Differential mortality patterns from hydro-meteorological disasters: Evidence from vital records of cause of death data by sex and age

Abstract

This paper evaluates the heterogeneous impact of hydro-meteorological disasters on populations, along the dimensions of age, sex, and development. The analysis is based on previously untapped cause of death data over the period 1995 – 2011 obtained from the WHO mortality database which collects civil registration records of 63 countries/territories. Using these data, we evaluate patterns of mortality related to meteorological disasters in the spirit of model life tables. We observe that mortality rates for men are consistently higher than for women across all age groups and that the differential by sex is larger for adults than for young children or the elderly. Furthermore, as the Human Development Index (HDI) improves, the mortality differential by sex becomes smaller. Comparing our disaster fatalities with those recorded in the Emergency Events Database (EM-DAT), we find that the number of deaths from hydro-meteorological disasters was underestimated in the WHO database especially in the case of high-impact events.

1 Introduction

There is evidence that both the frequency and intensity of extreme weather events such as storms, floods and droughts have been increasing over the past decades (IPCC 2007), with floods being the most common type of natural disasters worldwide. Apart from the socio-economic impact of floods on livelihoods, property and the economy, fatalities from floods are not inconsequential. During the past three decades, floods accounted for up to 230,000 deaths worldwide (EM-DAT 2010). Similarly, in the same period, mortality attributable to storms, particularly tropical cyclones, was as high as 447,000 deaths (ibid). Although the death toll from individual flood or storm events is generally lower than from other destructive disaster events like mega-earthquakes or tsunamis, the frequency of disasters resulting from floods and storms has increased in recent decades. Accordingly, in 2012 hydrological disasters were responsible for the largest share of natural disaster fatalities, accounting for 39% of global disaster mortality (Guha-Sapir, Hoyois, and Below 2013).

At first sight, the risk of death from storms and floods depends on their meteorological characteristics (e.g. speed of onset, scale, duration, velocity of flow and depth of water). However, the topography of the area, land use patterns and antecedent moisture conditions also matter (Ahern et al. 2005). In addition to geophysical characteristics, the level of economic development has been found to be significant in determining human and economic losses from natural disasters (Fankhauser and McDermott 2014; Toya and Skidmore 2007). With poorer infrastructure and housing construction, high-density settlement, lack of early warning systems and poorly-devised evacuation and shelter procedures, developing countries generally suffer much higher death rates from floods and cyclones than more developed countries (Doocy, Dick, et al. 2013). The fact that cyclone mortality in less developed nations occurs primarily during the impact phase due to drowning from storm surge implies that deaths from storms are to a certain degree preventable (Shultz, Russell, and Espinel 2005).

Likewise, at the individual level, it has been shown that flood- and storm-related mortality is not distributed evenly across population subgroups. Gender, age, ethnicity and socio-economic status are reported to be associated with the risk of mortality from hydro-meteorological disasters. While most studies showed that the elderly are more vulnerable to floods (Jonkman et al. 2009; Myung and Jang 2011; Thacker et al. 2008), it has also been reported that very young children, especially in low income countries, have higher flood-related mortality (Pradhan et al. 2007). Similarly, for storm-related deaths, both children and older adults disproportionately experience higher mortality risks (Brunkard, Namulanda, and Ratard 2008; Bern et al. 1993; Chowdhury et al. 1993). With respect to fatalities by gender, generally in developed countries, men experience higher flood- and storm-related deaths whereas in less developed countries, women have been shown to suffer a higher risk of mortality in some contexts (Alderman, Turner, and Tong 2012; Doocy, Dick, et al. 2013; Doocy, Daniels, et al. 2013). In addition, flood-related mortality in different age groups is not distributed evenly between men and women. While the vast majority of female fatalities is often found to be among the elderly (Coates 1999), in many countries flood-related deaths were more common among adult males (Ashley & Ashley 2008; Coates 1999). Gender differences in risk-taking behaviors may account for observed differences in mortality outcomes between men and women in certain types of natural disasters (Kruger & Nesse 2004).

