PLOS CLIMATE

REVIEW

Measuring the effect of climate change on migration flows: Limitations of existing data and analytical frameworks

Marc Helbling[1,2]*, Diego Rybski[3,4,5], Jacob Schewe[3], Stefan Siedentop[6,7], Manon Glockmann[3,8], Bastian Heider[6], Bryan Jones[9], Daniel Meierrieks[10], Albano Rikani[3,8,11], Peter Stroms[6]

1 Mannheim Centre for European Social Research (MZES), University of Mannheim, Mannheim, Germany, **2** WZB Berlin Social Science Center, Berlin, Germany, **3** Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany, **4** Department of Environmental Science Policy and Management, University of California Berkeley, Berkeley, California, United States of America, **5** Complexity Science Hub Vienna, Vienna, Austria, **6** ILS–Research Institute for Regional and Urban Development, Dortmund, Germany, **7** Technical University Dortmund, Dortmund, Germany, **8** Institute of Environmental Science and Geography, University of Potsdam, Potsdam, Germany, **9** City University of New York Institute for Demographic Research, Baruch College, New York, New York, United States of America, **10** WZB Berlin Social Science Center, Berlin, Germany, **11** Pierre Louis Institute of Epidemiology and Public Health, INSERM, Sorbonne Université, Paris, France

* helbling@wzb.eu

Citation: Helbling M, Rybski D, Schewe J, Siedentop S, Glockmann M, Heider B, et al. (2023) Measuring the effect of climate change on migration flows: Limitations of existing data and analytical frameworks. PLOS Clim 2(1): e0000078. https://doi.org/10.1371/journal.pclm.0000078

Editor: Thomas Thaler, University of Natural Resources and Life Sciences, AUSTRIA

Published: January 4, 2023

Funding: MH, DR, JS and SS received funding from the Leibniz Association (Project IMPETUS, K36/2017). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: The authors have declared that no competing interests exist.

Abstract

The aim of this paper is to review quantitative large-N studies that investigate the effects of climate change on migration flows. Recent meta-analyses have shown that most studies find that climate change influences migration flows. There are however also many studies that find no effects or show that effects are dependent on specific contexts. To better understand this complexity, we argue that we need to discuss in more detail how to measure climate change and migration, how these measurements relate to each other and how we can conceptualise the relationship between these two phenomena. After a presentation of current approaches to measuring climate change, international and internal migration and their strengths and weaknesses we discuss ways to overcome the limitations of existing analytical frameworks.

Introduction

Migration and climate change have become two of the most salient political and social issues over the last decades, with research on their relationship now abundant. While some studies find that climate change influences migration flows [1], others either do not [2] or reveal just indirect effects [3,4]. Recent meta-analyses by [5–7] have shown that most studies find that effects are dependent on specific contexts. It also appears that this broad range of findings can be explained by the fact that the studies use a wide variety of climatic and migration variables as well as different samples and estimation strategies [5,8]. Against this background, we argue that we need to discuss in more detail how to measure climate change and migration, how these measurements relate to each other and how we can conceptualise the complex relationship between these two phenomena.

The aim of this paper is to review quantitative large-N studies that investigate the effects of climate change on migration flows in economics and related fields. We thus focus on one specific approach and its limitations and leave out qualitative small-N research, which faces different challenges. In contrast to other review studies that systematically focus on the evidence collected so far [5–7] or methodological approaches [9,10], we consider a large selection of key studies to discuss various limitations in this field that we believe simplify the picture of how climate change affects migration flows [11,12]. In the following, we first present current approaches to measuring climate change, international and internal migration and their strengths and weaknesses, before discussing ways to overcome the limitations of existing analytical frameworks.

Measuring climate change

In most large-N studies, climate change has been quantified through time series of temperature and precipitation changes or related measurements of droughts, heatwaves, soil moisture and evapotranspiration (see S1 Table in the Supplementary Material for an overview). These can take simple forms such as annual or monthly means at country or grid cell level [13,14]. Some studies use weighting to tailor the indicators to the hypothesised mechanism of climate influence on migration: for instance, measurements can be weighted by agricultural areas and aggregated over the main growing season to obtain a proxy for crop growing conditions, or by population density if the hypothesis focusses on the direct effect of weather on humans [3,15].

