International Migration as Climate Change Adaptation: A Spatial and Temporal Analysis

by
Michael J Popović (SUNY Potsdam)
Jessica Rogers (SUNY Potsdam)

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The interest in the nexus of migration and global climate change has significantly increased over the last couple of decades. Thankfully, more social scientists and natural scientists are working together today to achieve a better understanding of the multifaceted impacts of the increasing environmental stressors and disasters on individuals, households, and communities and their significant policy implications. This project is one such collaboration where through the usage of migration data in conjunction with data on natural disasters, in an analysis utilizing ArcGIS software, we are investigating the connection between the occurrence of natural disasters and changes in international migration flows (Obokata, Veronis and McLeman 2014). Ultimately, the goal of this research project is to better understand the spatial and temporal variations of migration that occurs as risk management and global climate change adaptation strategies. In order to fully utilize the explanatory power of this innovative ArcGIS application, we want to first establish the basic connection between rapid on-set environmental disasters and an increase in international migration. Furthermore, we are testing the assertion in the literature that international migration is more likely to occur after high frequency disasters while a single, even large event, does not produce the same kind of pressures or "push" factors (Saldana-Zorrilla and Sandbery, 2009; Naude 2008). In addition to frequency, we are also testing for the effects of the intensity of the damage the events produce in terms of number of casualties and the dollar amount of damage caused. Through analysis of the data of three case studies (Dominica, Fiji, and the Philippines), we are able to find initial support for rapid on-set environmental disasters causing international migration. Frequency of events seems to influence migration patterns across all 3 cases, while number of casualties only seem to have some effect in Fiji[1]. While these are certainly only initial results and further quantitative data analysis will be necessary to capture the nexus of environmental disasters and international migration more carefully, this study makes us confident that further geospatial analysis will provide us with significant new insight into international migration as an adaptation strategy for global climate change.

The Nexus of International Migration and Environmental Disasters

The literature on human migration and mobility has undergone a number of transformations in theoretical lenses and methodological approaches and has recently seen significantly increased attention paid to the role of environmental factors impacting decisions to move and patterns in movements. While environmental stressors had been identified as an important context for migration decisions early on, the main focus of the literature concentrated on economic aspects of migration decisions and flows. Initially, scholars focused predominantly on the macroeconomic implications, causes, and effects of international migration in the context of

[1]In some initial data analysis, number of casualties had significant impact in places like Haiti.

economic development (Lewis 1954; Ranis and Fei 1961). Primarily, wage differentials between countries and regions as well as the variations of the rate of return on human capital were utilized to understand human mobility.

Parallel to this focus on economic development, historical-structuralist theories tried to explain migration in the context of dependency theory (Frank 1966) and world systems theory (Wallerstein 1974). Here migration flows, based on the changes in numbers of diaspora, those leaving their country of origin to live in another country, and migrant stocks, the total number of non-citizens living in a country, are explained as one of the many processes in a system that advanced, core economies have been constructed to control and exploit marginalized, peripheral countries and markets which prevents their long-term economic development. Based on the expansion of the sphere of influence of multinational firms and neocolonial elites, intensifying mobility of capital, goods, services and labor is aided by improvements in transportation and communication (Portes and Walton 1981; Petras 1981; Morawska 1990).

Most migration scholars in the 20th century can be found within neoclassical theory which emphasizes the individual assessment of these wage differentials (Todaro and Maruszko 1987; Borjas 1989) and stipulates that the greater the rate of return increases on human capital endowments are when individuals migrate, the greater is the likelihood of individuals to migrate (Sjaastad 1962). This narrow focus on the economic sphere is expanded to consider push and pull factors more generally with a particular focus on changes in demographic conditions (Lee 1966). In essence, this theory claims that people will migrate either because of social or economic attractions in the country of destination or due to relative deprivation in the country of origin. Therefore, potential emigrants will move to the country in which their discounted expected net returns are greatest over some time horizon (Borjas 1989; 1990). Much of this literature concentrates on the push factors, but the dual labor market theory of migration centers on the countries of destination where companies and governments create a segmented market with a secondary labor market for immigrants with very low wages to increase international competitiveness and to shore up support among labor and its unions (Piore 1979). Although these theories can be seen as a major advancement in the studies of international migration, many critiqued it for their inability to predict the origin of flows and changes therein and its focus on the economic cost-benefit analysis of an isolated rational actor (Pedraza-Bailey 1985, Portes and Bach 1985).

Stark and others have tried to address these problems by developing the New Economics of Labor Migration which was supposed to challenge many of the assumptions and conclusions of neoclassical economic approach (Stark and Bloom 1985). The main difference is the insight that each individual does not choose to migrate in social isolation. Larger units of related people, usually families, are crucial in this decision-making process. Usually, households or families will try to maximize the expected overall income, while minimizing or managing the risks they encounter (Stark and Bloom 1985; Stark and Taylor 1991; Taylor 1999; Boyd 1989; Massey and Parrado 1998). Through migration they will try to compensate for the absence or failure of certain kinds of markets, in which the family expected income or sees income potential. Therefore, it is not the difference in wages or the economic development in countries of origin which are crucial, but diversification of the familial labor force and risk management through remittances. Migration will increase or decrease according to the creation of certain markets, like insurance (unemployment or crop), capital or futures, and can itself be seen as a substitute for insurance (Massey et al. 1993; Yang and Choi 2007). Developing at the same time and complementary to the New Economics of Labor Migration is the sustainable livelihood perspective (De Haas 2010). From this perspective, migration is a potentially very important strategy available to households to address declining livelihoods due to environmental stressors such as climate change, land degradation, and water shortage or abundance (Warner and Afifi 2014).

This aspect of risk management and adaptation allows for a direct application of this approach to environmental shocks (Arango 2000), either through local, regional or international migration. However, this approach is not without its critics due to the depoliticization of environmental migration. Bettini and Gioli (2016) argue that this approach developmentalizes climate migration by putting the onus of adaptation on the victims of climate change. The underlying assumption here is that migrants ought to use labor migration and remittances to adapt to global climate change, shifting the responsibility on the vulnerable (Felli 2013). This critique does not take into account the migration network concept that allows families to distribute their risk as well as maximize their reward with varying levels of familial migration.

