneous results suggest heat may not be a driver of migration in all contexts. No literature reported on a so-called 'temperature threshold' above which

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migration is certain. Developing comparability in measurements of heat, heat impacts, and definitions of environmentally-induced migration and migrants may support future research on, risk reduction for, and response to the impact of heat on migration and migrants.

Introduction

The last decade (2011–2020) was the warmest on record, with global near-surface temperature reaching 1.0–1.1˚C higher than pre-industrial levels. The world also experienced numerous pronounced heatwaves, several of which are attributable to or clearly exacerbated by anthropogenic climate change [1]. Under the Paris Agreement, countries agreed to reduce greenhouse gas (GHG) emissions with an ambition to "holding the increase in global average temperature to well below the 2˚C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5˚C above pre-industrial levels [2]." Yet, with current climate policies, estimates suggest warming of 2.7˚C by the end of this century [3]. In the absence of achieving current commitments, global average temperature may even rise higher.

A rise in external heat compromises the body's ability to thermoregulate, with physiological impacts that may amplify existing health conditions, or result in a range of cardiovascular, respiratory, cerebrovascular, renal, psychological and hormonal impacts which can ultimately contribute to premature death and disability [4]. As such, it can be surmised that there are biophysical limits to living under extreme heat. There are a range of observed human responses in relation to rising heat, including adaptation *in situ*, temporary migration in the hottest months, longer-term seasonal migration, and permanent out-migration [5]. The academic literature suggests that heat stress and associated illnesses may limit *in situ* adaptation, stimulating internal and cross-border migration as a necessary response to extreme heat [6] and to limit the effect of rising temperature on health [7].

Importantly, during the migratory journey, migrants may be particularly vulnerable to heat exposure [8], and heat extremes upon settling in a destination may disproportionately impact migrants when compared to non-migrants [9, 10]. Several adaptation measures to heat are already utilised in some settings, such as energy-intensive air conditioning (AC), ventilation, insulation, and landscape design [11]. Such adaptation measures depend on planning and resources, while many areas at risk of extreme heat are low-resource settings, resulting in inequities between those who are able to adapt or migrate in the face of heat, compared to those who cannot.

The link between environmental degradation, displacement and migration is widely debated. Drivers of migration are rarely influenced by a solitary factor but are rather a result of multidimensional and interacting influences. Migrants and those not migrating are rarely homogenous groups which leads to challenges in comparing cohorts [12]. However, climate change projections indicate that without taking suitable action, more people are expected to be on the move whilst global temperatures rise, and heat may negatively affect migrants directly and indirectly. Despite the scattered literature and assumptions on the relationships between heat and migration, frameworks on the drivers of migration have limitedly to acknowledged heat or increasing temperatures as a migration driver [13]. Furthermore, to our knowledge, the landscape of how heat and migration interact, based on the current academic literature, has not been systematically mapped.

Therefore, this scoping review aims to explore the relationship between heat and human migration, by identifying current evidence on migration in the context of a heating planet.

Hereby, our research explores i) whether and how heat functions as a driver of migration, and ii) how migrants are impacted by heat during their migratory journeys and settlement at the destination location.

Methods

This scoping review examines the literature on heat and human migration and explores existing gaps in research, in accordance with the framework described by Munn *et al*. [14]. The protocol was prospectively registered on the Open Science Framework (DOI: 10.17605/OSF.IO/W2TXS). Findings were reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines (S1 Table) [15].

Definition of migration

For the purposes of this study, migration is defined following the International Organization of Migration (IOM) definition: "a person who moves away from his or her place of usual residence, whether within a country or across an international border, temporarily or permanently, and for a variety of reasons, including internal migrants, international migrants, environmental migrants, seasonal migrant workers, asylum seekers, refugees, rural-urban migration, short term migrants and trapped populations" [16]. Internal migration refers to migration within country borders, whilst international migration refers to migration outside country borders. Furthermore, temporary migration usually refers to labour migration across borders for a fixed period of time (usually less than 12 months), whereas permanent migration refers to a change of country of residence for one year or more [17]. All stages of the migratory journey were included in this scoping review, including e.g. migrants in transit and settled first-generation migrants.

Definition of heat

A core body temperature close to 37˚C is maintained through various thermoregulation systems to ensure the optimum temperature for human health and performance. However, above an air temperature of about 35˚C, and/or where air humidity is of a certain saturation that it is no longer possible to sweat, the body may be unable to cool sufficiently. Consequently, the experienced heat stress is associated with a multitude of negative health outcomes including heat cramps (painful involuntary muscle spasms), heat exhaustion (symptoms including heavy sweating, high pulse), heatstroke (body temperature rises to about 40˚C or higher), and hyperthermia (abnormally high body temperature); which can result in hospitalisation or death [4]. For the purposes of this review, studies are included which refer to heat or high temperatures in any form as it pertains to migration. This includes mentions of heat in relation to health, such as heat stress (heat in excess of what the body can tolerate without suffering physiological impairment). We included studies which explored climate change defined as temperature change, or included multiple climatic factors with heat as a defined variable.

One measure often used to quantify heat exposure of relevance to human wellbeing, is the Universal Thermal Climate Index (UTCI) [6, 18]. This is a heat index based on temperature, humidity, air movement and heat radiation; for example on the UTCI, "very strong heat stress" corresponds to an air temperature of 36˚C in the shade and a relative humidity level at 50% [6]. Moderate intensity continuous physical labour under such heat and humidity conditions could lead to a critical rise in body temperature within four hours [6].

Where reported, this review includes measures of humidity (a measure of the amount of water vapour in the air) and wet bulb globe temperature (WBGT; the lowest temperature to

which air can be cooled by the evaporation of water into the air at constant pressure) [19]. This decision was made taking into consideration that humidity and heat have been reported to interact in their impact on human physiology and human behaviour [20].

Search method and information sources

Searches were conducted in four electronic databases without time or language restriction from the date of inception of the databases through 31 July 2021: Ovid Medline, Global Health, Geobase and Social Sciences Citation Index. Key terms related to "human migration", "heat", "high temperature" and "climate change" were utilised, as informed by previous reviews [21, 22]. To identify any further relevant publications, the references of relevant publications were searched. OpenGrey and Google were searched to identify grey literature. In addition, hand-searches of the websites of five organisations working on migration and/or climate change or heat were also conducted. S2 Table provides the full search strategy for the different databases, and the websites searched.

Screening process

Records were imported to Endnote to remove duplicates. After deduplication, titles and abstracts of all records were independently screened by two researchers according to the selection criteria using the software Rayyan (https://rayyan.ai/reviews). After this phase, full texts were double-screened in a similar process. Conflicts in both phases were resolved until consensus was reached among four authors. To be included in the review, articles had to meet the following selection criteria: i) studies that report on the relation between heat and human migration, ii) studies reporting across the migratory journey (premigration, transit, seasonal migration, settling), including studies on individuals identified in the studies as "migrant workers" and first-generation migrants; and are one of the following study designs: iii) quantitative studies, including for example cross-sectional studies, cohort studies, case-control studies, interrupted time series, iv) qualitative studies, including for example participatory research, case studies, ethnographies, v) mixed-method studies, and vi) grey literature such as NGO reports containing primary data or analysis. Exclusion criteria included: i) non-human studies, ii) studies reporting on heat and health but not on migration, iii) studies on other climate- or weather-related drivers (e.g., drought, wildfires, floods), iv) systematic reviews, review papers, editorials, conference proceedings, and studies that lacked access to the full text, v) studies that are on second or further generation migrants, and vi) studies that focus on specific racial or ethnic groups without indicating whether these individuals are migrants. This includes for example "Latino workers". Dadkhah & Bianciardi's criteria were used to screen for predatory journals [23].

Data extraction

Data was subsequently extracted from all included papers using a pre-piloted data extraction form. The following information was extracted: type of study, study setting, methods, study objective, study period, population source, recruitment strategy, type of migration, stage of the migratory journey, primary exposure (heat or migration), outcome (heat or migration), secondary outcome (e.g. health), the total number of participants, total reporting outcome, the measure of association, adjustments, key findings, the definition of heat used, ascertainment of heat, the inclusion of humidity, mentions of other climate or weather impacts, mentions of impacts of heat on the individual, any alleviating/protective factors, vulnerable groups mentioned, recommendations, and study limitations, alongside space to add free text. Furthermore, within this study, we differentiated between studies that explicitly focus on heat and

human migration and studies that only briefly mention this relationship (for example, whilst focusing mostly on adaptation)—outlined in Table 1. Within the data synthesis, more weight was placed on studies that explicitly focused on heat and human migration. All studies were extracted by one reviewer and verified by a second to ensure completeness.

Data synthesis

Methods selection and application are based on Pope *et al.* [24] and Grant and Booth [25]. Due to heterogeneity in outcome and exposures measured, we used narrative synthesis methodology to analyse and report data. Studies with qualitative data (qualitative studies and mixed-methods studies) underwent additional qualitative thematic analysis. Authors independently used inductive analysis to develop and agree on a codebook. This codebook was then applied to all qualitative data by two independent authors (Table 3).

Patient involvement

No patients were involved in conceptualising or conducting the study.

Ethics review

Due to the nature of the study (scoping review), ethics approval was not required.

Results

From the search, 12,149 peer-reviewed records and 476 grey literature records were identified for screening. After duplicates were removed, 11,401 records were screened by title and abstract. 187 records were screened in full-text and a total of 50 records were included in the review, comprising 47 peer-reviewed records and 3 grey literature records (Fig 1).