Taking into account that demographic characteristics play a significant role in determining differential risk to hydro-meteorological disasters, better identification of who is more likely to perish during floods and storms would allow for the implementation of appropriate risk reduction measures that target relevant vulnerable groups. Nevertheless, empirical studies of demographic differentials in disaster-related mortality are overwhelmingly based on hazard events in the United States (Ashley and Ashley 2008; Jonkman et al. 2009; Jonkman and Kelman 2005; Thacker et al. 2008) and a few other developed countries (FitzGerald et al. 2010; Coates 1999). Literature on age-sex differences in disaster-related fatalities in developing countries, where mortality registration systems often underreport or are not widely available, is scarce. Likewise, there have not been many cross-national studies on demographic differential mortality due to natural disasters that include both developed and less developed nations. In addition, extant studies on the impacts of economic development on the scale of loss and damage from natural disasters do not generally consider how the level of development may affect population subgroups differentially.

Accordingly, this study aims at: 1) estimating the impact of hydro-meteorological disasters (i.e. floods and storms) on mortality of different population subgroups; and 2) investigating the relationship between development and age-sex differences in reducing fatalities from hydro-meteorological disasters. We use a mostly untapped resource in the disaster literature: cause of death data by age and sex from the WHO (World Health Organization) Mortality Database. The estimation of hydro-meteorological disaster deaths from the WHO data is then validated with the commonly used disaster data source, the Emergency Events Database (EM-DAT). Principal component analysis is employed to describe age-sex patterns in mortality from floods and storms across 63 countries/territories from 1995 – 2011. In this manner, we are able to describe age-sex mortality profiles related to hydro-meteorological disasters for many countries at the same time.

Furthermore, a first-difference approach is employed to estimate how the change in the level of development (measured by the Human Development Index) relates to the change in mortality rates of men and women in different age groups. This identification of patterns of disaster-related mortality by age, sex and level of development is particularly important as it would give us a hint on the extent to which future societies will be able to cope with natural disasters as their demographic composition and level of socio-economic development change.

The remainder of the paper is organized as follows. Sections 2 and 3 describe the data and methods used for the analysis, whereas the results are presented in Section 4. First we show the results from the WHO data; then we present a validation of our analysis via comparison with the number of deaths from hydro-meteorological disasters reported by EM-DAT. Section 5 discusses potential further uses of the WHO data, as well as the value of analyses of the sort presented herein. We close with a discussion and summary of our results.

2 Data

2.1 Cause of death data by age and sex

Our analysis requires information on cause-specific mortality by age and sex. We identified a data source almost untapped in the disaster literature i.e. death registrations by age, sex and cause of death. The data are published in a harmonized format by the WHO, which gathers vital statistics from civil registration systems submitted to the WHO annually by the national authorities of member countries. The database goes as far back as 1950. The number of deaths by country, year, sex, age group and cause of death is provided. Causes of death are classified according to the International Classification of Diseases (ICD), a system of diagnostic codes developed to classify diseases and categorize medical terms reported by physicians and coroners on death certificates for international compatibility and statistical purpose. The most up-to-date revision of the ICD classification is ICD-10, which came into use in WHO member states starting from 1994.The data are freely available for download online via the WHO mortality database website[1].

Disaster-related deaths are classified in ICD-10 under the label “exposure to forces of nature”. This broad category includes deaths related to excessive natural heat or cold, earthquakes, volcanic eruption, landslides, etc. Specifically, this study considers two groups of causes: “cataclysmic storm” (code X37) and “flood” (code X38), which are natural hazards likely to aggravate due to climate change (Nicholls 2004). These two categories include deaths both directly and indirectly related to hurricanes, storms, floods, tornadoes and tidal waves. Direct mortality from floods and storms refers to deaths caused by the environmental force of the disaster (e.g. storm surge, wind and flood). Indirectly related deaths apply to deaths attributable to unsafe conditions led by the disaster (e.g. electrocutions from downed power lines and hazardous roads) as well as a loss or disruption of usual services due to the disaster (e.g. loss of electrical services). Combining mortality from “cataclysmic storm” and “flood”, we have data for 63 countries/territories for the period 1995 – 2011. Figure 1 shows a map of countries for which data are available in ICD-10. The sample is skewed toward high-income countries that have efficient vital registration systems in place. However, a few developing countries in South-East Asia, Latin America and Africa are also present.