Developing from different theoretical traditions, but very much compatible with both the New Economics of Labor Migration and sustainable livelihood perspective, is migration network theory. It posits that migrants form networks of friends, family, and kin in potential destination countries that can be activated to reduce both cost and risk of migrating and establishing a livelihood at the destination. Through transnational living, migrants are increasingly able to maintain close ties with individuals and communities in the regions of origin which allows for more efficient networks and circular or repeated migration over the course of a lifetime (Greiner and Sakdapolrak 2013; Etzold 2017). Consequently, these networks allow families and communities to manage risk and increase resilience in the face of environmental stressors through risk diversification, know-how and technology transfer, and remittances (Deshingkar

2011; Scheffran et al. 2012). In particular, cumulative causation theory posits that migration flows are self-reproducing through community social ties for which there seems to be ample evidence from a variety of contexts. The influence of these migration networks can be seen in migration from both rural areas and urban centers (Paredes-Orozco 2019); however, the maturity of the diaspora community and labor market conditions can diminish the impacts these networks over time (Bachmeier and Bean 2009) with the strongest effects evident at the beginning of new settlement centers abroad (Liang 2014). The presence of these networks will undoubtedly also help shape environmental migration patterns and influence the likelihood of international and longer-term migration.

In the end, none of these approaches fully capture and explain the process of international migration in large part due to its multicausal drivers and complex nature. The British government tried to capture these complexities in its final project report Foresight: Migration and Global Environmental Change (2011). Here the human mobility decision context is captured on the macro, meso, and micro levels. The importance of the macro level with its political, social, economic, and environmental aspects is acknowledged, but additional attention is given to factors on the micro and meso level. The meso level focuses on explanations for the decision to stay or migrate that consider access to migration networks and the political as well as legal context among others. On the micro level of analysis, personal and household characteristics such as age, education, wealth, language, race, ethnicity, and others are included in the explanation. The Foresight study represents some of the most comprehensive explanatory framework that captures migration decisions, in all their complexities.

The complexities of the decision to migrate are obvious when considering the choice in its personal, familial, social, cultural, economic, and political context alone. Environmental factors are an additional dimension in the explanation for migration dynamics and can never explain migration on its own (Obokata, Veronis and Mc Leman 2014). Environmental changes and the effects of climate change however do influence all other dimensions and can have a multiplier effect. A decision to migrate may appear to be mainly due to economic considerations; however, often environmental deterioration exacerbates economic instability and can be considered "environmentally induced economic migration" (Afifi, 2010). Piguet at al. (2013) also suggests that somebody who may have moved once for economic reasons and is therefore familiar with the process, may be more likely to move again because of climate change.

In this project, the focus is on environmental migrants who "are persons or groups of persons who, for compelling reasons of sudden or progressive changes in the environment that adversely affect their lives or living conditions, are obliged to leave their homes or choose to do so, either temporarily or permanently, and who move either within their country or abroad" (IOM, 2007). More specifically, we are focused on international movement of people that includes migration, displacement, and planned relocation. Much of the environmental migration literature has focused on mobility that can be described as local or regional and has argued that international migration represents only a percentage of environmental migration in large part due to its prohibitive cost (Melde, Laczko, and Gemenne 2017, Foresight 2010, Findley 1994, Warner and Afifi 2014). Since most human mobility for any reason occurs predominantly within national borders, it seems intuitive that this should also hold true for environmental migration for a variety of reasons, such as migration network connections. The vast majority of the environmental migration literature finds empirical evidence that environmental factors do influence international migration (Obokata, Veronis and Mc Leman 2014). Different environmental stressors and disasters will influence migration decisions differently, but there is empirical evidence of this longer term and more distant international migration in places with a high frequency of disasters such as Mexico (Saldana-Zorrilla and Sandbery, 2009) and sub-Saharan Africa (Naude, 2008). Additional macro-level studies have also found results consistent with the premise of rapid onset environmental disasters directly causing international migration (Reuveny and Moore, 2009; Affifi and Warner, 2008).

While some migrants may consider international migration in response to environmental events from the outset, there is much evidence that the international movement is part of a multi-stage process that is sometimes described as a steppingstone pattern (Warner et al. 2012, Zelinsky 1971). An environmental event of great negative impact might first trigger a migration flow to a local or regional destination only to continue to other, farther, and often international destinations (Kugler 2006). In other cases, international migration was the only step like we saw during the acute Horn of Africa drought that drove people across international borders to access aid (Flavell, Milan, and Melde 2020).

In the context of international migration and due to the limitations of the available data, we are mainly focused on more long-term or permanent migration. It is important to notice that much of the current more local and regional environmental migration is temporary, seasonal, or circular and are a crucial component in securing the livelihood of individuals, families, and communities (FAO, 2018). While some movements can certainly be described as circular, they may occur over the course of decades with long residencies in few locations. We are capturing this kind of long-term migration in our data and see it distinctly different from the shorter-term, often seasonal, migration patterns. When environments get more permanently and irreparably damaged through environmental stressor or disasters, the resulting migration will in turn also become more permanent which is a likely scenario for the future of more people, even though research overall does not seem to support the popularized and securitized extreme population movement predictions found in some of the maximalist and often methodologically flawed work in this field (Myers, 1997 2002).

Permanent relocations, as a planned resettlement of entire communities to places where livelihoods can be maintained, are only slowly beginning and so are far mainly occurring internally in places like Alaska (Bronen, 2011), Fiji (Tronquet, 2015), and Sao Tome and Principe (Koskinen-Lewis et al., 2016). It is highly likely that larger communities will have to be relocated in the future and some of these relocations will only be viable when conducted internationally, especially in the context of island nations and sea-level rise. In addition, relocation may be the last steppingstone after disaster-induced displacement. Displacement is usually seen as a temporary movement over relatively short time periods with an ultimate return to the location of origin (Brzoska and Froehlich, 2015; Black et al., 2011), but cases of protracted displacement, as in the aftermath of the 2010 earthquake in Haiti, are starting to blur the lines between displacement and more permanent migration. Additionally, planned relocations or more permanent autonomous outmigration increase in likelihood if the disaster damage is lasting a long time or is permanent (Osterling, 1979; Myers, Slack, and Singlemann, 2008), which is a likely scenario for some based on climate change predictions.