Historical temperature and precipitation data for such studies is readily available in gridded format, for instance from the University of East Anglia Climatic Research Unit (CRU) [16]. Such gridded observational products rely on direct measurements by weather stations, meaning that data quality can be lower in regions of the world with low station density. Reanalysis products integrate direct observations into weather models to overcome limitations in the data regarding spatial coverage, temporal resolution and the number of variables measured. Such datasets, e.g. the ECMWF's ERA5 reanalysis, provide not only information on temperature and precipitation but also many other atmospheric variables on a daily or sub-daily basis and on global grids with a spatial resolution of below one degree [17]. This high spatial and temporal resolution allows researchers to use more elaborate temperature measurements, such as heatwave or warm spell indicators, or to construct multivariate indices that measure the effects of drought conditions—such as the Standardised Precipitation-Evaporation Index (SPEI) [18] or the Soil Moisture Anomalies index [19].

Indeed, although temperature and precipitation are important variables that lend themselves to easy interpretation based on everyday experience, they may not always be the most appropriate and comprehensive measure of climate change when studying climate-induced migration flows. While the mechanisms linking climate change with migration are not fully understood, there is a rich and growing literature on the many impacts that climate change has on individuals (in cities or rural areas), their societies and economies, not all of which are explained by temperature and precipitation alone [20]. For instance, a combination of high temperature and atmospheric humidity can create conditions under which even healthy people cannot survive outdoors—conditions which are expected to occur more frequently in parts of South Asia as global warming develops [21]. Due to the urban heat island effect, cities experience even more extreme climate conditions [22]. Similarly, major wildfires, high windspeeds or coastal flooding induced by storms can destroy settlements and force people to flee their homes [23].

Even agricultural production, for which temperature and precipitation are important inputs, is insufficiently explained by linear measurements of those two variables. For example, there are important non-linearities in crop response to heat: crop yields depend in complex ways on the timing of meteorological inputs relative to the crop's specific growth cycle, meaning that additional variables such as soil moisture are important, possibly inducing path dependencies across adjacent growing seasons [24,25]. Water-related problems such as water scarcity or river floods can result from the interaction of precipitation, evaporation and vegetation processes far upstream from where they appear, meaning that local or country-level precipitation may be poor proxies. Researchers can instead draw on an increasing array of observational [26] and model-based datasets (e.g. ISIMIP, www.isimip.org) directly providing the relevant variables to describe flood hazards, crop yields, water scarcity or many other climate impacts. Moreover, the 6th assessment report of the IPCC's Working Group II is an important reference for identifying the relevant variables to assess a given hypothesis in climate migration studies.

Measuring international migration

As for international migration flows, there is a trade-off between datasets that include flow data but only refer to OECD destination countries and datasets that include non-OECD destination countries but only provide data on migration stocks (see S1 Table in the Supplementary Material). Coniglio and Pesce, Backhaus et al. and Cai et al. [1,16,27] use annual data on bilateral migration flows from a very large number of origin countries to between 19 and 42 mostly OECD destination countries for the 1990s and 2000s. A frequently used dataset in this context is the OECD's International Migration Database (IMD). Though containing yearly data on inflows and outflows, it is based on national statistics and thus on different definitions and sources [5]. The main limitation of these datasets is that they do not measure South–South migration, an extremely relevant aspect in the study of climate change effects and a particular challenge in exactly these regions.

As a way of dealing with this problem, some studies use census data. Beine and Parson [2] as well as Cattaneo and Peri [3] draw on the Global Bilateral Migration Database (GBMD) provided by the World Bank [28], which contains migration stocks of 226 origin and destination countries in a ten-year rhythm between 1960 and 2010. While this allows for investigating a larger number of (destination) countries over several decades, there are also severe constraints. Most importantly, the dataset only constitutes a proxy for migration flows because it compares contiguous censuses. For example, it is impossible to know whether a decrease in stocks between two censuses results from decreasing flows, increasing return migration or outflows to a third country.