Characteristics of included publications

Articles assessed the impact of heat on human migration (n = 29 peer reviewed; n = 3 grey literature), or the experience of heat among migrants (n = 18 peer reviewed). Summary characteristics are provided in **Tables 1** and **2** respectively. Studies exploring the impact of heat on migration were based in Australia (n = 4) [11, 26–28], Bangladesh (n = 2) [29, 30], Brazil [31], Burkina Faso (n = 2) [32, 33], China [34], Ghana [35], Indonesia (n = 2) [36], Malaysia [36], Marshall Islands [37], Mexico (n = 1) [38], Pakistan (n = 2) [39, 40], Philippines (n = 2) [36, 41], Senegal (n = 2) [33, 38], South Africa [42], Tanzania [43], Uganda [44] and the United States (n = 4) [37, 45–47]. Two studies took a global perspective [48, 49], one study focused on Eastern Africa [50], and one on Central America and the Caribbean [51]. Studies exploring the impact of heat on current migrants were predominantly based in the United States (n = 11) [52–62], and further based in Australia [63], Italy [64], Mexico [59], Netherlands [65], Pakistan [66], Qatar [67]and Spain [68]. From the peer-reviewed records, 39 quantitative studies, 3 qualitative studies, and 5 mixed-methods studies were included (**Tables 1** and **2**). These included predominantly cross-sectional studies and ecological studies, or qualitative studies using in-depth interviews and focus group discussions. The results of the thematic analysis of qualitative and mixed methods studies are provided in **Table 3**.

Whilst this study did not apply a study period limitation, all studies were published after 2009, with the majority published in the last five years (n = 28). Study periods ranged from 1944 [53] to 2021 [11, 36, 65]. For the studies including human participants, the sample size varied from 22 [68] to 2.3 million [42]. No articles from predatory journals were identified;

Table 1. Summary characteristics of included articles on the impact of heat / high temperature on migration.

Study	Study design	Population	Country	Time period	Aims	Main question heat-migration	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Antwi-Agyei P. et al. 2018 [35]	Mixed-methods including key informant interviews (n = 9), FGD (n = 6 with average 14 pax)), household questionnaire surveys (n = 219)	Three farming communities (Lito, Kusawgu and Yapei-Yipala) experiencing a uni-modal rainfall pattern with one growing season	Ghana	April–June 2015	• Explore the effects of climate change coping and adaptation responses (what are key climatic and non-climatic stressors confronting households, how do households adapt, what are the outcomes of this adaptation)	No, main focus is on adaptive responses to climate change	Temporary migration	Data was obtained from the key informant interviews, FDGs and household questionnaire surveys that were conducted in three case study villages across the Central Gonja district of Northern Ghana	The study identified various measures of adaptation including temporary migration, extensification and intensification of agriculture, planting of drought-resistant varieties, irrigation, livelihood diversification.
Baez J. et al. 2017 [51]	Quantitative study using a triple difference-in-difference approach	Individuals included in the migration census data from Central American and Caribbean countries.	Central America and the Caribbean: Costa Rica, Dominican Republic, El Salvador, Haiti, Mexico, Nicaragua, and Panama	Unclear	• Evaluate the effect of repeated and prolonged heat exposure on inter-province migration	Yes	Internal migration	• Migration data are taken from censuses • Daily temperatures are extracted from the Global Land Data Assimilation System Version 2 (1983–2010) • GDP data adjusted using the purchasing power parity rates in 2011 international dollar	• A 1 standard deviation increase of heat is estimated to affect the lives of 7,314 and 1,578 unskilled young women and men • Youth facing heatwaves are more likely to move to urban centres
Bakar K. S. & Jin H. 2018 [26]	Quantitative study using spatio-temporal statistics	Residents of the Murray-Darling Basin	Australia	2006 to 2014 financial years	• Examine the possible environmental and socio-economic drivers associated with population flows of small communities • Examine possible predictive scenarios due to the effects introduced by climatic extremes.	Yes	In- and out-migration of the Murray-Darling Basin	• Community population flow data from the ABS • Quarterly unemployment data from SLA Markets publications, Australian Government • Socioeconomic data from SEIFA • Daily temperature and precipitation from stations managed by the Australian Bureau of Meteorology	• Environmental variables have a statistically significant association on shaping the population flows distribution • Long-term lagged effect of extreme temperature showed impact on net and out population flows (statistically significant).

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Table 1. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migration	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Bekaert E. et al. 2021 [49]	Quantitative modeling study	Civilian, non-institutionalised population aged >15 covering the entire country.	90 countries worldwide	2010	• Asses at a cross-country level the impact of self-reported exposure to environmental stress on people's migration intentions and their destination of choice	Yes	Internal and international migration	• Survey data of countries in which at least one Gallup World Pol (GWP) has been conducted in 2010	• Having experienced environmental stress (i.e., floods, droughts, or long periods of extreme heat or cold) elevates migration intentions • - The estimated relative risk ratio is highest for intraregional migration
Bohra-Mishra P. et al. 2014 [70]	Quantitative Cohort study of 7,185 original households over 1993–2007	Households that took part in the Indonesian Family Life Survey from 13 of the 27 provinces	Indonesia	1993–2007	• Investigate the effects of variations in temperature and precipitation together with disasters inferring their relative influence on migration	Yes	Permanent and temporary migration (individual and household)	• Indonesian Family Life Survey (IFLS), a household panel survey • Disaster measures from DesInventar database • Climate variations metrics using data provided by the University of Delaware	• Permanent migration is influenced by climatic variations whereas episodic disasters have little to no impact • Temperature has a non-linear effect on migration; above 25 C a rise is related to outmigration increase • Precipitation also has a similar nonlinear effect on migration, but smaller than temperature
Bohra-Mishra P. et al. 2017 [41]	Quantitative Cross-sectional study using census data	People that were part of the 2000 Philippines Census on Population aged 15–65 years at the beginning of migration period	Philippines	1990–2000	• Explore the effects of both climatic variations and extremes on aggregate inter-provincial migration flows in the Philippines	Yes	Internal: inter-provincial, largely rural to urban	• Migration data from 2000 Philippines Census of Population. • Climate variables from data provided by the University of Delaware.	• Rise in temperature increases outmigration • Precipitation does not have a consistent, significant effect • Outmigration is bigger in provinces more agriculturally dependent and have larger rural populations • Migration decisions of youth, men, and highly educated people are more influenced by temperature

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Table 1. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migration	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Call M. A. et al. 2017 [29]	Quantitative Cohort study using census data 1986–2003 on about 200,000 individuals	Individuals that were part of the Matlab surveillance system	Bangladesh	1986 to 2003	• Examine the evolution of temporary migration under changing environmental conditions in Bangladesh	Yes	Temporary migration (more than one month, followed by a return to the study area by 2003)	• Migration data from the Matlab Demographic Surveillance System • Riverine flooding, temperature and precipitation from the Dartmouth Flood Observatory and the NASA POWER database	• High temperatures have sustained positive effects on temporary migration • Migration decreases during extended precipitation
Call M. & Gray C. 2020 [44]	Quantitative Cohort study using the Uganda National Household survey (n = 8,213)	Ugandan households that were part of the Uganda National Household Survey	Uganda	2003–2013	• Estimate the impact of the climate and environmental predictors on temporary and permanent migration	Yes	Temporary migration (absent for at least 1 month during 12 months) Permanent migration (leaving the community	• Household data from the Uganda National Households Survey • Monthly temperature and precipitation from the University of East Anglia Climatic Research Unit	• Climate anomalies are the primary contributor to environmental migration with heat stress of particular importance • Short hot spells increase temporary migration
Cattaneo C. & Peri G. 2016 [48]	Quantitative study Ecological study using migration and environmental data	Global migrants from 115 countries part of the census 1960–2000	Global (115 countries)	1960–2000	• Analyse the effect of differential warming trends across countries on the probability of either migrating out of the country or from rural to urban areas	Yes	Rural to urban migration International migration	• Monthly mean temperature and precipitation data from weather stations obtained from Dell et al. 2012 • Extreme weather events from the International Disaster Database • Migration census data from Ozden et al. 2011 • Urbanization data from the World Urbanization Prospects • Data on value added in agriculture from World Development Indicators • GDP per capita from Penn World Table and World Development Indicators	• Higher temperatures reduce the probability of migration to cities and other countries in poor countries–trapping people in poverty • Migration is an important margin of adjustments to global warming in middle-income countries • Urban migration and international migration is increased by higher temperatures • Higher temperatures increase emigration towards close and non-OECD

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Table 1. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migration	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Carrico A. R. & Donato K. 2019. [30]	Quantitative cross-sectional study	Households in the southwest region of Bangladesh (n = 1695 households)	Bangladesh	2014	• Examine the relationship between extreme weather conditions and the likelihood of male household making internal migration trips • Explore how agricultural livelihoods relate to migration in response to extreme weather	Yes	First migrant trip (a trip outside of the upazila (subdistrict) for three months or longer	• Data from the Bangladesh Environment and Migration Survey (BEMS) • Daily temperature and precipitation data from the meteorological station in Jessore • From above indicators are used developed by the Expert Team on Climate Change Detection Indices	• No support that warm spells are more strongly related to migration than precipitation • Data suggest that relation between extreme heat and migration is a function of livelihood type • For internal migration, likelihood of making a first migrant trip is only employed in the agricultural sector after warm spells. • Similar but less reliable results found for international migration
Fan Q. et al. 2016 [45]	Quantitative Cross-sectional study using population census data	U.S. citizens that took part in the 2000 population census	United States	1991–2000	• Examine the effects of extreme weather on heterogeneous household location choices across the United States	Yes	Internal migration	• Population data from the Integrated Public Use Microdata Sample (5% microdata from 2000 U.S. Population Census) • Weather extremes data from the National Climate Data Center	• College graduates are more sensitive to extreme temperature; they are willing to pay more to avoid hot weather • The West and Southwest may be at risk of losing skills due to predicted increase in extreme heat days
van der Geest K. et al. 2020 [37]	Mixed-methods Cross-sectional survey (n = 278), focus group discussions, expert interviews and geo-spatial analysis	Marshallese migrants in the U.S. and Marshallese in the Marshall Islands	Marshall Islands, United States	Summer and autumn 2017	• Explore relation between climate and migration in the Pacific and beyond / to study whether climatic stressors are a driver of Marshallese migration	No, main focus is on climate change not specifically heat	International migration	• Household questionnaire data • Data from the focus group discussions and expert interviews	• Only a few respondents mention climate impacts or environmental change as migration driver • Respondents do identify impacts of climate change on their livelihoods • 62% of Marshallese migrants in the U.S. mentioned that climate change impacted their return decision