[FIGURE 1: ABOUT HERE]

2.2 Mortality from natural disasters data

A database compiled specifically to monitor disasters worldwide is the Emergency Events Database (EM-DAT) maintained by the Centre for Research on the Epidemiology of Disasters

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[1] http://www.who.int/healthinfo/mortality_data/en/

(CRED) since 1988. Apart from data on the occurrence of disasters in the world from 1900 to present, EM-DAT also contains information on loss and damage including the number of people killed and the number of people affected in a particular disaster. The data are collected from various sources with priority given to data from UN agencies, followed by the Office of U.S. Foreign Disaster Assistance (OFDA), national governments, and the International Federation of Red Cross and Red Crescent Societies. An event is qualified as a disaster in the EM-DAT database if it fulfills at least one of the following criteria: 1) 10 or more people reported killed; 2) 100 or more people reported affected; 3) the government declares a state of emergency; and 4) the government appeals for international assistance.

While both natural disasters and technological disasters are recorded in EM-DAT, here we focus only on mortality from hydro-meteorological disasters, i.e. floods and storms. This allows us to compare deaths from floods and storms registered in the WHO data with those of the EM-DAT data for each country.

3. Patterns of flood and cataclysmic storm mortality

3.1 Methods

We identified patterns of mortality by age and sex from cataclysmic storm (X37) and flood (X38) using data from the WHO database. Our method is based on classic demographic approaches developed in the context of model life tables. We use an approach inspired by the Lee and Carter (1992) model for forecasting mortality in the United States and the model life table system for sub-Saharan Africa (INDEPTH Network 2004). Since we are interested in the distribution of deaths related to storms and floods by age and sex, we subtract the average profile of deaths by age for all countries from the number of deaths D_{at}, for a given age group a during the year *t*, for all 63 countries/territories in the ICD-10 database and we model this quantity as the product of age-specific profiles and time-variant indexes:

$$D_{at} - \overline{D_a} = B_{a1}k_{t1} + B_{a2}k_{t2} + B_{a3}k_{t3} + e$$

In terms of estimation procedures, this is equivalent to performing a Singular Value Decomposition or Principal Component Analysis on the demeaned profiles of deaths by age for all countries in the data set. The goal is to summarize the available data in order to extract meaningful information about profiles by age for the available countries. We decided to use the first three principal components as they explain the majority of the variance (~50%) in the observed profiles and can be interpreted in a simple way. The main reason why the first principal components do not explain a larger portion of the variance is that the dataset, by its nature, contains a large number of combinations age-country-year with zero deaths, since disasters are relatively rare phenomena. As a result, the overall variance of the data points is quite large.

3.2 Results

[FIGURES 2 and 3: ABOUT HERE]

Figure 2 shows the first three principal components of the demeaned number of deaths related to floods and cataclysmic storms for females. The first component indicates a death profile by age very much skewed toward the elderly. The second component is skewed toward young children. The third component emphasizes this bimodal distribution of deaths by having negative values for observations for adults and positive values for children and the elderly.

Figure 3 shows the first three principal components of the demeaned number of deaths related to floods and cataclysmic storms for males. The first component shows that storm- and flood-related mortality for males spreads out rather evenly across age groups. The second component is moderately skewed toward very young children. The third component reveals a relatively large number of deaths for adult males that are not observed for females.

The mortality profiles by age differ considerably between men and women. While the three principal components for females summarize the fact that most deaths from floods and storms typically occur to young children and the elderly, the male death profile depicts a somewhat different pattern of higher mortality among adolescent and adult males. This bump in the number of deaths for male adults may be attributable to more risk-prone behavior or lower ability to assess risks in males compared to females (Byrnes, Miller, and Schafer 1999; Croson and Gneezy 2009). Besides, since men are more likely than women to engage in outdoor work and leisure activities, this increases their exposure to natural hazards and consequently puts them at higher mortality risk in flood and storm events.

The first three principal components account for more than 50% of the variance in the data and capture the key summary profiles of mortality from floods and storms for men and women. The observations have very high variance because of the nature of disaster data. For some countries, we observe only a small number of deaths over the course of several years resulting in a lot of age-specific cells that contain zeroes. The additional principal components explain the remaining variance due to the large number of zeroes in the data, but do not have any relevant structure and do not add much information to our analysis.