A few studies use a dataset on asylum seekers compiled by the United Nations High Commissioner on Refugees (UNHCR). It contains annual data on the number of asylum applications filed in the destination countries in the period 1951–2016 and the countries of origin of the asylum seekers [29,30]. While this dataset includes flow data for the entire world, it should be noted that only about 10 per cent of all migrants are asylum seekers [30: 1610]. Another problem is that many flow dyads between countries in the dataset go unreported, with debate ongoing over how to treat such cases [31]. Another challenge to use data on asylum seekers is the fact that it is not possible to apply for asylum on grounds of climate change [32]. For this reason, migrants might not apply for asylum but rather cross borders irregularly. To study the effects of climate change on irregular migration, Cottier and Salehyan [33] analyse data collected by Frontex, the European Border and Coast Guard Agency, from national border authorities on irregular border crossings detected at the external borders of the EU and Schengen associated countries.

Recent studies have started to use survey data based on retrospective questions or questions on migration intentions to measure (proxies of) migration flows [34–38]. The main advantage of this kind of data is that it can help circumvent ecological fallacy problems [39] and gain a better understanding of the potential migrants' individual characteristics. Tjaden et al. [40] show that there is a high correlation between migration intentions and emigration at the aggregate level (see also [41]). Such data is problematic, however, in that there might be reporting (recall) and understanding biases.

Measuring internal migration

A series of studies investigate the impact of climate change on internal migration [3,42–45]. However, data quality here is even more problematic than for international migration. Some single-case studies also use census data [46] or community surveys [47] to measure internal migration, though such sources suffer from problems similar to those described above. More specifically, it is not possible to systematically investigate to what extent internal migration constitutes temporary migration, for example in the case of 'survival migration' [11: 6]). It is often assumed that people return when short-term events such as floodings are over. Furthermore, data is often only available for single countries. Peri and Sasahara [48] have recently tried to overcome this lack of data at the subnational level by relating imputed census data to climate data at grid cell level for all countries in the world. However, they only provide data in a ten-year rhythm, meaning that shorter-term developments are not considered.

For these reasons, most studies have used urbanisation as a measure of internal migration, as it is generally a result of rural–urban migration [49: 19]. The validity of urbanisation as a proxy for internal migration can of course also be questioned because migration is not the only driver of urban population growth. It has, however, been shown that fertility rates in urban areas tend to be lower than in rural regions [50,51]. Another potential problem concerns international migration to urban areas, but this is mostly the case in developed destination countries.

The more important problems concern the lack of consensus on how to define urban areas and the general unavailability of fine-grained census data that would allow researchers to differentiate between urban and rural areas. Urbanisation can be measured by increases in factors characterising cities, such as the size of the urban area, population size and density, shares of urban land uses and land covered by artificial surfaces, building density, and road network density [50,52]. As none of these factors are exclusive to cities, urbanisation often relates to substantial densities. Yet, density thresholds have been criticised due to varying national urban population cut-off values and their general arbitrariness [53,54]. Specifically, an increase in population and population density in a specific area—usually defined by administrative boundaries—can serve as a proxy for urbanisation, though the use of census data limits both the spatial and the temporal resolution.

Alternatively, data on urban land cover or built-up areas is globally available in high spatial resolution [55]. However, the temporal resolution is still low, which constitutes a drawback when urbanisation trajectories need to be monitored over a longer period. Night light data is another factor that is sometimes considered [56]. The data has global coverage and is available for many years back. However, whether a place is lit at night is dependent on many factors, such as economic development.

Better data on rural–urban migration would help investigate the interactions between migration and climate change in both directions. Urbanisation processes have repercussions on emission levels of greenhouse gases [57,58] as well as on adaptation to climate change. For example, having more people adopt urban lifestyles could accelerate climate change, while migration to urban coastal zones and high-density urban areas might increase long-term climatic vulnerability [59,60].

Improving analytical frameworks

As we have seen, there are major gaps in the data used to measure migration flows. It will require major efforts by international organisations to extend existing databases but also to explore new data sources. Moreover, we need to develop detailed analytical frameworks that help us decide which indices best describe the influence of climate change on migration. This would allow us to understand which consequences of climate change lead to which kind of migration under which circumstances. To better understand these relationships, we first need to validate existing data and find out which indices are most relevant in this field. Moreover, future studies should account for the complexity of migration movements, the individual vulnerability of climate change migrants and contextual mechanisms.