A meaningful differentiation between voluntary and forced migration may, in general, be hard and is nearly impossible when it comes to environmental migration. This project includes movement that may be described as both voluntary or forced since this suggested dichotomy does not seem to capture actual migration decisions which seem to occur on a spectrum that may have purely voluntary and forced migration as its endpoints. While individuals, households, and communities may have different strategies for adaptation to climate change available to them, it is hard to distinguish how voluntary the movement of an individual or even an entire community is when they try to mitigate climate change impacts and ensure livelihoods. Often, migration is seen as a last resort even if it occurs preemptively or in the early stages of the environmental stressor (Alscher 2011, Schrepfer and Caterina, 2014; Foresight, 2011; Ionesco et al., 2017).

Environmental stressors and disasters can take on a variety of forms and most researchers fundamentally divide them into two categories: sudden and slow-onset events. Slow onset events best describe environmental processes such as the rising temperatures across the world and sea-level rise. While these are very important aspects of the global climate change impacts on human mobility, the extent is difficult to predict and quantify due to the multitude of factors that are unknown such as the extent of sea-level rise and the effectiveness of mediating and adaptation strategies beyond migration. For example, while sea-level rise (SLR) is likely to be one of the greatest global impacts of climate change on the environment and human migration, there is difficulty in uniformly measuring the impacts (Strauss et al. 2021), particularly during the study period of 1990-2015, due to a lack of detailed geospatial data on coastlines and riverine flooding impacts. We chose not to focus on the slow, but constant threat of SLR, while simultaneously acknowledging that the disasters we note may pale in comparison to SLR at some future date.

In this project we are primarily focusing on fast or sudden-onset disasters and their impact on migration. Specifically, we focus on 7 categories of natural disasters – drought, extreme heat, flooding, landslides, tornados, cyclones, and wildfires. Not all events in each category are considered due to our focus on sudden-onset disasters. For example, we are not focusing on prolonged multi-year or multi-decade droughts as we currently see in California or during the Sahel drought of the 1970s and 1980s where an over 30% decline in precipitation was measured over 2 decades (Giannini et al. 2008). Drought events included in our data are shorter in duration and more intense. Only landslides that can be attributed to causes that are influenced by climate change are included, which meant to exclusion of landslides due to volcanic activity or earthquakes. All of the environmental events included are influenced by global climate change and are assumed to intensify over time; however, the exact trajectory of this change is impossible to estimate precisely. Table 1 provides you with a short overview over the included events.

Natural Disaster Classifications and Definitions	
Drought	An extended period of unusually low precipitation that produces a shortage of water for people, animals, and plants. Drought is not solely a physical phenomenon because its impacts can be exacerbated by human activities and water supply demands. Drought is therefore often defined both conceptually and operationally. Operational definitions of drought, meaning the degree of precipitation reduction that constitutes a drought, vary by locality, climate and environmental sector.
Extreme Temperature, Heatwave	A period of abnormally hot and/or unusually humid weather. Typically, a heat wave lasts two or more days. The exact temperature criteria for what constitutes a heat wave vary by location.
Flood	The overflow of water from a stream channel onto normally dry land in the floodplain (riverine flooding), higher-than- normal levels along the coast and in lakes or reservoirs (coastal flooding) as well as ponding of water at or near the point where the rain fell (flash floods).
Landslide	Any kind of moderate to rapid soil movement incl. lahar, mudslide, debris flow. A landslide is the movement of soil or rock controlled by gravity and the speed of the movement usually ranges between slow and rapid, but not very slow. It can be superficial or deep, but the materials have to make up a mass that is a portion of the slope or the slope itself. The movement has to be downward and outward with a free face.
Tornado	A violently rotating column of air that reaches the ground or open water (waterspout).
Hurricane, Cyclone, Typhoon	Large-scale closed circulation system in the atmosphere with low barometric pressure and strong winds that rotate clockwise in the southern hemisphere and counterclockwise in the northern hemisphere. Maximum wind speed of 64 knots or more. They are called hurricane for the western Atlantic and eastern Pacific, typhoon in the western Pacific, and cyclone for the Indian Ocean and South Pacific.
Wildfires	Any uncontrolled and non-prescribed combustion or burning of plants in a natural setting such as a forest, grassland, brush land or tundra, which consumes the natural fuels and spreads based on environmental conditions (e.g., wind, topography). Wildfires can be triggered by lightning or human actions.

Table 1- Description of Environmental Disasters – Source: International Disaster Database (EM-DAT 2021)

Estimating initial displacement and longer-term migration in the aftermath of rapid onset environmental events is difficult and most scholars have shied away from making predictions due to the multitude of unknown factors. With probabilistic risk assessment methodologies, some attempts have been made to quantify the current magnitude of this problem (IDMC, 2018); however, most of these estimates and some future predictions are likely low estimates as they are in part based on significant assumptions, especially when it is assumed that no increase in environmental disasters will occur, counter to climate change predictions (Ginnetti, 2015).

While fully capturing the number of people adapting to climate change by moving is impossible, all of these events can and will trigger human mobility. How this migration is triggered can vary depending on the event and the overall context. For example, in the literature on droughts, three kinds of results can be identified (Piguet et al., 2013), with some studies confirming the link between drought and extreme heat events and international migration (Afifi and Warner, 2008; IDMC, 2018). Bohra-Mishra et al. (2014) found that climatic changes, especially above 25C have impacts that lead to permanent migration. Another set of studies conclude that droughts are unlikely to generate significant international migration in part due to a lack of access to the necessary financial resources and alternative adaptation opportunities (Findley 1982; 1989; 1994; Henry, Boyle, and Lambin 2003). Others find some migration in response to droughts and extreme heat, but patterns are varied, and few generalizations are possible (Henry, Schoumaker, and Beauchemin 2004). Piguet et al. “conclude that a link does exist between rain deficits and migration, but that is remains highly contextual” (2013, 11). One of the contextual aspects is the steppingstone approach to migration (Warner et al., 2012), where international migration may only occur as a step after local and regional migrations were deemed insufficient adaptation strategies. While we know that all of these environmental stressor and disasters cause migration, "the relatively small number of empirical studies, the wide array of study sites, and the diversity of methods used, make it difficult to draw anything more than a tentative conclusion as to which environmental phenomena have the greatest tendency to stimulate migration" (Obokata, Veronis, and McLeman, 2014, 119).