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Table 1. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migration	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Hanberry B. B. 2020 [46]	Quantitative	U.S. citizens	United States	Fire risk was presented for 1971–2000, 2010–2039 and 2040–2069	• Examine recent, past, current and near future fire and heat hazards combined with population growth • Examine whether US residents will move from heat risk areas into fire risk areas and whether some residential densities are more at risk	Yes	Unclear	• Climate and Land Use Scenarios data	• People in the U.S. experience more exposure to fire hazard and heat over time due to climate change, but adaptive response by migration was limited • Movement to urban centers may offset exposure to fire but not heat, as urban areas are heat islands
Hirvonen K. et al. 2016 [43]	Quantitative Cross-sectional study using survey data (n = 915 households at baseline, >3,300 2010)	Households from 51 villages that were interviewed in Kagera for the Kagera Health and Development Survey	Tanzania	Unclear	• Explore the extent to which migration rates are constrained by liquidity constraints in rural Tanzania	No, main focus on whether migration rates are constrained by liquidity constraints	Internal migration	• Population data from the Kagera Health and Development Survey • Temperature data from NASA's MERRA • Historical precipitation data from the Tanzanian Meteorological Agency	• Household consumption co-moves with temperature, making households vulnerable to local weather events • These temperature-induced income shocks inhibit long-term migration among men, preventing them from tapping in opportunities
Lohano H. D. et al. 2015 [40]	Quantitative Ecological study using district-level Census data in Pakistan	Citizens of Pakistan that are part of the Census data	Pakistan	Unclear	• Investigate how changes and variability in weather may affect internal migration through the agriculture channel.	Yes	Internal migration (through the agriculture channel)	• Migration data for each district of Pakistan from census reports • Data on production and area of each crop from government publications • Data on crop prices from FAOSTAT database • Consumer price index from State Bank of Pakistan • Mean temperature and precipitation from the Pakistan Meteorological Department	• Temperature has a non-linear effect on crop revenue per hectare • Predicted temperature increase and variability are likely to decrease crop revenue in warm districts and increase in cooler districts • This would decrease in-migration and increase in-migration in different district

(*Continued*)

Table 1. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migration	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Mastrorillo et al. 2016 [42]	Quantitative Cross-sectional study using Census data	Migrants 15–64 years old, identified in the census data.	South Africa	1997–2001 and 2007–2011	• Examine the effect of spatiotemporal variability in temperature and precipitation on inter-district migration flows defined by five-year intervals	Yes	Interdistrict migration	• South Africa's 1996, 2001 and 2011 censuses • 2007 Community Survey • Climate data from the African Drought and Flood Monitor project	• Increases in positive temperature enhance out-migration • Compared to White and high-income migrants, Black and low-income migrants are more affected by climate • A channel through which adverse climate influences migration may be agriculture
Mueller V. et al. 2014 [39]	Quantitative Cohort study using a longitudinal survey (n = 4,428)	Individuals part of the Pakistan Panel survey between 15–39.	Pakistan	1991–2012	Understand the relationship between climatic factors and drive to migrate	Yes	Permanent migration	• Population data from the Pakistan Panel Survey and two tracking studies • Weather data from various data sources including e.g. NASA-POWER, Dartmouth Flood Observatory	• Heat stress increases long-term migration of men, driven by negative impacts on non-farm and farm income
Mueller V. et al. 2020 [50]	Quantitative Cohort study using a longitudinal survey (55,277 person-years)	Participants in the LSM-ISA survey based in Ethiopia, Malawi, Tanzania and Uganda	Eastern Africa (Ethiopia, Malawi, Tanzania, Uganda)	2009–2014	• Identify whether workers use temporary migration as a form of adaptation to climate variation • Explore what motivates this behaviour	Yes	Temporary migration	• Migration, labour and demographic data from the Living Standards Measurement Study-Integrated Surveys on Agriculture • Climate data from MERRA	• A standard deviation increase in temperature leads to a decrease in urban temporary out-migration • Climate variability does not impact rural out-migration • Local employment opportunities and urban out-migration vary inversely

(*Continued*)

Table 1. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migration	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Nawrotzki R. J. et al. 2016 A [38]	Quantitative using longitudinal data to perform multilevel discrete-time event-history models	Households in between four and six communities located throughout Mexico	Mexico	1986–1999	• Explore whether climate change more strongly impacted international compared to domestic migration from rural Mexico	Yes	Domestic migration International migration	• Migration and socio-demographic data from Mexican Migration Project • Climate data from Global Historical Climate Network–Daily data sets	• Climate change more strongly impacts international migration from rural Mexico compared to short distance and domestic migration • Warming of temperature increased international outmigration • Higher precipitation declines odds of international migration
Nawrotzki R. J. et al. 2016 B [32]	Quantitative Ecological study	Households in Burkino Faso and Senegal that were part of the Terrapop dataset	Burkina Faso, Senegal	2002 and 2006	• Explore variations in the climate-migration association in Burkina Faso and Senegal based due to differences in local food security	Yes	International migration	• Sociodemographic data and detailed climate information from the TerraPop data access system • Food security data from Demographic and Health Surveys	• Increase in heatwaves is associated with decrease in international migration in Burkina Faso • Adverse impacts of heat waves and droughts are amplified in highly food insecure departments
Nawrotzki R. J. et al. 2017 A [33]	Quantitative Ecological study (n = 133,686 households in Burkina Faso and 57,052 households in Senegal)	Households in Burkino Faso and Senegal that were part of the Terrapop dataset	Burkina Faso, Senegal	1960–2010	Investigate the impact of climate variability on the odds of household-level migration	Yes	International migration	• Population and climate data from TerraPop extraction system of PUMS-International	• Excessive precipitation increases international migration from Senegal • Heat waves decrease international mobility in Burkina Faso • Climate change impact show clear seasonal pattern, stronger effects when heatwaves overlap with growing season

(*Continued*)

Table 1. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migration	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Nawrotzki R. J. et al. 2017 B [72]	Quantitative Crossectional study using individual level Census data	Individuals part of the Mexicum censuses from IPUMS International	Mexico	2000–2010	• Examine whether climate shocks influence internal migration patterns between rural and urban areas in Mexico • If so, explore differences manifested in nonlinearities and thresholds in the observed climate-migration relationship	Yes	Rural-urban migration	• Individual level population data from Mexican censuses (2000 / 2010) • Climate data from Terra Populus linked to census data at municipality level	• Increase in heat months is likely associated with rural-urban migration in a U-shaped, quadratic functional form • After 34 heat months threshold is surpassed, the relationship between heat months and rural-urban migration is positive and progressively increasing in strength.
Oliveira J. & Pereda P. 2020 [31]	Quantitative Cross-sectional study using Census data	Workers aged 25–60 in Brazil that took part of the census	Brazil	1980, 1991, 2000 and 2010	• Study impacts of climate on migration, spatial distribution of people and economic activity	Yes	International migration Regional migration	• Population microdata from population censuses of 1980, 1991, 2000 and 2010	• Under future climate conditions migration rates are 9.65% higher with 0.9 million more people migrating inter-regionally • Under A2 scenario (high emissions) migration rates are projected slightly larger due to higher temperature changes than B1 scenario (low-emissions)
Poston D. L. et al. 2009 [47]	Quantitative Ecological study using aggregate-based analysis	People included in the US census	United States	1995–2000	• Explore whether climate is an influential factor in internal migration	Yes	Internal migration (in, out and net)	• Population weighted climate data from the National Climatic Data Center, US Bureau of the Census	• Temperature is significantly related with net migration but not with out-migration or in-migration • Humidity is associated significantly with all three migration rates • Wind is not significantly associated with any of the migration types

(*Continued*)

Table 1. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migration	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Zander K. K. et al. 2016 [7]	Quantitative Cross-sectional study using questionnaires (n = 1839)	Working-age people living in Australia	Australia	Last two weeks of May and the first two weeks of October 2014	• Explore the extent to which heat influences intentions to move away from the current place of residence and compare this with other common determinants of moving intentions and mobility	Yes	Migration (not further described)	• Commissioned online survey during two waves. Sample was derived from an online panel (MyOpinions PermissionCorp)	• 11% of survey respondents intend to migrate because of increasing temperature • Those more likely to have intend to move are men, those stressed by heat, those worried about climate change, those with high mobility • Age does not explain movement intend
Zander K. K. et al. 2019 [36]	Quantitative Cross-sectional study using questionnaires (n = 2219)	Urban			populationsbased in Indonesia, Malaysia and Philippines	Indonesia, Malaysia, Philippines	22 May 2017 and 21 January 2021	• Assess heat stress among the urban population • Investigate how heat stress affected intentions to move as an adaptation strategy	Yes
Migration (not further described)	• Online survey administered through the use of an online crowdsourcing platform Microworkers	• Though in different levels, almost all respondents experienced heat stress (98%) • 23% reported that they were very likely to move due to heat and 50% that they probably would • Women and older people were associated with stronger moving intentions							

(*Continued*)