Validating existing data

While collecting better and more migration flow data will help overcome some limitations, we also need to validate existing databases to gain a better understanding of what we actually investigate. Most studies will continue using flow data derived from migrant stock data [61]. Berlemann et al. [62] show that the various methods such as stock differentiation, migration rates and demographic accounting used to generate such flow data influences what climate change effects are found. Their study provides a good example of how we can start solving some of the problems discussed above. Systematic validity tests of different data sources and indices will allow us to better understand to what extent they are interrelated. Such tests should also be applied to survey data measuring migration aspirations, as we need to gain a better understanding of the extent to which this data helps us measure and predict actual migration.

Accounting for more complex migration movements

Having more valid migration flow data available will also allow us to improve our knowledge of different migration dynamics. With a few exceptions, most current research looks at either internal or international migration. However, this prevents us from understanding how these two forms of migration are interrelated in the context of climate change [2,44,38]. We also know from other fields that migrants do not always move to their preferred destination directly, but take a step-by-step approach in which intermediate destinations and stopovers are usually cities [63]. Ideally, it should be possible to track migrants over a longer period, thus gaining a better understanding of changing migration strategies that possibly reflect waning or increasing climate change effects [64]. To study internal migration, some studies use panel data based on household surveys in Nepal and Indonesia [65,66], censuses in South Africa [47] or credit records in Puerto Rico [67]. Lu et al. [68] draw on call detail records (CDRs), which provide information on the time of calls and mobile phone towers used, to follow the positions and movements of people during a cyclone in Bangladesh. While all these panel data allow for following people over time, they are limited to individual countries and may not be representative, as in the case of credit or call detail records, or they can only be interpreted together with qualitative data [69]. It is even much more challenging to follow people who migrate internationally. Initial studies are already investigating the possibilities of smartphone technologies to conduct such research with migrants [70–72].

Accounting for the individual vulnerability of climate change

While survey data will likely remain of limited use in predicting actual migration, it allows us to better understand who is most affected by climate change, as it provides more detailed information on potential migrants [10: 8–9]. This possibility points to a major gap in the current research on the nexus between climate change and migration. While existing studies primarily predict the number of migrants, we hardly know anything about the composition of migrant groups. This lack of information might be responsible for some of the uncertainty around how climate change affects migration flows. While some argue that it mainly affects vulnerable groups with no other means to adapt to climate change, such as people on low incomes or working in agriculture [3,73], others argue that perceptions of and knowledge about climate change plays an important role [70,35,37: 9].

Accounting for mechanisms and impact channels

Different social groups might also react differently in different contexts. It has already been widely shown that countries with a larger agricultural sector are more affected [1,15,27,46]. There are, however, also many other potential channels through which climate change affects migration intensity that have so far received little attention (see also S1 Table in the Supplementary Material). Climate change can, for example, affect an economy more generally [74], but also public health [75], and can have politico-institutional repercussions [76]. All these factors constitute important push factors of migration, making it difficult to disentangle them from direct climate change factors.

More elaborate hypotheses about the mechanisms or channels linking climate change to migration could also help in choosing the appropriate climate change measurement methods in a given study. For instance, a modelling study by Rigaud et al. [77] uses spatially explicit estimates of multi-year average water resources and agricultural yields to calibrate a gravity model of population change and estimate climate-induced changes in internal migration. The underlying hypothesis is that persistent shortfalls in water availability and crop productivity had the potential to undermine rural livelihoods, prompting those affected to move to cities or more productive rural environments. Another study employs flood modelling results to estimate future changes in river flood hazard levels and subsequently to project the future risk of flood-induced population displacement [78]. Focusing on international refugee flows, Abel et al. [79] combine data on asylum applications, conflict occurrence and the SPEI (as a drought indicator) to show that climate conditions in all probability affected refugee flows indirectly through their effect on conflict risk, but only in specific periods and regions of the world. These examples illustrate the different factors at which climate change can influence migration: from climate change–fuelled weather extremes that pose direct threats to human lives, deteriorating environment-dependent livelihoods, to indirect effects mediated by other migration drivers such as conflict and in the way countries as a whole are differently affected by and able to cope with the effects of climate change.