Ultimately, the likelihood of human mobility due to environmental and climate effects is fundamentally dependent on the vulnerability and resilience of individuals, households, and communities. Vulnerability can be understood as the "degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC, 2007). The greater the opportunities and resources for adaptation to climate change, the more resilient people and communities are. Usually, communities with an abundance of resources are capable to engage in a variety of adaptive strategies to respond to climate change, while marginalized and systemically oppressed or disadvantaged communities, mostly located in the global South, are often the most vulnerable. The response to climate change can be understood as the interplay between vulnerability, resilience, and adaptation, where migration can become one of the few viable strategies. Migration as a strategy might be particularly attractive as a risk management and adaptation approach due to the often-resulting remittances that are often first aide and significant mitigating factor during and after a crisis.

The interplay of the factors can be understood in terms of impacts of environmental stressors and disasters. While the frequency of events certainly plays a significant role in the decision to migrate, the destruction and damage the event leaves behind is of greater significance. An illustration of this is the variation in outcomes can be seen in Haiti versus the Dominican Republic, where both destruction and death tolls tend to be significantly in higher in the former than the latter. Feng, Kruger, and Oppenheimer (2010) also find that the effects of environmental events, such as impacts on crop-yields, and less so the intensity of the event itself determine migration, underlining the importance of considering vulnerability and resilience of affected populations.

Approaching Environmental Disaster and International Migration Data

Detailed data for international migration in general and in particular human mobility impacted by environmental and climate stressors is largely lacking. Data on migration is often incomplete and usually not sufficiently longitudinal to account for many of the environmental change processes that occur on a slow timescale. While more data on human mobility is available in the context of sudden-onset natural disasters, even this data is often based on estimates and is lacking details for many types of analysis. A notable contribution to better data comes from the Internal Displacement Monitoring Centre (IDMC) which has put out reports since 2008 on people internally displaced by conflict and violence as well as environmental disasters (IDMC 2020). Even though this work is a significant contribution to the field, it still has a number of inherent problems and is lacking demographically disaggregated information which is common to most data sets. It is also not focused on international migration which is at the center of this project and for which detailed annual data is not available at this point.

Environmental data is more readily available and often focuses on specific stressors and disasters including events associated with global climate change. Since the environmental data is significantly more detailed than the migration data, certain consistency issues may arise in the analysis (Neumann and Hilderink 2015). Despite the potential shortcomings, this project tries to position itself as part of the recent methodological innovations in research methods of the environment-migration nexus. Fieldwork and interview research will remain crucial aspects of this work, innovative uses of modeling (Kniveton, Smith and Wood 2011, Hassani-Mahmooei, and Parris 2012), and uses of cell phones to track populations after disasters (Lu et al. 2016) are emerging as methods to overcome data collection issues. These recent innovations have expanded our understanding of environmental migrations, but so far the powerful tools of geographic information science have been underutilized. This current project is a first step in exploring this methodological application.

The initial data on human migration was obtained from the United Nations, Department of Economic and Social Affairs, Population Division, specifically *Trends in International Migrant Stock: The 2017 Revision* (United Nations database, POP/DB/MIG/Stock/Rev.2017). This provided international migrant stock at mid-year by major area, region, country or area, from 1990 to 2015 every 5 years. The data table we focused on was migrant stock by origin and destination, which provided numbers for the migrant stock in a given country, as well as the total diaspora (those living in other countries). While this dataset also provides substantial information on gendered migrant stock, estimated refugee stock (including asylum seekers), we focused on total numbers for our initial analysis.

To begin to understand the spatial components of how these data were connected to global climate change events, the data was joined to a high-resolution georeferenced Country boundary shapefile in ArcGIS Pro (v 2.8.3) provided by the Center for Geospatial Technology, Texas Tech University (2020). The climate data was downloaded from the public EM-DAT mapping tool for the years 1985-2015 (EM-DAT, CRED / UCLouvain, Brussels, Belgium – www.emdat.be (D. Guha-Sapir)). We used the Disaster Classification tool to limit our download to Natural Disasters, ultimately creating 7 categories described in Table 1 – Landslides, Extreme Heat, Tornados, Tropical Cyclones, Floods, Wildfires and Droughts.

The EM-DAT data table was joined with the countries and migration data to connect the disasters to individual countries. The tables were summarized across the 5 years prior to the data of the migration numbers to get the total number of types of disasters in each country, the total number of disasters, the total deaths, injured, homeless, and the total damages (in $US). To make comparisons between countries, we calculated per capita deaths and damage values. The total country population was obtained from the United Nations Population Division Department of Economic and Social Affairs (2019). We used the total population for the country for the year corresponding to the migration data. The top 10 countries with the highest per capita deaths and per capita damages were extracted and are presented alphabetically in the appendices (Tables 1-6). There were several countries that overlapped in the 2 categories and thus fewer than 20 countries are represented in each table.

We also examined the total number of disasters in each country and the table that lists the highest number of incidents is also a list of some of the largest countries in the world, and so no analysis was done on that data at a macro scale, but only on the frequency of events within an individual country and its effect on migration. Finally, the magnitude of the disasters was not included directly in the analysis as it was difficult to compare the impact of a Category 4 hurricane with a flash flood as the magnitude is calculated very differently. Instead, we chose to focus on the per capita death and damage rates. By focusing on the number of deaths caused by disasters per capita and the total value of damages per capita in each country, we believe we captured the reasons that people would seek to leave the country in a way that makes comparisons between countries and between time periods reasonable.

Finally, to compare the countries with the most deaths and disasters to their changes in migration we looked at the total numbers of diaspora, those living elsewhere than their country of origin, as well as the change in migrant stock. The combination of these changes in numbers indicate movement out of the country, though focusing on the movement of the diaspora indicates likely permanent migrations rather than steppingstone migrations that migrant stock might indicate.