Gender differences in mortality from floods and storms

The principal component analysis indicates substantial difference in age-specific mortality profiles between men and women. We cannot however identify which gender is more vulnerable to mortality from floods and storms. In the subsequent analysis, we therefore compare age-specific mortality rates from hydro-meteorological disasters between men and women for each country over the period 1995 – 2011. Figure 4 presents the results from selected countries that represent the general patterns of hydro-meteorological disasters by age and sex, both in terms of death distribution and death rates per 1,000 population.

[FIGURES 4: ABOUT HERE]

Countries with a higher proportion of the elderly such as South Korea, Japan (not shown) and the United States, show a monotonic increase in mortality with age. Most of the deaths occur in adults or the elderly, with greater male fatalities especially among the older age groups. Paraguay, Nicaragua and Cuba (not shown) are examples of the second pattern, where the highest rates and the largest number of deaths occur in male adults. Argentina, the Philippines, Mexico, Brazil, and Guatemala (not shown) are countries where most of the meteorological disaster-deaths affect young children in absolute terms. In the case of Argentina, Mexico and Brazil, the rates of mortality are higher among young children and the elderly, especially for females. In the case of the Philippines and Guatemala, the young population age structure implies that, in relative terms, mortality rates for young children are not very high, despite the fact that the largest number of deaths, in absolute terms, are among children.

Turning to gender differences in fatalities from floods and storms for all countries with ≥ 10 deaths over the period 1995 – 2011 as presented in Figure 5, we find that in most countries, the absolute number of deaths is larger for males than for females. Since men generally exhibit more risky behaviors and engage in more dangerous activities than women, this might explain why men are more vulnerable to flood- and storm-related mortality than women. Note that for most countries, loss of life due to floods and storms do not exceed 200 deaths in the period observed. However, in tropical cyclone-prone areas such as Mexico, Japan, the Philippines and the United

States, the number of registered deaths from floods and storms is considerable and male mortality is always greater than that of women.

[FIGURES 5: ABOUT HERE]

Since the total number of deaths is subject to the size of the population exposed to the disasters, in Figure 6 we plot the proportion of flood- and storm-related mortality for men and women. The finding is consistent with the previous analysis which considers the absolute number of deaths. For almost all countries, of the total mortality from hydro-meteorological disasters, the proportion of male death is larger than that of women. In Paraguay, Nicaragua and South Africa, over 70% of flood- and storm-related fatalities are men.

[FIGURE 6: ABOUT HERE]

4. Meteorological disaster mortality and development

Having found evidence for a gender difference in mortality from hydro-meteorological disasters, subsequently we examine whether the observed reduction in life loss given economic development follows the same trends for men and women as well as for different age groups. Development is measured by the UNDP Human Development Index (HDI). In order to have a larger sample that covers a longer time period, in addition to ICD-10 data, we include data from previous classifications: ICD-7, ICD-8 and ICD-9. Those datasets extend as far back as 1970. However, in the older versions of the ICD, deaths related to cataclysmic storms or floods were not classified with a specific code. Thus, we select causes of death potentially related to meteorological disasters i.e. “accidental drowning and submersion”. Since drowning accounts for the majority of the fatalities from floods and also, to a certain extent, storms (Jonkman and

Kelman 2005), deaths from drowning may naturally increase especially in the event of flash floods and coastal floods.

[FIGURE 7: ABOUT HERE]

Figure 7 presents the relationships between the HDI and hydro-meteorological-related deaths by age groups (i.e. aged <15 years, 15-44 years and ≥45 years) and gender. We observe a strong negative correlation between hydro-meteorological disaster mortality and the HDI which holds across all age groups. With respect to gender, although mortality rates are larger for men than for women, the speed of change for males is, on average, faster. This means that we expect differences by gender to become narrower across countries as the HDI improves.

In order to statistically quantify the relationship between hydro-meteorological disaster mortality and the HDI, we estimate a first-difference type model, with indicator variables for age groups and sex:

$$(d_{ia,t} - d_{ia,t-1}) = B_0 + B_1 (HDI_{ia,t} - HDI_{ia,t-1}) + B_2 I_F + B_3 I_F (HDI_{ia,t} - HDI_{ia,t-1}) +$$

$$+ B_4 I_{0\text{-}15} + B_5 I_{0\text{-}15} HDI_{ia,t} + B_6 I_{45+} + B_7 I_{45+} HDI_{ia,t} + e$$

where $d_{ia,t}$ is hydro-meteorological disaster rate (per 1000 people) for country *i*, population subgroup *a* (age and sex), at time *t*. I_F is a dummy variable for females, $I_{0\text{-}15}$ is a dummy variable for age group 0-15, I_{45+} is a dummy variable for age group 45 years old and above. Table 1 presents the results from the first-difference estimator of mortality rate from floods and storms given the changes in the level of HDI.