Conclusion

Boas et al. [80: 902] argue that climate-related migration is not the exception from the norm but rather the 'new normal'. However, empirical evidence on the complex interplay between climate change and migration is still weak. A better understanding of the inherent complexity of this field in the long term requires scholarly consensus on analytical frameworks, definitions and measurement methods. We have highlighted a few strategies to advance research towards such a consensus. Moreover, a wide range of data on climate change and its impacts is available from direct observations, remote sensing and models, much of which has yet to be used to fine-tune the representation of climate in climate migration studies. This goes hand in hand with a need to further develop the underlying hypotheses and to more explicitly model the different potential pathways through which climate change might affect migration. Finally, accounting for the connections between different types and scales of migration can help reveal some of those pathways, painting a more holistic and relevant picture of human mobility in a changing climate.

Supporting information

S1 Table. Overview of key variables and data sources.
(DOCX)

References

1. Coniglio ND, Pesce G. Climate variability and international migration: An empirical analysis. Environment and Development Economics 2015; 20: 434–468.
2. Beine M, Parsons Ch. Climatic factors as determinants of international migration. Scandinavian Journal of Economics 2015; 117: 723–767.
3. Cattaneo C, Peri P. The migration response to increasing temperatures. Journal of Development Economics 2016; 122: 127–146.
4. Helbling M, Meierrieks D. How climate change leads to emigration: Conditional and long-run effects. Review of Development Economics 2021; 25: 2323–2349.
5. Berlemann M, Steinhardt MF. Climate Change, Natural Disasters, and Migration—a Survey of the Empirical Evidence. CESifo Economic Studies 2017; 63(4): 353–385.
6. Hoffmann R, Dimitrova A, Muttarak R, Cuaresma JC, Peisker J. A meta-analysis of country-level studies on environmental change and migration. Nature Climate Change 2020; 10: 904–912.
7. Šedová B, Čizmaziová L, Cook A. Meta-analysis of climate migration literature. In Center for Economic Policy Analysis Discussion Paper. 2021.
8. Beine M, Jeusette L. A meta-analysis of the literature on climate change and migration. Journal of Demographic Economics (online first). 2021.
9. Ty Miller J, Thai Vu A. Emerging research methods in environmental displacement and forced migration research. Geography Compass 2021; 15(4): e12558.
10. Piguet E. Linking climate change, environmental degradation, and migration: An update after 10 years. WIREs Climate Change 2022; 13(1): e746.
11. Cattaneo C, Beine M, Fröhlich CJ, Kniveton D, Martinez-Zarzoso I, Mastrorillo M, et al. Human migration in the era of climate change. Review of Environmental Economics and Policy 2019; 13(2): 189–206.
12. Black R, Adger WN, Arnell NW, Dercon S, Geddes A, Thomas D. The effect of environmental change on human migration. Global Environmental Change 2011; 21: S3–S11.
13. Marchiori L, Maystadt JF, Schumacher I. The impact of weather anomalies on migration in sub-Saharan Africa. Journal of Environmental Economics and Management 2012; 63(3): 355–374.
14. Sedova B, Kalkuhl M. Who are the climate migrants and where do they go? Evidence from rural India. World Development 2020; 129: 104848. https://doi.org/10.1016/j.worlddev.2019.104848
15. Cai R, Feng S, Oppenheimer M, Pytlikova M. Climate variability and international migration: The importance of the agricultural linkage. Journal of Environmental Economics and Management 2016; 79: 135–151.
16. Harris I, Osborn T J, Jones P, and Lister D. Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. Scientific Data 2020; 7(1): 109. https://doi.org/10.1038/s41597-020-0453-3 PMID: 32246091
17. Hersbach H, Bell B, Berrisford P, Hirahara S, Horányi A, Muñoz-Sabater J, et al. The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society 2020; 146(730): 1999–2049. https://doi.org/10.1002/qj.3803
18. Vicente-Serrano SM, Beguería S, López-Moreno JI. A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index. Journal of Climate 2010; 23(7): 1696–1718. https://doi.org/10.1175/2009JCLI2909.1