Results

In order to gain a better understanding of the relationship between rapid-onset environmental events and international migration and to determine the effects of frequency and intensity of events as indicated by deaths and damages, we decided to initially concentrate on three case studies. To focus on the results of several countries as our case studies we decided to choose a country from different regions of the world, and to avoid those countries where there were obvious alternative and complex reasons for emigration (e.g. Honduras (Reichman 2013) or Haiti (Audebert 2017) or Somalia (IDMC 2019)) despite their strong showing in the most impacted countries over our time frame.

We chose to focus on the Caribbean country, Dominica, Fiji in the South Pacific, and the Philippines in Southeast Asia. In addition, there were notable issues within Bangladesh and Indonesia that deserve consideration but did not necessarily rise to the top of the lists repeatedly though all appear on one of the top 10 lists (See Supplemental Material).

Dominica

The small island country in the Lesser Antilles, Dominica is a strong case study for migration due to climate disasters. The country had 6 major disasters between 1985-2015, and they were all tropical cyclones: Hurricanes Hugo, Marilyn, Luis, Lenny, Dean, Erika and as well as Tropical Storm Orphelia. In addition, Hurricane Maria hit Dominica in 2017, continuing the trend of catastrophic disasters. While the death toll was rarely high from these individual hurricanes (only 34 direct deaths), the damage was catastrophic, totaling $US 235 million. For a country that relies on fishing and tourism (Pinnegar et al. 2019), these disasters are clearly leading to steady immigration out of the country. The devastation from these hurricanes has led to food shortages and reliance on pelagic fishing when hurricanes make closer reef fishing difficult. The immigration data from our study showed more than. While its migrant stock grew slightly over the study period, the diaspora grew substantially over the time frame. Most immigration out of Dominica was to the United States or more regionally to Guadeloupe.

Dominica - Population 70,000								
Migration Year	Change in Diaspora	Change in Migrant Stock	# Events	Type of Events	Dead	Injured	Homeless	Total Damages ('000 US$)
1990-1995	2,796	649	2	TC	2	1	5000	215,000
1995-2000	3196	521	1	TC			315	
2000-2005	15739	733	0	TC				
2005-2010	9195	706	1	TC	2	30		20,000
2010-2015	-3527	773	2	TC	30	20	670	482,810

Table 2 – Migration changes and disaster details from 1990-2015 in Dominica TC=Tropical Cyclone

While Dominica is a solid example for the case of climate change derived migration, they are not unique among the Caribbean Island nations in this case. For each of our study years, several Caribbean nations were part of the most deaths and most damages lists, Antigua and Barbuda, Monserrat, and the Bahamas among them. Each island had only 1-2 events per time period, preventing more detailed analysis, but all show an overall net migration over the total time frame.

Fiji

In contrast to Dominica, which had regular, but infrequent, if devastation storm, Fiji in the South Pacific was hit by more and an increased variety of environmental disasters over the study years, including flooding, drought, as well as tropical cyclones. Fiji also had a much larger increase in the diaspora over the study period, with a very flat number of migrant stock. Their damages and deaths are also relatively constant, which supports their level of constant and increasing emigration. There were several notable connections in the data regarding Fiji supported by the literature. For example, one large storm such as Hurricane Kina in 1993, despite $100 million in damages (compared to a $1.6 billion GDP), did not trigger large international migration. However, sustained storms, such as 4 in 2007 along, and 9 total between 2005-2010 did lead to over 11% of the population leaving Fiji. And supporting the theory of frequency of storms leading to migration, and not the total damages, one large riverine flood in 2012 did not trigger large migration despite the damage of over $70 million (compared to $4.0 billion GDP). This example supports the idea that multiple events, regardless of total deaths or damage, trigger international migration. There was a strong correlation between the number of events and the number of diaspora and migrant stock (0.82, and 0.64 respectively). While not definitive, it does support the ideas above and indicates more research is needed.

Fiji - population 900,000									
Migration Year	Change in Diaspora	Change in Migrant Stock	# events	Type	Dead	Injured	Homeless	Damage '000 US$)	Notes
1990-1995	16342	-259	3	TC	22	3	13000	111600	1993 Kina $100 000 000
1995-2000	25416	-276	3	D, TC	37		1772	30500	
2000-2005	24768	-291	5	Fl, TC	38			34000	
2005-2010	27628	916	9	Fl, TC	32			124699	4 Tropical Cyclones in 2007
2010-2015	22995	400	4	Fl, TC	17			128427	one large riverine flood in 2012

Table 3 - Migration changes and disaster details from 1990-2015 in Fiji. D=Drought, Fl = Flood, TC = Tropical Cyclone

Like many island countries in the South Pacific, Fiji is planning for large community relocation based on the different threats. Fijian international migration is likely also due to sea level rise and the resulting degradation of fresh water, the presence and increase in other climate change related disasters is part of that voluntary relocation (Gharbaoui & Blocher 2016; McNamara & Combes 2015). There are also potentially larger cultural barriers to voluntary migration from Fiji, and the likelihood of entire communities planning relocation (Charan et al. 2017; Bertana 2020).

Philippines

The Philippines, a nation of more than 2000 inhabited islands in southeast Asia, was bombarded by dozens of tropical cyclones, often more half a dozen each year during the study period. There was no correlation between the number of deaths nor the amount of damage with migration changes, the number of events was strongly correlated to the international migration (0.68). In addition, the number of diaspora increases steadily for more than 2 decades, with a decreasing migrant stock as well. Longer data analysis (or finer migration data) will be necessary to see more detail. According to the IPCC (2021), fewer but more extreme tropical cyclones have affected the Philippines during our study period than long-term averages. However, it is the strong correlation between the number of storms over a relatively short period (5 years) and not just the total damage that leads to migration, and the likely increase in number and severity of storms will only add to the pressure of local areas.