[TABLE 1: ABOUT HERE]

We found the coefficients B_1 and B_3 to be highly significant. These results confirm our observations based on visualizations of trends in Figure 7. There is a strong negative relationship between mortality rate and the HDI. The slope is less steep for women as compared to men. The estimated coefficients for age groups are not statistically significant. However, we observe that the coefficient for interaction of age group 0-15 and HDI is negative, whereas the one for age group 45+ is positive. This may be interpreted as follows: at high levels of development mortality rates are smaller for children and higher for the elderly, relative to the adult population.

5. Validating deaths from hydro-meteorological disasters estimated from the WHO database

For the first time the WHO mortality database is used to estimate age-sex differentials in deaths from hydro-meteorological disasters. However, since the WHO mortality data are based on the cause-of-death statistics obtained from country civil registration systems, fatalities from natural disasters might be undercounted, especially in the case of deaths which are indirectly related to floods and storms such as fatal car accidents, heat stroke, heart attacks or other conditions associated with lack of medical supplies, unsafe conditions or disruption of usual services. In this section, we compare the aggregated number of deaths from floods and storms reported by the WHO with those recorded by the EM-DAT over the period 1995 – 2011 for each country with available data.

[FIGURE 8: ABOUT HERE]

Figure 8 presents the differences in the absolute number of hydro-meteorological disaster-related deaths reported by the WHO and the EM-DAT when deaths in the WHO database were <10. In most countries (34 countries), the number of fatalities from floods and storms identified was greater in the WHO database as compared to that of the EM-DAT. In 17 countries, the number of flood- and storm-related deaths was found to be higher in the EM-DAT data but the difference in most countries (15 countries) is never greater than 5 deaths in absolute terms. The number of fatalities was the same in the WHO and EM-DAT databases for 4 countries: Colombia, El Salvador, Grenada and the Netherlands.

On the other hand, in the case where deaths from hydro-meteorological disasters were ≥ 10 deaths, the differences between the WHO and EM-DAT data are in the opposite direction. Table 2 presents a list of countries with ≥ 10 deaths per disaster event from meteorological disasters including the percentage difference between the number of deaths reported by the WHO and the EM-DAT data sources. Except for Canada, the number of deaths from floods and storms reported by the WHO over the period 1995 – 2011 is monotonously lower than that reported by EM-DAT for the remaining 35 countries. The percentage differences range from as small as -7.0% to – 99.9%.

[TABLE 2: ABOUT HERE]

While in case of low-impact disaster events (<10 deaths per event) deaths from hydro-meteorological disasters documented by EM-DAT were lower than those identified by WHO, the opposite is true in case of higher-impact disaster events where there were ≥ 10 deaths per event. That deaths from meteorological disasters were undercounted by EM-DAT in low-impact disaster events is due to the nature of the CRED's data collection. One criterion used by the CRED for an event to be qualified as a disaster is that 10 or more people are killed in a particular event. Thus, based on this definition, small disaster events are underrepresented in the EM-DAT database.

On the other hand, for high-impact disaster events with ≥ 10 deaths, we systematically find that deaths documented in the WHO database are underestimated when compared to those reported by EM-DAT. This is due to the sources from where the data on the number of deaths were taken.

While the WHO mortality database relies on civil registration of respective national authorities, CRED has obtained their death estimates from various sources both official and non-official ones. The number of fatalities might be overestimated or underestimated for a number of reasons such as to attract international assistance or to cover failure in disaster management. Another reason for the discrepancy between the WHO and EM-DAT data is related to how the missing persons are recorded. In certain disaster events where the number of missing persons (i.e. the bodies were not recovered) is high, these perished persons would not be registered in the WHO database while the CRED documents both the number of those confirmed dead and those missing.