19. Martínez Flores F, Milusheva S, Reichert AR. Climate Anomalies and International Migration: A Disaggregated Analysis for West Africa. Policy Research Working Paper No. 9664. World Bank, Washington, DC. 2021.
20. Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, et al., editors. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 2014. Available from: https://ipcc-wg2.gov/AR5/report/full-report/.
21. Im E-S, Pal JS, Eltahir EAB. Deadly heat waves projected in the densely populated agricultural regions of South Asia. Science Advances 2017; 3(8): 1–8. Available from: https://doi.org/10.1126/sciadv.1603322 PMID: 28782036
22. Li Y, Schubert S, Kropp JP, Rybski D. On the influence of density and morphology on the Urban Heat Island intensity. Nature Communications 2020; 11(1): 1–9.
23. Anzellini V, Desai B, Leduc C. Global Report on Internal Displacement. Internal Displacement. 2020. Available from: https://www.internal-displacement.org/global-report/grid2020/.
24. Samaniego L, Thober S, Kumar R, Wanders N, Rakovec O, Pan M, et al. Anthropogenic warming exacerbates European soil moisture droughts. Nature Climate Change 2018; 8(5): 421–426. Available from: https://doi.org/10.1038/s41558-018-0138-5.
25. Schauberger B, Archontoulis S, Arneth A, Balkovic J, Ciais P, Deryng D, et al. Consistent negative response of US crops to high temperatures in observations and crop models. Nature Communications 2017; 8: 13931. Available from: https://doi.org/10.1038/ncomms13931 PMID: 28102202
26. Tellman B, Sullivan J A, Kuhn C, Kettner AJ, Doyle CS, Brakenridge GR, et al. Satellite imaging reveals increased proportion of population exposed to floods. Nature 2021; 596(7870): 80–86. Available from: https://doi.org/10.1038/s41586-021-03695-w PMID: 34349288
27. Backhaus A, Martinez-Zarzoso I, Muris Ch. Do climate variations explain bilateral migration? A gravity model analysis. IZA Journal of Migration 2015; 4(3). Available from: https://doi.org/10.1186/s40176-014-0026-3.
28. Özden C, Parsons CR, Schiff M, Walmsley TL. Where on earth is everybody? The evolution of global bilateral migration 1960–2000. World Bank Econ. Rev. 2011; 25(1): 12–56.
29. UNHCR (2017). UNHCR Statistical Online Population Database. Available from: http://popstats.unhcr.org/en/persons_of_concern.
30. Missirian A, Schlenker W. Asylum applications respond to temperature fluctuations. Science 2017; 358 (6370): 1610–1614. https://doi.org/10.1126/science.aao0432 PMID: 29269476
31. Marbach M. On Imputing UNHCR Data. Research and Politics. 2018.
32. McAdam J. Climate Change, Forced Migration, and International Law. Oxford: Oxford University Press; 2012.
33. Cottier F, Salehyan I. Climate variability and irregular migration to the European Union. Global Environmental Change 2021; 69: 102275.
34. Fussell E, Hunter LM, Gray CL. Measuring the environmental dimensions of human migration: The demographer's toolkit. Global Environmental Change 2014; 28: 182–191. https://doi.org/10.1016/j.gloenvcha.2014.07.001 PMID: 25177108
35. Koubi V, Spilker G, Schaffer L, Böhmelt T. The role of environmental perceptions in migration decision-making: Evidence from both migrants and non-migrants in five developing countries. Population and Environment 2016; 38: 134–163.
36. Bertoli S, Docquier F, Rapoport H, Ruyssen I. Weather Shocks and Migration Intentions in Western Africa: Insights from a Multilevel Analysis. Manuscript; 2019.
37. Helbling M, Auer D, Meierrieks D, Mistry M, Schaub M. Climate Change Literacy and Migration Potential: Micro-Level Evidence from Africa. Climatic Change 2021; 169.
38. Bekaert E, Ruyssen I, Salomone S. Domestic and international migration intentions in response to environmental stress: A global cross-country analysis. Journal of Demographic Economics 2021; 87: 383–436.
39. Piguet E. Linking climate change, environmental degradation, and migration: A methodological overview. Wiley Interdisciplinary Reviews: Climate Change 2010; 1(4): 517–524.
40. Tjaden J, Auer D, Laczko F. Linking migration intentions with flows: Evidence and potential use. International Migration 2019; 57: 36–57.
41. Lu M. Do people move when they say they will? Inconsistencies in individual migration behavior. Population and Environment 1999; 20: 467–488.
42. Barrios S, Bertinelli L, Strobl E. Climate change and rural-urban migration: The case of sub-Saharan Africa. Journal of Urban Economics 2006; 60: 357–371.