Table 1. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migration	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Zander K. K. et al. 2020 [27]	Quantitative Cross-sectional study using questionnaires (n = 1101)	Adults (>18yrs) collectively forming a representative sample of national age, gender and residential distribution	Australia		• Explore the extent to which people in Australia consider natural hazards in their location choices and mobility decisions	Yes	Internal migration	• Online commissioned survey that was sent using Survey Sampling International to sent links to panel participants	• Secondary in people's migration decisions were environmental factors • High wildfire risk was most important • Heat waves lacked in influence on migration decisions
Zander K. K. & Garnett S. T. 2020 [28]	Quantitative Cross-sectional study using questionnaires (n = 650)	Residents of the Greater Darwin Area who filled out a randomly distributed questionnaire	Australia	2019	• Assess the extent to which heat influences migration intentions • Identify the type of people most likely to leave because of heat	Yes	Internal migration International migration	• Population data from a mail-drop off questionnaire	• Heat (coupled with humidity) was the third most important reason for international migration • A strong age-effect; heat became more important than employment for people >50 yrs and became mot important reason to leave >69 years
Zhou J. 2011 [34]	Quantitative Cross-sectional study using survey data (n = 25,959 individuals)	Residents in china that were part of the Chinese Household Income Project	China	2002	• Estimate the effect of extreme weather events on migration	Yes	Rural to urban migration	• Population data from the Chinese Household Income Project (CHIP) • Climate data from the China Meteorological Data Sharing Service System	• Migration preference from rural area to a city is correlated with avoiding exposure to hot weather • High temperature change raises probability to migrate in a nonlinear manner
Grey literature									
Karácsonyi et al. 2021 (Book) Kerstin K. Zander et al. (Chapter 8) [11]	Quantitative Cross-sectional study (n = 1925)	Respondents to the MyOpinions survey in Australia (n = 1925).	Australia	October 2014	• Investigate the impact of increasing heat stress on the intention to migrate to cooler places as adaptation strategy	Yes	Internal and international migration	• Online survey through MyOpinions that has a continuously update panel of >300,000 respondents within Australia	• 11% of respondents indicated being stressed by heat and that this was a reason for migration intentions (n = 133) • People living in NT were more likely to intend to move due to heat

(*Continued*)

Table 1. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migration	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Umar M. A. & Saeed F. 2018 (PRISE working paper) [91]	Quantitative working paper using a household survey (n = 80)	Households ro rural (non-migrant) and peri-urban areas (migrant) from Faisalabad city and district	Pakistan	Unclear	• Understand the relation between heat stress and migration decisions (both related to livelihood impacts and through thermal comfort levels)	Yes	Rural to urban migration	• A household survey conducted by PRISE	• Majority of rural population is using as an adaptation strategy to reduce climatic vulnerability migration. • Role of heat stress in the decision of migration is not significant in the study areas (in terms of its impact on thermal comfort)
Wodon Q. et al. 2014 (World bank study) Josep G. et al. (Chapter 9) [92]	Quantitative study using cross-sectional data	Households part of the 2004 census of the Republic of Yemen with individuals in 333 districts.	Republic of Yemen	2004	• Determine the determinants of past net internal migration rates	Yes	Internal migration	• Internal migration data for the Republic of Yemen census of 2004 • Weather data on annual mean temperature and rainfall and their variability are collected from BIOCLIM	• Results suggest that the impact of temperature on net migration rates is small. • When modelling predicted values for future temperature it is suggested that there are limited changes in patterns of migration resulting from rising temperatures

Abbreviations: ABS: Australian Bureau of Statistics; FAOSTAT: Food and Agricultural Organization of the United Nations; MERRA: Modern-Era Retrospective analysis for Research and Applications; SEIFA: Socio-Economic Indices for Areas; POWER: Prediction of Worldwide Energy Resource; PRISE: Pathways to resilience in semi-arid economies

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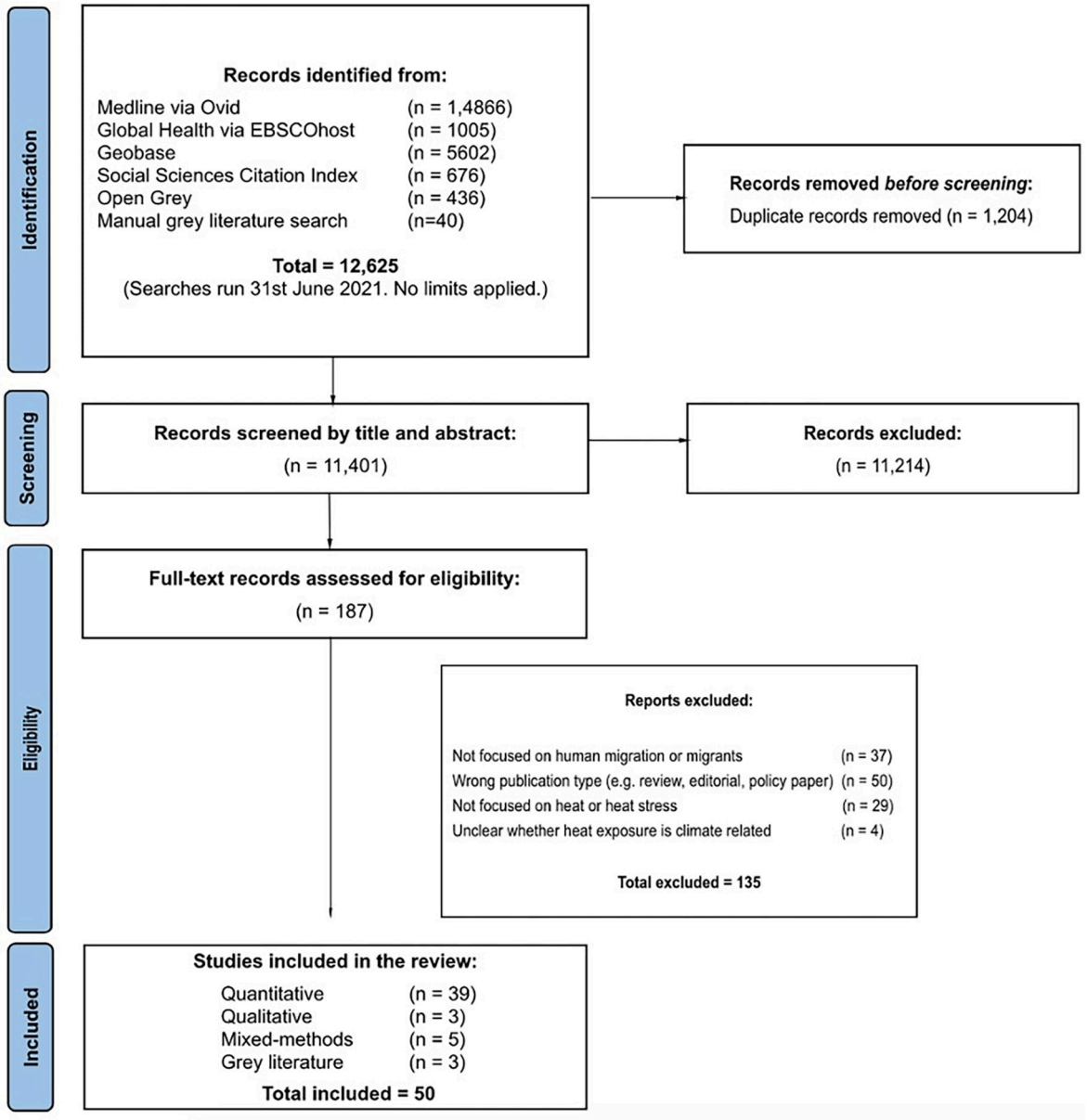

Fig 1. Flow diagram of search.

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due to the scoping review study design, a more nuanced Quality Assessment of the papers was not performed [69].

Migration characteristics

The characteristics of migration and migrants varied when heat was being explored as a driver for migration, or when heat was explored for its impacts on migrants. However, in both categories, studies predominantly explored migration or migrants from low- and middle-income countries (LMICs) migrating to high-income countries (HICs). In the former category, the majority of papers (n = 19) concerned internal migration, including pre-migration (migration contemplation or intention to migrate) (n = 5) [7, 27, 35, 36, 47], rural-urban (n = 3) [34, 37,

Table 2. Summary characteristics of included articles on the impact of heat / high temperatures on migrants.

Study	Study design	Population	Country	Time period	Aims	Main question heat-migrants	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Arnold T. J. et al. 2020 [52]	Mixed-method Qualitative in-depth interviews (n = 30), and cross-sectional survey data (n = 165)	Lantinx child farmworkers 10–17 yrs old working in agriculture in the last 12 months	United States	2016–2017	• Describe how Latinx children perceive heat hazards reports frequencies of HRI symptoms and protective behaviours among Latinx child farmworkers • Examines associations between personal characteristics and experience of HRI symptoms and protective behaviours	Yes	Seasonal migration	2016 in-depth interview and 2017 baseline survey interview data from a longitudinal Community-Based Participatory Research study examining the health and safety of Latinx child farmworkers	Among child farmworkers HRI is common. Children discussed symptoms such as dizziness, headaches and feeling as fainting which they attributed to working in heat and sun. Work organisations often prevent children from taking precautions even though the children often understand the dangers of working in heat.
Chambers S. N. et al. 2020 [53]	Quantitative spatial analysis in combination with remote sensing and heat balance equation	Migrants in Southern Arizona	United States /Mexico	Records from 1944–2020	• Develop a methodology and model to measure the projected increase in core temperature for migrants in the Sonoran Desert	No—main focus on development geospatial measure	International migration	• U.S. Geological Survey data	Traversing of rugged terrain can serve as an avoidance strategy and border policy effect, but also used as a survival strategy
Culp K. & Tonelli S. 2019 [54]	Mixed-methods Cross-sectional survey (n = 148) and intensive surveillance on smaller group (n = 20) consisting of field trials (n = 57)	Hispanic or Latino farmworkers from two farms in Iowa. One farm contracting workers directly from Mexico, one from Texas	United States	June-July (year not clearly stated)	• Examine HRI signs and symptoms in Midwestern migrants and seasonal farmworkers with HRI symptoms • Measure workers' physiological response to different climate conditions performing crop production tasks	Yes	Seasonal migration International migration	Cross-sectional survey and intensive surveillance data	Workers of field trials in the uncomfortable category had statistically significant higher body temperatures than those in mild or moderate categories. These workers also had a higher mean heart rate and breathing rate.