One example of substantial discrepancy between the number of deaths recorded in WHO and EM-DAT is in the case of Venezuela where EM-DAT reported 30,117 deaths from hydro-meteorological disasters in comparison to only 37 deaths in the WHO database. Such high number of fatalities is due to a single storm event in December 1999 which brought about heavy rainfall and triggered thousands of landslides on steep slopes of the Sierra de Avila north of Caracas as well as flooding and massive debris flows in the State of Vargas along the Caribbean Sea. The early estimated death toll was between 5,000 and 50,000 while at present 30,000 (the number recorded by EM-DAT) is the figure generally recognized as the approximate number of deaths (Wieczorek et al. 2001). The reason why the WHO mortality database missed recording such a high figure was because in this particular disaster event, most people were buried in the landslides or swept to sea by the mud, debris flows and flooding. Since the vast majority of these bodies were never recovered, such life loss was not registered with standard procedures. In addition, there were not even recent census figures available for Vargas prior to the disaster event, making the estimation of the exact number of people perished improbable.

[FIGURE 9: ABOUT HERE]

With much better civil registration and vital statistics systems in developed nations (Mahapatra et al. 2007), it is possible that the discrepancies in the number of fatalities reported by the WHO mortality database and the EM-DAT are smaller in more developed countries. Accordingly, we produce a scatterplot of the relationship between the HDI and the percentage differences between the number of deaths reported by the WHO and EM-DAT over the period 1995 – 2011 as displayed in Figure 9. The relationship between the two factors is significant and positive (Pearson's r=0.374, p=0.025). This suggests that the higher the HDI, the lower the discrepancy between the number of fatalities documented in the WHO and EM-DAT databases.

6. Discussion

Using the age-sex specific cause-of-deaths data from the WHO mortality database over the period 1995 – 2011, we were able to identify demographic differential patterns of hydro-meteorological disaster mortality and their relationship with societal development. The first objective of the study is to describe age-sex differentials in mortality patterns from floods and storms. We observed heterogeneous patterns of mortality that could be summarized, in the spirit of model life tables, into three main families. In some countries, children and the elderly are the most affected group. This applies particularly to female mortality. In others, adult men are the group that suffer the most in terms of mortality from meteorological disasters.

When focusing on the aggregated number of flood- and storm-related mortality by sex, we found that virtually in almost all countries male fatalities were greater than those of females. This finding is in contrast with the previous study by Neumayer and Plümper (2007) which reports that more women are killed more than men, or more women are killed at an earlier age than men by natural disasters. Apart from the fact that we only consider flood and storm events while Neumayer and Plümper include all types of natural disasters, our study estimated mortality by gender directly from sex-specific death records from the WHO mortality database. The study of Neymayer and Plümper, on the other hand, derived the estimation of sex-specific fatalities from the data on gender gap in life expectancy taking into account the intensity of a disaster. Hence, it is plausible that women are not always more vulnerable to natural disasters than men especially in certain types of disasters such as floods and storms where risk-taking behaviors as well as risk of exposure (e.g. men are more engaged in outdoor work and leisure activities) could play a role in determining mortality risk. In contrast, in the event of sudden-onset disasters like earthquakes or tsunami where physical capability matters considerably, women frequently perish more than men.

The second important goal of the article is to investigate the relationship between development and disaster mortality and how this relationship differs by age and gender. Consistent with previous studies (Patt et al. 2010; Striessnig, Lutz, and Patt 2013), we showed a strong negative relationship between mortality and development as measured by the HDI. Our study further adds to the extant findings that the decline in mortality rates from hydro-meteorological disasters occurred at faster pace for men than for women. Meanwhile, we do not find strong evidence that the speed of reduction in mortality rate given a change in the HDI differs between age groups. That the mortality reduction is greater for men when HDI improves could be due to unequal access to resources that allows men to enjoy higher benefits from socio-economic development. It could however also be related to the fact that mortality rate from meteorological disasters is much higher for men as compared to that of women. Thus there is more room for improvement for the former.

The finding that countries that are more developed as measured by the HDI, a composite index of life expectancy, educational levels and economic prosperity, tend to fare better in terms of disaster mortality suggests that development could play a key role in reducing vulnerability to natural disasters. The factors that are behind development (e.g. health, education, income) tend to be protective factors against disasters. The whole chain of causal relationships nevertheless is not completely clear. More highly educated people may have a better understanding of the risks associated with disasters (Muttarak and Lutz 2014). People with higher socio-economic status may have more means to protect themselves or to escape from disaster-risk areas. Richer societies may have the means to prepare for disaster and to coordinate interventions. Good health may increase the probability of survival, etc. Regardless of the specific mechanisms at play, from a policy perspective it is important to consider development as one of the tools to enhance the adaptive capacity of societies.