43. Annez P, Buckley R, Kalarickal J. African urbanization as flight? Some policy implications of geography. Urban Forum 2010; 21: 221–234.
44. Maurel M, Tuccio M. Climate instability, urbanization and international migration. Journal of Development Studies 2016; 52: 735–752.
45. Helbling M, Meierrieks D. Global warming and urbanization. Journal of Population Economics 2022; online first. Available from: https://link.springer.com/article/10.1007/s00148-022-00924-y.
46. Dallmann I, Millock K. Climate Variability and Inter-State Migration in India. CESifo Economic Studies 2017; 63(4): 560–594.
47. Mastrorillo M, Licker R, Bohra-Mishra P, Fagiolo G, Estes LD, Oppenheimer M. The influence of climate variability on internal migration flows in South Africa. Global Environmental Change 2016; 39: 155–169.
48. Peri G, Sasahara A. The impact of global warming on rural-urban migrations: Evidence from global big data. NBER Working Papers No. 25728; 2019.
49. International Organization for Migration [IOM]. World Migration Report 2015: Migrants and Cities: New Partnerships to Manage Mobility. International Organization for Migration: Geneva, Switzerland; 2015.
50. UN Population Division. World Urbanization Prospects 2018. Highlights (ST/ESA/SER.A/421). New York; 2018.
51. Buckley C. Rural/urban differentials in demographic processes: The Central Asian states. Population Research and Policy Review 1998; 17: 71–89.
52. Seto KC, Sánchez-Rodríguez R, Fragkias M. The new geography of contemporary urbanization and the environment. Annu. Rev. Environ. Resour. 2010; 35: 4.1–4.28.
53. Brenner N, Schmid C. The 'Urban Age' in Question. International Journal of Urban and Regional Research 2014; 38(3): 731–755.
54. Taubenböck H, Weigand M, Esch T, Staab J, Wurm M, Mast J, et al. A new ranking of the world's largest cities—Do administrative units obscure morphological realities? Remote Sensing of Environment 2019; 232.
55. Pesaresi M, Huadong G, Blaes X, Ehrlich D, Ferri S, Gueguen L, et al. A Global Human Settlement Layer From Optical HR/VHR RS Data: Concept and First Results. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 2013; 6(5): 2102–2131.
56. Ma T, Zhou Ch, Pei T, Haynie S, Fan J. Quantitative estimation of urbanization dynamics using time series of DMSP/OLS nighttime light data: A comparative case study from China's cities. Remote Sensing of Environment 2012; 124: 99–107.
57. Ribeiro HV, Rybski D, Kropp JP. Effects of changing population or density on urban carbon dioxide emissions. Nature Communications 2019; 10(1): 1–9.
58. Dodman D. Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories. Environment & Urbanization 2009; 21(1): 185–201.
59. Klein RJT, Nicholls RJ. Assessment of coastal vulnerability to climate change. Ambio 1999; 28(2): 182–187.
60. Adger NW, Arnell NW, Black R, Dercon S, Geddes A, Thomas DSG. Focus on environmental risks and migration: causes and consequences. Environ. Res. Lett. 2015; 10(6): 60201.
61. Abel GJ, Cohen JE. Bilateral international migration flow estimates for 200 countries. Scientific Data 2019; 6(1): 82. https://doi.org/10.1038/s41597-019-0089-3 PMID: 31209218
62. Berlemann M, Haustein E, Steinhardt M. From Stocks to Flows–Evidence for the Climate-Migration-Nexus, IZA Discussion Paper No. 14450, IZA Institute if Labor Economics; 2021.
63. Paul AM. Stepwise International Migration: A Multistage Migration Pattern for the Aspiring Migrant. American Journal of Sociology 2011; 116(6): 1842–1886.
64. Beauchemin C, Schoumaker B. Micro Methods: Longitudinal Surveys and Analyses. In White M. J. (Ed.). International Handbook of Migration and Population Distribution. Dordrecht: Springer; 2016. pp.175–204.
65. Bohra-Mishra P, Massey DS. Environmental degradation and out-migration: New evidence from Nepal. In Piguet E., Pécoud A., de Guchteneire P, editors. Migration and climate change. Cambridge: Cambridge University Press; 2011. pp.74–101.
66. Bohra-Mishra P, Oppenheimer M, Hsiang SM. Nonlinear permanent migration response to climatic variations but minimal response to disasters. Proceedings of the National Academy of Sciences 2014; 111 (27): 9780–9785. https://doi.org/10.1073/pnas.1317166111 PMID: 24958887
67. DeWaard J, Johnson JE, Whitaker SD. Out-migration from and return migration to Puerto Rico after Hurricane Maria: evidence from the consumer credit panel. Population and Environment 2020; 42(1): 28–42.