(*Continued*)

Table 2. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migrants	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Fleischer N. L. et al. 2013 [55]	Quantitative Cross-sectional survey (n = 405)	Adults attending the South Georgia Farmworker Health Project clinics	United States	June 11–23, 2011	• Determine which risk factors could potentially reduce the prevalence of HRI symptoms among migrant farmworkers in Georgia	Yes	Not clearly stated	Cross-sectional survey data of migrant workers who attended the Emory University Physician Assistant Program's South Georgia Farmworker Health Project	71% experienced at least one symptom in the preceding week while working or spending time outside (including headache), and 63% of participants had experienced at least one symptom (excluding headache).
Fuller S. & Bulkeley H. 2013 [68]	A qualitative pilot study using interviews (n = 22)	UK nationals that have moved to Spain aged 37–80	Spain	Unclear	• Explore adaptive practises in relation to heat with people who have recently migrated to Spain	No, main focus is on adapting strategies for UK migrants to Spain	International migration	• Qualitative interview data	• Recent UK migrants to Spain adapt in various ways including air conditioning, adapting routines (daily and annually)
Hansen A. et al. 2014 [63]	Qualitative study using in-depth interviews and FGDs (n = 36)	Key informants associated with migrant groups: government, NGOs, migrant/ refugee health services	Australia	December 2011—April 2012	• Explore how migrants from different cultural backgrounds and climate experiences manage periods of extreme heat in Australia	Yes	International migration	• Qualitative data from interviews and focus groups	• Sociocultural barriers encountered by some migrants and refugees that hinder environmental adaptation to periods of extreme heat • Most at risk are new arrivals, people in new and emerging communities and older migrants
Kearney G. D. et al. 2016 [56]	Quantitative Crossectional study based on questionnaires (n = 158)	Farmworkers recruited from five migrant housing camps that were >18 yrs	United States	August—September 2013	• Estimate the prevalence of heat-related symptoms and potential risk factors associated with sun safety-related behaviour among Latino farmworkers	Yes	Not clearly reported, H-2A status implies temporary or seasonal migration	• Crossectional survey data interviewer-administered	• 72% experienced at least one HRI symptom and lacked proper cooling methods outdoors • 27% workers had three or more HRI symptoms

(*Continued*)

Table 2. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migrants	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Mashhoodi B. et al. 2021 [65]	Quantitative Ecological study using semi-parametric geographically weighted regression models	Inhabitants of the Netherlands	Netherlands	Summer 2014	• Identify inequalities in land surface temperature	No, main focus is on inequalities in exposure to land surface temperature	International migration	• Population data from the Dutch central bureau for statistics • Average summertime land surface temperature from MODIS satellite images	• At a local-scale, western and non-western immigrants are more often exposed to high land surface temperature
Messeri A. et al. 2019 [64]	Quantitative Crossectional study based on a self-administered survey (n = 104)	Workers based in Palagio farm, Oscar Tintori farm and Temporary business associations set up for construction on the Florence tramway	Italy	Summer 2017	• Investigate how cultural aspects influence heat-stress precipitation and management among immigrant and native workers	Yes	International migration	• Crossectional survey data • Microclimatic monitoring data from a complete weather station (HOBO U30 NRC)	• Migrant workers reported less impact from heat on productivity and thermal discomfort than Italian workers • Migrant workers were mainly informed on heat-health issues through written/oral communication whilst native workers received training
Pradhan B. et al. 2019 [67]	Quantitative Crossectional survey based on mortality data	Nepali migrant workers in Qatar that were included in the mortality data from Nepalese government agencies	Qatar	2009–2017	• Explore whether occupational heat exposure causes cardiovascular mortality among Nepali migrant workers	Yes	International migration	• Mortality data from Nepalese government agencies related to foreign migrant workers daily climate data from the Climate Data and Heat Exposure Software and Database monthly Qatar grid cell climate data from the Climate Research Unit, University of East Anglia	• Increased CVD mortality is most likely due to severe heat stress during hot periods • Out of 571 deaths 200 could have been prevented during 2009–2016 with effective heat protection in local occupational health and safety programs

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Table 2. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migrants	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Quandt S. A. et al. 2013 [57]	Quantitative Crossectional survey (n = 170)	Migrant farmworker camps selected in 16 counties in eastern North Carolina	United States	June—October 2010	• Describe the burden of heat experienced by migrant farmworkers in grower-provided housing in North Carolina and the impact of air conditioning or fans	Yes	Unclear	• Temperature and relative humidity measurements by Digital Thermo Hygrometers with DataLogger	• Most heat index measurements in the common and sleeping rooms exceeded the danger threshold
Quandt S. A. et al. 2019 [58]	Qualitative In-depth interviews (n = 30) and conceptual models	Latinx child farmworkers ages 10 to 17 that were hired to work in agriculture in North Carolina	United States	June—September 2016	• Describe Latinx children hired to work in agriculture in North Carolina experience their work situation	No, the main focus was on the experience of the work situation	Seasonal migration International migration	• Data from open-ended face-to-face interviews	• Significant demands to work quickly and take risks including operating mechanical equipment and working in excessive heat • Heat most oppressive physical work demand
Ruttan T. et al. 2013 [59]	Quantitative Retrospective cohort study / validation study	Cases with a cause of death attributed to heat and that were suspected undocumented border-crossers (unknown nationality or non-U.S. nationality)	United States/ Mexico	January 2002—August 2009	• Validate and refine the association between death and DHT build a prediction model of heat deaths among undocumented border crossers	Yes	International migration	• Mortality data from the Pima and Cochise County Medical Examiner's case records • Ambient temperature data from the NOAA National Weather Service (Tuscon main reporting station)	• Probability of at least one heat death was 50% at a critical threshold DHT of 40˚C
Taylor E. V. et al. 2018 [60]	Quantitative Cross-sectional study using mortality and census data	Individuals that died due to excessive heat exposure based on the NVSS restricted mortality data	United States	January 2005—December 2014	• Determine whether non-US citizens have a higher mortality risk of heat-related deaths than do US citizens.	Yes	International migration	• NVSS restricted mortality data on death from excessive heat exposure • US Census ACS data on self-reported citizenship status and birthplace	• Age-adjusted standardized mortality ratio for non-US citizens compared with US citizens 3.4 (95% CI = 3.2, 3.6) • Higher risk for Hispanic non-US citizens (risk ratio [RR] = 3.6; 95% CI = 3.2, 3.9) and non-US citizens aged 18 to 24 years (RR = 20.6; 95% CI = 16.5, 25.7)

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Table 2. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migrants	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Umar M. A. et al. 2018 [66]	Mixed-methods Ecological component using three regional climate models Qualitative household survey (n = 80)	Peri-urban (migrant) and rural (non-migrant) population in Pakistan	Pakistan	Unclear	• Understand the differences in exposure, impacts, and responses to heat stress between peri-urban (migrant) and rural populations (non-migrant) • Explore how crucial a role heat stress plays in impacting migration decisions	No, main focus is on the impact of heat stress	Rural to urban migration (internal)	• Data of three regional climate models from the Climate Service Center, Germany; Rossby Centre, Sweden; CSIRO, Australia	• Peri-urban participants came from rural areas to reduce their vulnerabilities—however due to low education level / skills—they have only been limitedly able to reduce vulnerabilities and improve livelihood
Wagoner R. S. et al. 2020 [71]	Quantitative, Cross-sectional study using a questionnaire (n = 28)	Migratory farmworkers from a commercial grape farm near Hermosillo, Mexico	Mexico	March, June and August 2016	• Assess the heat and hydration status of a vulnerable occupational groups during the growing season • Describe the demographics and occupational history of a largely invisible population	Yes	Temporary (seasonal) migration	• Questionnaire data from migratory farmworkers • Wet Bulb Globe Temperature measurements using a handheld electronic heat stress monitoring device	• Across the different seasons, the majority were dehydrated post-shift, and mean core body temperature of workers was not significantly different • Dehydration status of the body can moderate the response of the body to heat
Yabiku S. T. et al. 2009 [61]	Quantitative, Cross-sectional study using survey data (n = 808)	People that were part of the Phoenix Area Social Survey	United States	2006	• Examining the potential role of environmental factors in explaining the immigrant health paradox with a focus on self-rated health, heat stress and asthmatic symptoms	Yes	International migration Internal migration	• Survey data from the Phoenix Area Social Survey	• Local frequent migration negatively impacts health • Subjective measurements of the local environment have a great effect than objective measurements • Local environment and neighbourhood partially mediate difference been foreign-born Hispanics and US-born non-Hispanic Whites • Hispanic foreign-born respondents report highest frequency of heat stress

(*Continued*)

Table 2. (Continued)

Study	Study design	Population	Country	Time period	Aims	Main question heat-migrants	Migration type	Key data sets	Estimate/key finding
Peer-reviewed publications									
Zhang K. et al. 2016 [62]	Quantitative, Cross-sectional study using EHR from 14481 patients.	Patients that went to the Colorado center during the study period	United States	June to August 2013	• Estimate the effects of heat on mean daily counts of clinic visits among migrant and seasonal farmworkers	Yes	Seasonal migration International migration	• EHR data from one health centre in Colorado participating in the Community-Based Research Network • Hourly weather data from the NCDC • Hourly ozone measurements from three US EPA monitors	• Heat effects on average daily clinic visits among migrant farmworkers were positive. • No statistically significant associations between heat and clinic visits among other stratified groups was observed

Abbreviations: ACS: American Community Survey; CI: confidence interval; EHR: electronic health record; EPA: Environmental Protection Agency; FDG: focus group discussions; HRI: heat-related illness; NCDC: National Climate Data Center; NOAA: National Oceanic and Atmospheric Administration; NVSS: National Center for Health Statistics through the National Vital Statistics System

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48], and inter-district migration (including labour mobility) (n = 7) [27, 35, 40–42, 51, 70]. Some studies mentioned temporary international migration (n = 5) [29, 35, 44, 50], whilst others included permanent migration (n = 9) [27, 31–33, 37, 38, 48, 49, 70] [Table 1]. Of the studies concerning the impacts of heat on migrants, 3 were non-specific with regards to the type of migration assessed [55–57]. 13 papers assessed the impact of heat exposure on temporary or permanent international migrants [52–54, 58–65, 67, 68]. Of these, 10 studies explored heat on agricultural workers: 4 studied settled Hispanic/Latino migrant workers in the USA [54–56, 62], and 3 concerned seasonal migration of Latinx farmworkers [52, 57, 58] in the USA. Whereas, 2 studies explored the impact of heat on migrant construction workers: Nepali migrant workers in Qatar [67], and migrant workers (primarily from Albania) constructing the Florence tramway, Italy [64]. 2 studies focused on heat exposure in migrants crossing the US-Mexico border [53, 59]. Experience of heat in HIC was explored for UK nationals migrating to Spain [68], and non-agricultural or labour migrants in Australia [63], the Netherlands [65], Pakistan [66] and the US [61, 66].