Using the WHO mortality database, we were able to identify which demographic groups are more vulnerable to meteorological disasters and whether the impact of development on disaster-mortality reduction varies between gender and age groups. However, the WHO data are not without limitations. First, although the WHO mortality database is the most official source for comparative analyses that we are aware of, the sample of countries is biased. Developing countries with poor or non-existing civil registration systems are not represented. Therefore, our results should not be generalized to those developing countries for which our demographic knowledge generally comes solely from survey data.

Second, since the age-sex specific cause-of-deaths data provided by the WHO are obtained from civil registration systems, the number of fatalities from meteorological disasters can be undercounted owing to: 1) how cause of death is identified; 2) whether there were many missing persons in a disaster event. Indeed, our validation procedures comparing the number of fatalities reported by the WHO with those reported by the EM-DAT show that especially in high-impact disaster events, the WHO systematically reported lower number of deaths than that of the EM-DAT. If the underestimation of disaster mortality is distributed evenly across subgroups of population, we do not need to worry that our findings on age-sex differential mortality are biased. Given the lack of other global data sources, we cannot directly test if this could be the case.

Third, although mortality is an indicator of disaster impact that is relatively directly measurable, over the course of social and economic development, fatalities from natural disasters have become preventable to a certain extent leading to a decline in disaster-related mortality over time (Goklany 2009). Subsequently, in the absence of high-impact disasters, mortality might not be a valid indicator of natural disaster impacts. In addition to direct impacts, floods have a number of indirect effects including morbidity and livelihood disruption which may potentially lead to additional mortality. Although these indirect effects are important, their size is in the "second" or "third" order comparing to the direct effects. Direct mortality, like mortality related to drowning, accounts for the large majority of fatalities from hydro-meteorological disasters. Non-mortality measures, like economic damage or injuries, could also be considered. However, measures like economic loss may strongly be dependent on the level of GDP for specific countries and their estimates are much more uncertain. Estimates of direct mortality are more precise. Moreover, the value that societies attach to human life can be assumed to be quite universal around the world although differences may exist. Therefore, the number of deaths is an appropriate indicator for comparative analyses.

7. Conclusion

Understanding the relationships between demographic differential vulnerability and socio-economic development helps us assess the potential impact of climate change on mortality, and how that differs at various stages of development for countries in different regions of the world. This information is important because it allows us to evaluate the potential ability of societies to cope with climate change in the future, and to identify the groups within a population that are more at-risk of suffering from the consequences of climate change.

Our study has shown that flood- and storm-related fatalities can take different patterns across the globe. One pattern is of high mortality risk among young children and the elderly especially for females while another depicts greater fatality among young adult males. Documenting the differences across countries is a relevant step to understand why some groups are more at a disadvantage in some countries compared to others. We have also observed that the reduction in disaster-related mortality along with the improvement in the HDI is not distributed equally between men and women. Understanding the social, economic and geographic factors that explain the differential impact of disasters would help reduce the unequal distribution of consequences of climate change.

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Table 1: First-difference estimates of mortality rate (x 1000) from meteorological disasters given changes in Human Development Index.

Variable	Coefficient Estimate	p-value
Intercept	-0.0084*	0.0599
Difference in HDI	-0.5812***	0.0000
Female	+0.0009	0.2141
Female x Difference in HDI	+0.4524***	0.0000
Age 0-15	+0.0028	0.6546
Age 0-15 x HDI	-0.0040	0.6359
Age 45+	-0.0052	0.4039
Age 45+ x HDI	+0.0062	0.4662

Table 2: Number of deaths from floods and storms reported by WHO and EM-DAT over the period 1995 – 2011 for each disaster event with ≥ 10 deaths in WHO database