68. Lu X, Wrathall DJ, Sundsøy PR, Nadiruzzaman M, Wetter E, Iqbal A, et al. Detecting Climate Adaptation with Mobile Network Data in Bangladesh: Anomalies in Communication, Mobility and Consumption Patterns during Cyclone Mahasen. Climatic Change 2016; 138(3–4): 505–519. https://doi.org/10.1007/s10584-016-1753-7 PMID: 32355373

69. Boas I, Dahm R, Wrathall D. Grounding Big Data on Climate-Induced Human Mobility. Geographical Review 2020; 110(1–2): 195–209.

70. Keusch F, Leonard MM, Sajons C, Steiner S. Using smartphone technology for research on refugees–Evidence from Germany. Sociological Methods & Research 2019; 50: 1863–1894.

71. Jacobsen J, Kühne S. Using a Mobile App When Surveying Highly Mobile Populations: Panel Attrition, Consent, and Interviewer Effects in a Survey of Refugees. Social Science Computer Review 2021; 39 (4): 721–743.

72. Ndashimye F, Hebie O, Tjaden J. Effectiveness of WhatsApp for measuring migration in follow-up phone surveys-Lessons from a mode experiment in two low-income countries during COVID contact restrictions. OSF Preprints; 2021.

73. Niles M, Mueller N. Farmer perceptions of climate change: associations with observed temperature and precipitation trends, irrigation, and climate beliefs. Glob Environ Chang 2016; 39: 133–142.

74. Kalkuhl M, Wenz L. The impact of climate conditions on economic production. Evidence from a global panel of regions. Journal of Environmental Economics and Management 2020; 103: 102360. Available from: https://doi.org/10.1016/j.jeem.2020.102360.

75. Watts N, Amann M, Arnell N, Ayeb-Karlsson S, Belesova K, Berry H, et al. The 2018 report of the Lancet Countdown on health and climate change: shaping the health of nations for centuries to come. The Lancet 2018; 392(10163): 2479–2514. Available from: https://doi.org/10.1016/S0140-6736(18)32594-7 PMID: 30503045

76. Werrell CE, Femia F, Sternberg T. Did We See It Coming? State Fragility, Climate Vulnerability, and the Uprisings in Syria and Egypt. The SAIS Review of International Affairs 2015; 35(1): 29–46. Available from: https://www.jstor.org/stable/27000974.

77. Rigaud KK, Sherbinin A De, Jones B, Bergmann J, Clement V, Ober K, et al. Groundswell: Preparing for Internal Climate Migration; 2018. Available from: https://openknowledge.worldbank.org/handle/10986/29461.

78. Kam PM, Aznar-Siguan G, Schewe J, Milano L, Ginnetti J, Willner S, et al. Global warming and population change both heighten future risk of human displacement due to river floods. Environmental Research Letters 2021; 16(4): 044026. Available from: https://doi.org/10.1088/1748-9326/abd26c.

79. Abel GJ, Brottrager M, Crespo Cuaresma J, Muttarak R. Climate, conflict and forced migration. Global Environmental Change 2019; 54: 239–249. Available from: https://doi.org/10.1016/j.gloenvcha.2018.12.003.

80. Boas I, Farbotko C, Adams H, Sterly H, Bush S, van der Geest K, et al. Climate migration myths. Nature Climate Change 2019; 9: 801–903.