Philippines - population 70,117,000									
Migration Year	Change in Diaspora	Change in Migrant Stock	# events	Type	Dead	Injured	Homeless	Damage '000 US$)	Notes
1990-1995	475,728	44,379	65	D, Fl, L, St, TC	9,923	7,698	1,954,261	$2,351,476.00	
1995-2000	560,965	60,675	40	D, Fl, L, St, TC, W	1,567	1,424	231,031	$453,194.00	
2000-2005	634,708	-44,555	46	D, Fl, L, St, TC	3,242	2,009	194,903	$306,574.00	
2005-2010	1,004,328	-35,332	88	Fl, L, St, TC	5,749	4,797	54,745	$2,142,402.00	2 Storms in 2006 alone totaling $248million - GDP $95Billion
2010-2015	718,404	2,310	85	D, Fl, TC	12,152	40,538	39,062	$17,123,708.00	Typhoon Haiyan in 2012 caused more than 5 times the damage of any other storm during the study

Table 4 - Migration changes and disaster details from 1990-2015 in the Philippines. D=Drought, Fl = Flood, L = Landslide, St = Storm, TC = Tropical Cyclone, W = Extreme Weather

In addition, the Philippines' islands are at increased risk of flooding due to sea-level rise, and thus the increased tropical cyclone activity will magnify the impact of multiple climate change induced disasters (Jamero et al. 2017). The global humanitarian effort following Typhoon Haiyan (Matias, 2020), with the US and Canada offering increased immigration options for familial connections of victims, is a good start toward helping countries like the Philippines adapt to these increasing events, but those trapped by economic limitations will be forced to find other mechanisms of adaptation instead of international migration. Matias (2020) suggests creating a climate humanitarian visa to better enable climate change victims' adaption by migration, supporting the idea of network migration as a result of climate disasters.

Overall, there seems to be evidence that high frequency of rapid-onset environmental disasters increase international migration in their aftermath to a certain degree. The frequency with which these events occur seem to be the best predictors for international migration in response to the intensifying environmental events in the context of climate change. The number of causalities, while significant in some cases, does not seem to impact migration flows in all cases. The degree to which damage occurred does not seem to have an effect in any of the investigated cases. Further research is necessary to test the generalizability of these initial case study findings.

Next Steps

This paper is a very first step in a series of projects we hope to engage in that utilize this data and adds additional dimension to the application of ArcGIS to the topic of environmental migration. Since we found some evidence in this paper for the claim that a high frequency of environmental disasters add additional pressures that will lead some people to migrate internationally, while singular large events do not, we want to test how generalizable these findings are. Through usage of the 2019 Revision of World Population Prospects dataset from the United Nations, we will test this hypothesis across the 201 countries and territories included in the dataset.

While the frequency question is certainly an important one with significant policy implications for global climate change responses, our main focus will stay with the International Migrant Stock – 2017 revision dataset because it allows us to advance our spatial analysis of the migrant flows. Due to the geographic specificity of the data, we will be able to test and visually illustrate the claim that environmentally induced or influenced migration also follows established social and migration networks which become key determinants of migration destinations. While it seems highly likely that migrants that were significantly influenced in their decision to migrate by environmental stressors and disasters will follow established migration networks, the changing climate in the global scale is likely to alter migration routes and associated networks due to the changing attractiveness or availability of destinations.

Many studies have shown that people mainly migrate to neighboring countries. This may be in part influenced by a selection bias in the cases in the literature (Obokata, Veronis, and McLeman 2014); however, there are many arguments why this claim is likely true, even if only the cost of migration is taken into account (Melde, Laczko, and Gemenne 2017, Foresight 2010, Findley 1994, Warner and Afifi 2014). Through the usage of GIS analysis we will be able to test and visualize this claim.

In addition, gender plays an important role in many migration decisions and experiences in contexts such as increased injury and fatality rates of women during disasters (Frankenberg et al., 2011; Aguilar, 2004), exposure to gender-based violence in post-disaster situations (Gyawali et al., 2016), and women experience negative effects of the absence of the male household members who have migrated as a risk management and adaptation mechanism (Warner et al., 2012; Jungehulsing, 2010). Our data allows us to test a few hypotheses that are related to the geographic context of gendered migration. For example, Findley (1994) and Henry et al. (2004) both found longer-term migration – particularly by men – decreased in drought years (in Mali and Bukina Faso respectively), but the short-term and local mobility of women and children increased. We will test this hypothesis in the international context.

Furthermore, we are able to distinguish between native populations living abroad in the diaspora and immigrant populations within each country. Again, due to the geographic specificity of the data from the United Nations we can test which migration routes these different groups take to better understand the complexity of these social systems. Additionally, we can investigate migration pattern variations based on age of the migrant.

In its final conclusion, macro-level research such as this problem will never fully be able to capture all aspects of the multifaceted process of international human mobility and this work leaves us wanting for more. As researchers we understand, appreciate the importance, and engage in field research to allow for micro-level and qualitative analyses of both the environmental as well as human aspects of the nexus of migration and climate change. This work can provide us with additional starting points to expand our work in these areas as well.

Conclusion

This study is only an initial step in the exploration of the questions at hand; however, the results presented in the three case studies make us cautiously optimistic about this approach to understanding international migration in response to environmental pressures and disasters. Significantly more research is going to be required to fully reap the benefits and achieve new potentially powerful insights from the introduction of ArcGIS in the study of migration as adaptation strategy to global climate change. A deeper understanding of the geospatial dimension of international migration networks and flows is crucial now, and even more so in the future. Through the innovative usage of this analytical tool, we might be able to better understand structures and spatial distribution of migrant flows, the role of gender in migration destination choice, and various other aspects of other migrant subgroups.