Definition and ascertainment of heat

There was high heterogeneity in the definition of 'heat' utilised across studies. For studies concerning the impact of heat on migrants, definitions were primarily concerned with the impact of heat on human physiology. This included measures such as body temperature [53, 54, 71], heat-related deaths [59, 60, 67], heat stress and symptoms related to heat [57, 61, 66, 67, 71], and clinic visits related to heat [62]. Some studies observed how heat influences human behaviour and perception, for example regarding respondents "perception of heat" [68].

Furthermore, 15 studies reported on average air temperature (whether Celsius or Fahrenheit) over time. Whereas other studies recorded "high" temperatures, defined in a number of ways: higher than 32˚C/ 90˚F [45, 54, 64]); higher than 27˚C (uncomfortable to work) [29, 54,

Table 3. Thematic analysis of qualitative and mixed-methods studies.

	Impact of heat on migration		Impact of heat on migrants					
	Antwi-Agyei P. et al. 2018 [35]	Van der Geest et al. 2020 [37]	Arnold T. J. et al. 2020 [52]	Culp K. & Tonelli S. 2019 [54]	Fuller S. & Bulkeley H. 2012 [68]	Hansen A. et al. 2014 [63]	Umar M. A. et al. 2018 [66]	Quandt S. A. et al. 2019 [58]
Themes // Study type	**Mixed methods**	**Mixed methods**	**Mixed methods & Qualitative**	**Mixed methods**	**Qualitative**	**Qualitative**	**Qualitative**	**Qualitative**
Type of migration								
Seasonal			X	X				X
Labour	X		X	X				X
International		X			X	X		
Rural-Urban							X	
Impact of heat on health & wellbeing								
Self reported	X	X	X	X	X	X	X	X
Physiological measurement				X				
Adaptive measures				N/A		N/A		N/A
Air Conditioning/ cooling equipment			X		X		X	
Adapting day-to-day routine e.g. work hours, meal times			X		X		X	
Oral hydration					X		X	
Adaptive clothing					X			
Livelihood diversification	X						X	
Agricultural diversification	X							
Precipitating factors & vulnerabilities					N/A			
Socioeconomic status	X					X		
Education level		X					X	
Age (older/ younger)			X			X	X	X
Work environment								
• Operating equipment								X
• Agricultural labour	X		X	X		X	X	X

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70]; "in excess of extreme temperature quintiles" [26]; more than 1 standard deviation (SD) above a 30-year baseline [26, 32, 72]; numbers of heatwaves (temperatures >45˚C for 5 days) [32]; and, a z-score to measure temperature variation [50]). Indexes used to measure heat include Universal Thermal Climate Index (UTCI) [54], Neighbourhood Heat Index [61], Wet-Bulb Globe Temperature (WBGT) [54, 64], and the Moisture Index [39, 42].

Humidity as it directly relates to heat and human functioning was mentioned in 7 articles [45, 39, 54, 57, 62–64], or more generally with regards to precipitation in 3 articles [29, 40, 42].

Impact of heat on migration

Overall, 29 studies explored the impact of heat on migration (Table 1), this included 28 quantitative studies, and 3 mixed-methods studies. Of these studies 2 adopted a global approach [48, 49], 22 studies focused on one particular country, while 6 included 2 or more countries [32, 33, 36, 37, 50, 51]. Australia was the most studied (n = 4). From the quantitative studies, 16 reported a significant positive association between heat exposure and human migration (exposure to heat increasing the likelihood of migration) [26, 31, 33, 38, 41, 44, 48–51, 70, 73] and 7

reported statistically non-significant positive associations [27, 35, 37, 40, 45, 46]. 6 studies reported statistically significant negative associations (heat exposure decreasing the likelihood); for example, two studies found a standard deviation increase in temperature leads to a decrease in urban temporary out-migration [30, 50]; and that in Burkina Faso, an increase in heatwaves is associated with decrease in international migration [32, 33]. Two articles that explored the impact of heat exposure on the intention to migrate reported that between 11% (133/1266) [7] and 50% (1109/2219) [36] of survey respondents probably would move as a result of increasing temperatures and heat. A quantitative modelling study across 90 countries found that exposure to environmental stress, including extreme heat, extreme cold, drought and flood, was associated with a statistically significant increase of domestic, intra-regional and international migration across different contexts [49]. In contrast, an ecological study using migration and environmental data from 115 countries over 1960–2000 displayed more nuanced results, with higher temperatures being significantly associated with higher emigration rates in middle-income countries and lower rates in low-income countries [48]. In addition, higher temperatures could lead to reduced migration rates from rural to urban areas, in part due to a poverty trap, where increasing temperature decreases rural population income, reducing the probability of emigration [48].

Climatic factors and migration

Studies varied in terms of how heat was considered; some focused on acute heat events—such as heatwaves, or 'uncharacteristically high heat'[26, 32, 33, 39, 72]; others considered heat across a season [41, 29, 35, 40, 70], and others longer term or more gradual changes in temperatures [38, 51]. Several studies considered other environmental factors with decisions to migrate. Hazards examined include drought [33, 35, 72], floods [27, 35, 39, 41], irregular precipitation [29, 31, 35, 38–40], and typhoons [41], and wildfires and cyclones [27]. Sometimes, disasters were considered directly [70]. In Australia, a cross-sectional study using spatio-temporal data between 2006 and 2014 explored various environmental and non-environmental factors in the Darling Basin, and found a statistically significant association between long-term exposure to extreme temperatures and out population flows [26]. However, another study conducted in Australia using a best-worst scaling design to explore both environmental and non-environmental factors influencing migration decisions, indicated that the leading determinants of internal labour mobility were non-environmental (e.g., safety, living cost, access to health services). Whilst wildfire risk did have an impact on migration decisions, the impact of heatwaves on migration decisions was not statistically significant [7]. Similar results were found in the United States, with wildfires being associated with increased migration to urban centres whilst elevated temperatures were not. This could be explained by the urban heat island effect, referring to higher air temperatures in city centres compared to surrounding suburban areas [46]. In contrast, another United States-based study exploring the impacts of climate variables (e.g. temperature, humidity, precipitation, wind) on migration between 1995 and 2000 found a significant relationship between temperature and net migration, but not when assessing out-migration or in-migration individually [47].

Heat, migration and agricultural productivity

Six studies explored agricultural productivity as a potential moderator of the link between heat and human migration [4, 30, 33, 40–42]. In Bangladesh, a strong and significant positive interaction was found between livelihoods type and extreme heat for internal migration of household heads [30]. Men working in the agricultural sector were the only population group for which exposure to a warm spell was associated with a higher likelihood of making the first

migrant trip [30]. In the Philippines, higher temperatures were associated with a decrease in rice yield (used as a proxy for agricultural productivity) and increased outmigration; the authors suggest an economic driver (agricultural productivity) for migration driven by heat as a mediator for migrating, particularly for men [41]. In South Africa, positive temperature extremes significantly increased out-migration across districts within five-year intervals. The relationship was found to be particularly strong among Black and low-income South African people. As a consequence of the apartheid, this population group is largely located in the most marginal agricultural lands, suggesting that the association might be influenced by the impact of temperature on agriculture [42]. A significant nonlinear relationship was found in Pakistan, with high temperature decreasing agricultural productivity in warmer districts and increasing it in colder ones. As a result, the study predicted that increased absolute temperature and temperature variability between 2016 and 2035 could increase out-migration in warmer districts of Bangladesh and increase in-migration in colder ones [40]. When modelling migration trends based on temperature rise and the associated decline in agricultural productivity in Brazil, it was projected that under a low-emission scenario, aggregate migration rates would be 9.65% higher compared to migration rates under the current climate [31].

Heat, migration and economic opportunities

Six studies considered more broadly how economic considerations interacted between heat and migration [32, 33, 37, 39, 43, 50]. For example, in Pakistan heat stress was found to increase the long-term migration of men, driven by a negative effect on farm and non-farm income [39]. A regional study conducted in Ethiopia, Malawi, Tanzania and Uganda indicated that an increase in temperature by one standard-deviation led to a decrease in urban temporary out-migration [50]. Interestingly, urban out-migration rates were the highest when labour non-participation rates were low; this observation does not seem to support the hypothesis that migration decisions are driven by urban push factors, as under that hypothesis out-migration is expected to rise when employment opportunities decline [50]. In rural Tanzania, the relationship between heat and migration was found to be mediated by overall household consumption. As temperature shocks reduce household liquidity, it constrains long-term migration among men, which supports the existence of "geographical poverty traps" [43], relating to climate-related degradation of economic opportunities associated with a decreased likelihood of migration. As a result, people are unable to migrate and are thus "trapped" in a geographic location (i.e., as per the definition of immobile or "trapped populations" [38, 41]—those who would wish to move but who cannot). A similar situation was identified in rural Burkina Faso, where heat waves were associated with a decline in international mobility [32, 33]. A mixed-methods study conducted among 278 migrants from the Marshall Islands to the United States revealed that the majority of respondents did not mention climate factors as part of their primary migration decision. Instead, they prioritised access to better education, healthcare or work, whilst recognising the climate change impact on these services. However, the study did find positive correlations between heatwave impacts and current migration or having migrant relatives ($p < 0.01$). Overall, participants indicated that people may be more likely to make a final migration decision after prolonged heat [37].