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Supplemental Material

Appendices – Highest Frequency, Highest Death, Highest Damage

Supplemental Table 1 – Highest Number of Storms

NAME	Year	Total Number	Total Deaths	Total Injured	Total Damages (US$ '000)	Deaths per Capita	Damage Per Capita (US$ '000/'000 people)	Total Population
	1990-1995							
United States		123	1,721	1,267	78,777,000	0.006	297.09	252,120
China		69	12,848	164,232	48,637,060	0.010	39.19	1,176,884
Philippines		56	8,987	6,409	1,874,933	0.129	26.87	61,895
India		39	8,750	825	8,674,102	0.009	9.00	873,278
Bangladesh		37	141,753	150,768	3,232,800	1.231	28.07	103,172
Australia		23	65	1,163	2,813,460	0.004	156.36	16,961
Thailand		23	494	277	2,553,221	0.008	42.93	56,558
Indonesia		20	664	249,858	126,346	0.003	0.64	181,413
Russia		20	452	463	2,518,900	0.003	16.99	147,532
Vietnam		20	1,479	406	558,800	0.020	7.46	67,989
	1995-2000							
United States		132	1,625	2,328	51,933,950	0.006	184.35	265,164
China		83	13,622	423,024	71,637,926	0.011	55.51	1,240,921
India		52	27,173	7,969	7,956,980	0.026	7.53	963,923
Philippines		40	1,567	1,424	453,194	0.020	5.81	69,784
Bangladesh		39	3,022	48,978	5,039,000	0.024	39.47	115,170
Russia		32	95	168	1,076,281	0.001	7.35	148,227
Vietnam		30	6,507	2,386	2,360,855	0.081	29.54	74,910

Australia		29	71	128	3,937,833	0.004	207.35	17,993
Mexico		29	1,852	440	2,811,810	0.019	28.43	91,663
Brazil		24	433	390	234,000	0.002	1.34	162,020
	2000-2005							
China		113	4,876	308,224	42,408,633	0.004	31.87	1,290,551
United States		112	2,800	1,278	250,743,900	0.009	850.00	281,711
India		71	24,802	12,043	11,925,634	0.022	10.39	1,056,576
Philippines		46	3,242	2,009	306,574	0.038	3.55	77,992
Indonesia		45	167,548	2,230	4,896,661	0.740	21.64	211,514
Bangladesh		36	1,987	9,026	2,700,000	0.014	19.42	127,658
Russia		35	587	1,292	944,597	0.004	6.57	146,405
Australia		34	36	232	3,094,100	0.002	153.34	18,991
Vietnam		33	1,164	346	945,470	0.014	11.28	79,910
Thailand		30	8,882	8,808	1,928,273	0.136	29.48	62,953
	2005-2010							
China		114	8,752	14,024	55,644,686	0.006394	40.651852	1,330,776
United States		102	1,187	2,060	94,105,360	0.003841	304.536787	294,994
Philippines		89	5,749	4,797	2,142,402	0.061181	22.799567	86,326
India		80	8,412	959	8,819,151	0.006815	7.145172	1,147,610
Indonesia		53	3,357	4,847	1,264,976	0.013881	5.230757	226,289
Vietnam		40	1,893		4,523,400	0.021519	51.421173	83,833
Mexico		31	342	14	9,633,700	0.002998	84.437286	106,005
Pakistan		30	3,721	3,874	11,648,118	0.020739	64.919276	160,304
Australia		29	594	2,530	16,836,354	0.026811	759.945469	20,179

Bangladesh		27	6,047	64,595	2,684,000	0.040976	18.187309	139,036
	2010-2015							
China		131	3,785	1,061	98,849,311	0.003	70.26	1,368,811
United States		122	1,831	5,322	214,643,400	0.006	668.92	309,011
Philippines		89	12,256	40,573	17,123,708	0.120	167.69	93,967
India		60	12,343	5,736	34,948,096	0.009	26.67	1,234,281
Indonesia		50	609	192	5,170,000	0.002	20.01	241,834
Japan		43	20,856	123,803	222,753,800	0.163	1740.47	128,542
Brazil		28	1,171	357	8,472,500	0.006	41.44	195,714
Mexico		27	423	593	10,021,200	0.003	82.24	114,093
Vietnam		27	515	874	9,122,032	0.006	98.43	87,968
Bangladesh		21	596	22,241	264,000	0.004	1.69	147,575

Supplemental Table 2 – Highest Number of Deaths

NAME	Year	Total Number	Total Deaths	Total Injured	Total Damages (US$ '000)	Deaths per Capita	Damage Per Capita (US$ '000/'000 people)	Total Population ('000)
	1990-1995							
Bangladesh	1995	37	141753	150768	$1,522,000	1.231	28.070	115,170
China	1995	69	12848	164232	$12,492,900	0.010	39.194	1,240,921
Philippines	1995	56	8987	6409	$821,264	0.129	26.868	69,784
India	1995	39	8750	825	$1,700,285	0.009	8.999	963,923
Afghanistan	1995	10	2299	64	$18,010	0.127	3.534	18,111
United States	1995	123	1721	1267	$254,170	0.006	297.088	265,164
Tajikistan	1995	4	1594	0	$61,408	0.277	82.067	5,765
Vietnam	1995	20	1479	406	$480,479	0.020	7.460	74,910
Nepal	1995	7	1414	319	$53,200	0.066	9.612	21,576
Haiti	1995	4	1135	0	$87,000	0.147	6.456	7,745

	1995-2000							
India	2000	52	27173	7969	$1,054,000	0.026	7.531	1,056,576
Honduras	2000	8	14642	12001	$3,000	2.227	582.188	6,575
China	2000	83	13622	423024	$36,088,444	0.011	55.510	1,290,551
Vietnam	2000	30	6507	2386	$583,440	0.081	29.544	79,910
Nicaragua	2000	10	3389	228	$7,105	0.669	197.522	5,069
Bangladesh	2000	39	3022	48978	$1,309,500	0.024	39.473	127,658
Somalia	2000	7	2335	0	$450,000	0.263	0.000	8,872
Papua New Guinea	2000	6	2314	676	$45,500	0.396	7.392	5,848
Mexico	2000	29	1852	440	$156,870	0.019	28.431	98,900
United States	2000	132	1625	2328	$20,523	0.006	184.352	281,711
	2000-2005							
Indonesia	2005	45	167548	2230	$562,498	0.740	21.639	226,289
Sri Lanka	2005	7	35648	23176	$480,160	1.824	68.841	19,545
India	2005	71	24802	12043	$662,345	0.022	10.392	1,147,610
Italy	2005	11	20098	20	$0	0.345	105.111	58,281
France	2005	22	19572	198	$0	0.320	118.347	61,120
Spain	2005	8	15151	151	$0	0.344	70.567	44,019
Thailand	2005	30	8882	8808	$40,884	0.136	29.477	65,416
Haiti	2005	20	5659	2921	$29,203	0.615	11.149	9,195
China	2005	113	4876	308224	$2,842,051	0.004	31.868	1,330,776
Philippines	2005	46	3242	2009	$194,903	0.038	3.551	86,326
	2005-2010							
Myanmar	2010	10	138567	20190	4057000	2.738	80.177	50,601
Russia	2010	11	55820	996	3824163	0.389	26.653	143,479
Somalia	2010	13	20138	12	0	1.672	0.000	12,044
China	2010	114	8752	14204	55644686	0.006	40.652	1,368,811
India	2010	80	8412	959	8819151	0.007	7.145	1,234,281
Bangladesh	2010	27	6047	64595	2684000	0.041	18.187	147,575
Philippines	2010	89	5749	4797	2142402	0.061	22.800	93,967