Heat exposure duration and migration

Some studies with a longitudinal design concluded that heat had varying effects on migration depending on the duration of the exposure [29, 38, 44, 71, 72]. Short hot spells were found to be positively associated with temporary migration in two cohort studies conducted in Bangladesh [29] and in Uganda [44]. Furthermore, a cohort study conducted in Indonesia, including

7,185 households over1993-2007, found that long-term temperature variations had a nonlinear effect on province-to-province outmigration, with a statistically significant positive association for temperatures above 25˚C [70]. Similarly, in Mexico a non-linear relationship was found between the duration of exposure to above-average temperatures and with rural to urban migration, increasing after 34 months [72]. Another study conducted in rural Mexico found that higher temperatures lead to an increase in rural to urban migration after a threshold of 34 months of exposure is passed [38].

Heat, migration, in relation to age and gender

Several studies explored the variation of different age groups and genders on the decision to migrate [7, 11, 36, 41, 45]. A study conducted in Australia found that men were already more likely to be moving because of heat than women, and women were more likely to intend to move in the distant future. Age did not seem to have an influence on their intention [11]. In contrast, a later cross-sectional Australian study indicated a strong age-effect, with heat becoming an important migration factor for people aged 50 and older, though no specific reason was given [7]. Similarly, a study conducted among 2,219 participants based in urban areas of Indonesia, Malaysia and the Philippines suggested heat had a statistically significant stronger effect on migration intention for older adults compared to younger people, as well as having a significantly stronger effect on women's decision to migrate compared to men's decision to migrate [36]. Another cross-sectional study conducted in the Philippines of 69 provinces suggested that heat has a stronger impact on inter-provincial migration decisions among younger age groups (20-29yrs), men and highly educated people [41]. In the United States, college graduates seemed to avoid extreme temperatures in their study location choices, potentially putting warmer parts of the United States at risk of losing skills in the context of climate change [45].

Recommendations

Across the included studies, several recommendations are made in relation to adaptation to, mitigation and preparedness for the impacts of heat of migration. For example, identifying vulnerable populations can help prepare for shocks (such as to population flows or agricultural challenges) [31], whilst rural-urban migration could be mitigated and negative impacts of migration reduced through livelihood-based climate adaptation programmes and better employment [33]. More broadly, heat adaptive strategies (as discussed in the last section of the results) can support people exposed to heat [35, 46].

Impact of heat on migrants

Overall, 18 studies explored the impact of heat on migrants (Table 2), this included 12 quantitative studies, 3 qualitative studies, and 3 mixed-methods studies. Most studies were conducted in the United States (n = 9) [52, 54–58, 60–62]. Two studies were conducted across the United States-Mexico border [53, 59], and others were conducted in Mexico [71], Spain [65, 68], Australia [63], Netherlands [65], Italy [64], Qatar [64, 67] and Pakistan [66]. The types of migration included: international (n = 8) [53, 59, 60, 63–65, 67, 68], both international and seasonal (n = 3) [54, 58, 62], both international and internal (n = 1) [61], seasonal (n = 1) [52], and rural-to-urban (n = 1) [66]. In 3 studies the type of migration was not clearly stated [55–57]. The description of migrants includes agricultural workers (n = 6) [54–57, 62, 71], labour migrants [64, 67], refugees (n = 1) [63], undocumented (n = 2) [53, 59], international (n = 2) [68] and rural/ urban (n = 1) [66]. Two studies focused on Latinx children farmworkers, aged 10–17 years [52, 58]).

Heat and human health

The studies conducted in the United States or Mexico focused mainly on migrant farmworkers, who described negative associations with heat, comprising symptoms of dizziness and headache [52, 55], higher body temperatures causing higher mean heart rate and breathing rates [54], heat-related illnesses [56], dehydration [71], and higher average daily clinic visits [62]. Other studies within similar populations of farmworkers in the United States highlighted other heat hazards, which included heat index measurements in communal areas exceeding dangerous thresholds [57], as well as significant demands to work quickly, taking operational risks and creating oppressive physical demands [58].

A qualitative study indicated that migrant farmworkers in South Georgia experienced high levels of Heat-Related Illness (HRI): 71% of participants had experienced at least one symptom in the preceding week while working or spending time outside when including headache as a symptom, and 63% of participants had experienced at least one symptom when excluding headache [55]. Similarly, among farmworkers recruited from five migrant housing camps in the USA, nearly two-thirds (72%) of farmworkers experienced at least one HRI symptom and lacked proper cooling methods when working outdoors [56]. Among migrant child farmworkers working in the USA that reported working in hot weather, HRI was also common with 79/165 participants reported HRI (47.9%). Children discussed symptoms such as dizziness, headaches and feeling as fainting which they attributed to working in heat and sun [52, 55]. Studies reported different HRI symptoms including; extreme thirst (n = 1) [54, 55], headache (n = 2) [52, 55], muscle cramps, dizziness and/or nausea and vomiting (n = 3) [52, 54, 55], confusion (n = 2) [54], and dry skin (n = 2) [52, 55]. HRI was mostly concentrated in the obese (BMI kg/m2 $\geq$ 30 −40) and very obese group (BMI>40) [54]. Factors moderating the impact of heat stress include dehydration status [71]. Other populations in the United States who were undocumented migrants or were not citizens of the United States likewise experienced higher levels of heat stress [61] and increased risk of heat-related death [59, 60] compared to United States citizens.

Two studies explored mortality in relation to migrants exposed to heat. Nepali migrant workers aged 25–35 years in Qatar were found to have a higher risk of cardiac mortality during hot periods than the global population of the same age [67], meaning a large proportion of these CVD deaths during hot months were considered a result of serious heat stroke [67]. A cross-sectional study calculating the standardised mortality ratio and relative risk for heat-related deaths between non-US and US citizens found an increased mortality risk among non-US citizens compared with US citizens for heat-related deaths, especially those younger and of Hispanic ethnicity [60]. Other negative associations for migrants include socio-cultural barriers, especially new arrivals, older people and those joining new communities [63]. In the Netherlands, migrant inhabitants from different countries face exposure to high land surface temperature [74], whilst in Italy migrants seem to experience less impact on productivity or thermal discomfort compared to native workers [64]. Another study conducted in Pakistan demonstrated that people migrate to peri-urban areas to seek better livelihood opportunities, but due to low educational levels, they are limitedly able to reduce exposure to heat stress [66]. There were no studies providing positive impacts of heat on migrants.

Mitigating and aggravating factors

Roughly half of the papers (n = 25) reference alleviating and/or aggravating factors in the heat-migration nexus. Aggravating factors to heat or high temperatures include infrastructure (such as basic housing and lack of AC) [63], sociocultural (such as newly settled, poor English, and observing Ramadan) [63], educational level [7, 63, 66], socioeconomic (such as liquidity

constraints) [48]. Black and low-income groups were found to be more vulnerable to climate-induced migration than white and high-income people in South Africa, which could in part be explained by apartheid meaning black South Africans are largely located on some of the most marginal agricultural lands [42].

In relation to workplace adaptations, adaptive responses referenced included: improving hydration [54, 56, 71], taking rest breaks and providing access to shaded areas [55, 56]; sunscreen [56], fans [57], and sun-protective clothing [54, 56, 66]. Structural adaptations, such as AC, and planting trees or other vegetation, were also referenced [46]. Beyond the workplace, a study in Australia found that culturally appropriate clothing was often considered beneficial to prevent heat exposure, for example, sun umbrellas and covered swimwear [63]. In addition, strong social and family connections [63], and higher earning potential [41] improve the migratory experience in the context of heat. Further adaptive strategies referenced included the use of temporary migration, extensification and intensification of agriculture, planting of drought-resistant varieties, irrigation, and livelihood diversification [61]. In Pakistan, strategies to mitigate heat effects for undocumented migrants include traversing through rugged terrain [53].

Broader recommendations call for research methodology and aims to be improved: for example, modelling migratory patterns across border crossings [53] and moving research beyond dichotomous measures comparing migrants and native-born people [61]. Early warning systems that can support public health preparedness to heat must be culturally and linguistically competent [63]. Overall, research could be supported by better definitions of migrants and their drivers [60, 70].

Discussion

To our knowledge, this scoping review provides the first comprehensive systematically obtained overview of human migration in the context of heat. Five databases were searched, to explore the impact of heat on migration, as well as the impact of heat on migrants in different phases of their migratory journeys. The findings suggest that the relationship between heat and human migration is multidirectional and heterogeneous across contexts. 29 peer-reviewed articles assessed the impact of heat on human migration, primarily concerning internal migration (n = 19/29). 16 studies report a significant positive association (exposure to heat increases the likelihood of migration), 7 report a non-significant association (tending towards positive), and 6 studies report statistically significant negative associations (exposure to heat decreased likelihood of migration). Higher temperatures may be associated with higher emigration in middle-income countries, and lower rates in low-income countries [48]. Moderating factors in the heat-migration pathway include other climatic factors (such as cold spells, precipitation and wildfires), agricultural productivity, economic opportunities, age, and gender. 18 studies assessed the impact of heat on migrants. The vast majority of studies reported negative impacts of heat (e.g. heat-related illness, heat stress and premature mortality) among migrants compared to non-migrants. These negative impacts were influenced by poor infrastructure, insufficient workplace adaptation, lower educational level and socio-economic factors. No studies reported a positive impact of heat on health.

Push and pull factors in the heat-migration nexus

Migration is usually influenced by a combination of factors [75]. Heat has been found to push people to migrate during certain seasons [52, 58], temporarily [35, 50], and/or permanently (out-migration) [42, 44, 47, 50]. Migration push factors, away from heat, may include complex drivers such as poverty, physiological discomfort, disasters [70], water [5] and food insecurity

[32], and human conflict [76]. Although these factors may drive migration in some cases, numerous more subtle factors influence the likelihood of people choosing, or being able to, migrate. These factors include rural-vs-urban living (57), gender (61) and age (44, 45, 55, 73), the availability and access to health services and healthcare [37], and economic opportunities. Identified pull factors toward cooler climates include better livelihoods, safety, and economic opportunities. There are also trends of migration toward warmer climates, for example, choosing to move toward areas of heat for agricultural opportunities, or retiring to hot coastal regions as a proactive choice for some [59].

Heat exposure during the migratory journey

For people on the move, heat and heat stress pose risks at all stages across the migratory journey. During the transit phase—especially in certain well-established migratory corridors such as border crossings from Mexico to the USA [8, 53, 59] - a wide range of detrimental impacts of heat have been documented among migrants. For those in temporary settlements such as camps, heat can cause direct (HRI) [77] and indirect threats (wildfire, drought, air pollution) [78] which can be worsened by a lack of access to alleviating mechanisms such as water and shade. As has been highlighted in this review, the risks associated with heat also follow migrants upon settling in a new home. Migrants may find themselves working in extreme heat —with the associated threat to morbidity and mortality [79] - for economic reasons, migrants from LMICs to HICs also experience heat more intensely than non-migrants, for a variety of factors spanning socioeconomic, cultural, gender and infrastructure [65]. Beyond this, migrating towards areas of heat can also be a planned, proactive choice for some—for example British retirees in Spain—despite the necessary adaptations required to achieve comfort in a hotter climate [68].

Definition and measurement of heat

There is considerable heterogeneity in how 'heat' is defined and measured across the included studies. This included measuring heat based on air temperature, Wet Bulb Globe Temperature, and Land Surface Temperature. Further indices in the literature [64] also include day temperatures, night temperatures, heat wave days, WBGT, Humidex (heat and humidity), and reflected solar radiation. The heterogeneity surrounding the definition and measurement of heat is reflective of the wider established literature; for example, a systematic review [22] aiming to identify approaches for identifying heat-vulnerable populations, found considerable variability in how heat vulnerability/risk models and indices (HV/R) were calculated across studies, causing challenges in comparability and consistency across analysis. This, as with any heterogenous measurement or definition, makes accurate comparison and intervention testing more challenging. Beyond measures of heat, climate- and climate change-induced migration is challenging to attribute and predict, similarly due to the heterogeneity of tools and definitions across this nexus for climate, climate change, and migration [5].

The wider context of 'climate migration'

Some studies claim to project numbers of people who will be displaced by climate change in the future [80] which, if the numbers were accurate, would assist policy and practice, especially preparedness rather than always being responsive. However, estimating patterns and numbers of people who will be or have been displaced due to climate change has proven challenging [81], in part because migration is often driven by more than one factor [75]. Displacement due to disasters involving weather (e.g. storms and floods) is quantified more readily; in comparison, heatwaves and extreme heat events seem to cause relatively little acute displacement [82].

Whilst data remains limited, slow-onset processes—such as increased heat and droughts—can additionally affect human mobility as has been suggested in the findings of this review [83]. This is reflected in much of the literature concerning climate change and migration (and/or health), where heat is rarely addressed in detail [84–86]. Likewise, whilst several global health institutions have initiated workstreams to address the climate-migration-health nexus, heat has rarely been specifically explored [87], with the IOM's 2017 report "Extreme Heat and Migration" (7) being one example.

Despite migration sometimes being a proactive adaptation mechanism in response to extreme heat and other climate change impacts, current political and media discourse around migration—particularly migration from LMICs to HICs—has become largely politicised and weaponised [75]. Furthermore, within countries, there is particular concern for vulnerable subpopulations who are more likely to suffer and may be unable to migrate [48], due to poverty, age, cultural and livelihood ties, and disability often aggravated by persisting structures of inequity. Gender inequities may also play a role; some studies found that young men may be more likely to and be more able to migrate compared to women and girls, which could be related to traditional gender roles that continue to exist in patriarchal societies [88]. Populations unable to migrate are often referred to in the literature as 'trapped populations' [6, 43]; to be further exposed to poverty and other direct and indirect risks affected by climate change [89].

National and local heat health action plans

In response to rising temperatures, several countries have drawn up national or local heat health action plans (NHAP), which include recommendations on cooling mechanisms that, unlike AC, do not aggravate air pollution, GHG emissions, or result in an increased urban heat island effect" [90], nor exclude access due to cost (as may be the case with AC). Yet, thus far, NHAPs remain variable in quality and are often poorly implemented [90]. Recommendations from a Lancet Series on Heat and Health suggest putting health at the centre of all multisectoral NHAPs in order to deliver benefits beyond health. This includes early warning systems, public communications, community-level responses (e.g. health promotion, portable water stations, and outreach to vulnerable populations), and advice on longer-term preventative measures to reduce risks (e.g. reducing the urban heat island through urban planning) [77, 90]. Furthermore, facilitating migration as a proactive adaptation measure could reduce the exposure of individuals to extreme heat impacts. Migration in such contexts can take many forms, from seasonal migration schemes and permanent relocation to financing adaptation measures [6].

Strengths and limitations

This scoping review has several limitations. Due to the diverse nature of different migratory journeys, different migrants, different people at the migrants' origin(s) who do not migrate, different people at the destination(s), and the different factors that collectively contribute to an individual's decision to move or not move, comparing experiences of heat and human migration in different settings between studies is challenging without risking oversimplification. Nonetheless, to seek understanding, migration and mobilities studies accept comparative approaches, even while being aware of their limitations, namely that no population group is homogenous and that different groups and subgroups can have different attributes making the baselines for comparison different. Heterogeneity and aggregation in data and reporting, and variable study quality, lead to difficulties in conducting meta-analyses.

Furthermore, within the included studies there is insufficient linking between meteorological data over time and migration data. As a result, further challenges arise when attributing causality to migration drivers in the context of multiple intersecting factors that can drive and influence migration [78]. The tenuousness of causality is demonstrated more in the difficulties of determining and applying a definition of high temperature (or heat) and humidity combinations that is specific to the population, subgroups within the population, and the location of study. Considering 35˚C air temperature as an absolute threshold for which heat-related effects are observed for all populations loses contextuality and specificity for a particular geographical region, population, and subgroup. Rather than a direct link between a defined heat-humidity value and migration, dealing with heat-humidity and outcomes can differ based on exposure to temperature and humidity at all stages of a migratory journey. Such subtleties are rarely discussed in published research and are not fully explored or understood.

Our study has several strengths, including the synthesis of both peer-reviewed and grey literature, a comprehensive detailed search strategy to find all available evidence, a broad definition of migration that included individuals along different phases of the migratory journey, and the inclusion of both humidity and health to allow for a more detailed examination of the heat-migration nexus. These aspects are helpful contributions toward determining possible impacts of heat and humidity, notwithstanding the limitations which is why work should continue, especially on disaggregating data of migrants and non-migrants at origins and destinations while examining multiple ways of defining and comparing cohorts. The data might have also been better stratified to assess short, seasonal, and long-term heat exposure and how migration response differs under such scenarios. Finally, there are a number of geographical regions not represented in the literature and thus this review—India, central Africa and central Asia, among others; as such, caution must be taken if extrapolating the findings.

Conclusions and directions for future research

This scoping review provides suggestive evidence that heat may influence migratory patterns, and that there are consequences for migrants exposed to heat. This was seen in terms of intentions to move, risks when on the move, and upon settling. However, the results of the included studies are heterogeneous, and heat may not always be a driver of migration in all contexts. Furthermore, none of the included literature reports on the so-called 'temperature threshold' above which migration is certain. This is in part due to other alleviating or aggravating factors that may influence the heat-migration nexus. Whilst this may be an accurate reflection of the intersection of two complex systems, considering the advantages and disadvantages of moving towards homogeneity in the way heat is measured would be useful. Such homogeneity may support more informative mapping and better preparedness, though risks losing local contextuality and different response specificity for different people in different areas. Further research could be supported through some level of consistency and/or comparability of definitions for heat and humidity, and of environmentally-induced migration and migrants.

The review and analysis here show that major research gaps exist. There is a lack of consensus on definitions of migrants and migration, as well as heat stress and exposure, which helps with contextuality while hindering comparability. Data can be difficult to obtain from longitudinal databases if it is not accurately disaggregated. It is difficult to access some areas experiencing high temperatures and migration, so populations are left out of studies. To measure heat exposure requires better and more linked-up and comparative data. Similarly, gathering migration-related data, whether internal or international migration, poses challenges, particularly among undocumented migrants and those without household addresses, as they may not be captured in the datasets from household surveys and censuses commonly used in

research. Many of the datasets included in this review are longitudinal, spanning multiple years. While this is useful and necessary for monitoring trends, such studies are timely and costly, limiting replicability in new settings, especially those that are hard to access.

Some gaps are addressable for further research. Only a small minority of the studies in this review utilised qualitative or mixed methodologies. Such an approach could bring in more lived experiences and support a deeper understanding of people's situations in relation to heat and how they are impacted by migration on a personal level, currently systematically lacking from the findings. This could help inform policy to ultimately improve lives, through heat adjustment strategies. Modelling studies can help forecast migration and heat trends, thus informing planning and preparedness. Alleviating and aggravating factors that impact the heat-migration nexus could be better understood; for example, when cooling is required compared to solely hydration, and how this may be mediated for people on the move by limited access to both clean drinking water, and safe, accessible and culturally-appropriate places to urinate. Furthermore, the migration experience is highly variable, requiring differing approaches that may benefit from more nuanced research for people who can move freely with a passport and financial means, those forced to take a more treacherous journey, labour migrants, and the 'trapped populations' unable to move from heating regions. Mental health impacts remain a substantive research gap that must be filled. Mental health impacts of heat, mental health impacts of migration, and mental health systems each have huge bodies of work. They need to be brought together to examine mental health in the context of migration-heat interactions. Finally, researchers and practitioners working in heat, migration, and associated fields, must be cognisant that their work has the potential to become further politicised, blame-focused, and contribute to harmful and xenophobic narratives. While challenging, this should not dissuade or prevent research. Instead, it is important to consider how research outputs can be translated into policy, practice and the support of discourse.

Supporting information

S1 Table. PRISMA-ScR guidelines.
(DOCX)

S2 Table. Search strategy.
(DOCX)

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