Pakistan	2010	30	3721	3874	11648118	0.021	64.919	179,425
Indonesia	2010	53	3357	4847	1264976	0.014	5.231	241,834
Vietnam	2010	40	1893	3604	4523400	0.022	51.421	87,968
	2010-2015							
Japan	2015	43	20856	123803	$3,416,891	0.163	1740.466	127,985
India	2015	60	12343	5736	$954,297	0.009	26.675	1,310,152
Philippines	2015	89	12256	40573	$39,062	0.120	167.693	102,113
China	2015	131	3785	1061	$754,890	0.003	70.263	1,406,848
France	2015	15	3330	0	$1,409,000	0.052	32.023	64,453
United States	2015	122	1831	5322	$54,588	0.006	668.925	320,878
Brazil	2015	28	1171	357	$149,200	0.006	41.436	204,472
Thailand	2015	17	1011	8	$17,254	0.015	643.354	68,715
Afghanistan	2015	20	1003	573	$25,645	0.029	4.213	34,414
Indonesia	2015	50	609	192	$12,955	0.002	20.009	258,383

Supplemental Table 3 – Highest Damage

NAME	Year	Total Number of Disasters	Total Deaths	Total Injured	Total Damages (US$ '000)	Deaths Per Capita	Damage Per Capita (US$ '000/'000 people)	Total Population ('000)
	1990-1995							
China		69	12,848	164,232	$12,492,900	0.010	39.194	1,240,921
India		39	8,750	825	$1,700,285	0.009	8.999	963,923
Bangladesh		37	141,753	150,768	$1,522,000	1.231	28.070	115,170
Philippines		56	8,987	6,409	$821,264	0.129	26.868	69,784
North Korea		3	74	0	$500,000	0.003	691.144	21,862
Vietnam		20	1,479	406	$480,479	0.020	7.460	74,910
United States		123	1,721	1,267	$254,170	0.006	297.088	265,164
Thailand		23	494	277	$214,140	0.008	42.935	59,467

Haiti		4	1,135	0	$87,000	0.147	6.456	7,745
Tajikistan		4	1,594	0	$61,408	0.277	82.067	5,765
	1995-2000							
China		83	13,622	423,024	$36,088,444	0.011	55.510	1,290,551
Bangladesh		39	3,022	48,978	$1,309,500	0.024	39.473	127,658
India		52	27,173	7,969	$1,054,000	0.026	7.531	1,056,576
Vietnam		30	6,507	2,386	$583,440	0.081	29.544	79,910
Somalia		7	2,335	0	$450,000	0.263	0.000	8,872
Brazil		24	433	390	$292,500	0.002	1.339	174,790
Philippines		40	1,567	1,424	$231,031	0.020	5.811	77,992
North Korea		6	254	446	$178,905	0.011	357.712	22,929
Venezuela		8	30,023	3,072	$157,388	1.241	130.619	24,192
Mexico		29	1,852	440	$156,870	0.019	28.431	98,900
	2000-2005							
China	2005	113	4,876	308,224	$2,842,051	0.004	31.868	1,330,776
India	2005	71	24,802	12,043	$662,345	0.022	10.392	1,147,610
Indonesia	2005	45	167,548	2,230	$562,498	0.740	21.639	226,289
Sri Lanka	2005	7	35,648	23,176	$480,160	1.824	68.841	19,545
Mexico	2005	28	225	320	$303,800	0.002	89.284	106,005
Brazil	2005	23	545	885	$215,450	0.003	12.676	186,127
Philippines	2005	46	3,242	2,009	$194,903	0.038	3.551	86,326
United States	2005	112	2,800	1,278	$97,865	0.009	849.998	294,994
Vietnam	2005	33	1,164	346	$60,185	0.014	11.278	83,833
Thailand	2005	30	8,882	8,808	$40,884	0.136	29.477	65,416
	2005-2010							
United States		102	1,187	2060	$94,105,360	0.004	304.537	309,011

China		114	8,752	8752	$55,644,686	0.006	40.652	1,368,811
Chile		5	599	10334	$30,023,000	0.035	1759.587	17,063
Australia		29	594	2530	$16,836,354	0.027	759.945	22,155
Pakistan		30	3,721	3721	$11,648,118	0.021	64.919	179,425
Mexico		31	342	14	$9,633,700	0.003	84.437	114,093
India		80	8,412	8421	$8,819,151	0.007	7.145	1,234,281
Japan		20	448	4282	$4,960,000	0.003	38.587	128,542
Oman		2	92	0	$4,900,000	0.030	1611.082	3,041
Vietnam		40	1,893	1893	$4,523,400	0.022	51.421	87,968
	2010-2015							
Japan	2015	43	20,856	123,803	$3,416,891	0.163	1740.466	127,985
India	2015	60	12,343	5,736	$954,297	0.009	26.675	1,310,152
China	2015	131	3,785	1,061	$754,890	0.003	70.263	1,406,848
Vietnam	2015	27	515	874	$299,605	0.006	98.428	92,677
Brazil	2015	28	1,171	357	$149,200	0.006	41.436	204,472
Bangladesh	2015	21	596	22,241	$59,000	0.004	1.690	156,256
United States	2015	122	1,831	5,322	$54,588	0.006	668.925	320,878
Mexico	2015	27	423	593	$40,741	0.003	82.237	121,858
Philippines	2015	89	12,256	40,573	$39,062	0.120	167.693	102,113
Afghanistan	2015	20	1,003	573	$25,645	0.029	4.213	34,414