Country	WHO	EM-DAT	% difference[a]
Canada	12	11	9.1
Slovakia	50	54	-7.4
United Kingdom	9	10	-10.0
Panama	13	16	-18.8
Paraguay	25	33	-24.2
Cuba	15	20	-25.0
Republic of Korea	708	1439	-50.8
United States of America	1895	3958	-52.1
Grenada	18	39	-53.8
Czech Republic	27	64	-57.8
France	63	161	-60.9
Japan	314	874	-64.1
Argentina	38	133	-71.4
Australia	12	55	-78.2
Poland	9	46	-80.4
Guatemala	306	1571	-80.5
Philippines	509	2678	-81.0
Brazil	263	1447	-81.8
Spain	11	62	-82.3
Germany	17	100	-83.0
Malaysia	12	76	-84.2
Haiti	11	88	-87.5
Mexico	233	1967	-88.2
Romania	26	238	-89.1
Dominican Republic	37	347	-89.3
Portugal	4	46	-91.3
Colombia	43	506	-91.5
Austria	1	12	-91.7
Sri Lanka	2	25	-92.0
Thailand	50	727	-93.1
Peru	4	82	-95.1
Nicaragua	166	3601	-95.4
South Africa	8	186	-95.7
Bulgaria	1	39	-97.4
El Salvador	1	275	-99.6
Venezuela	39	30117	-99.9

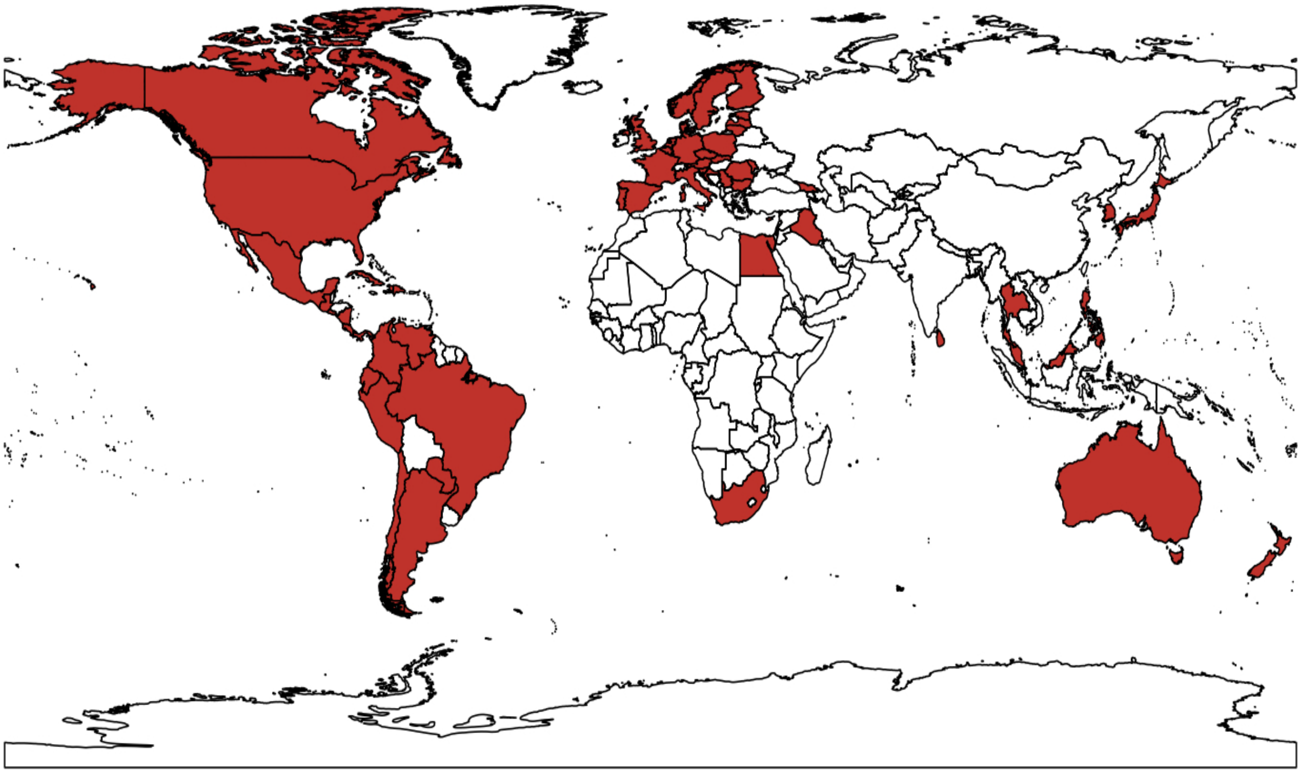
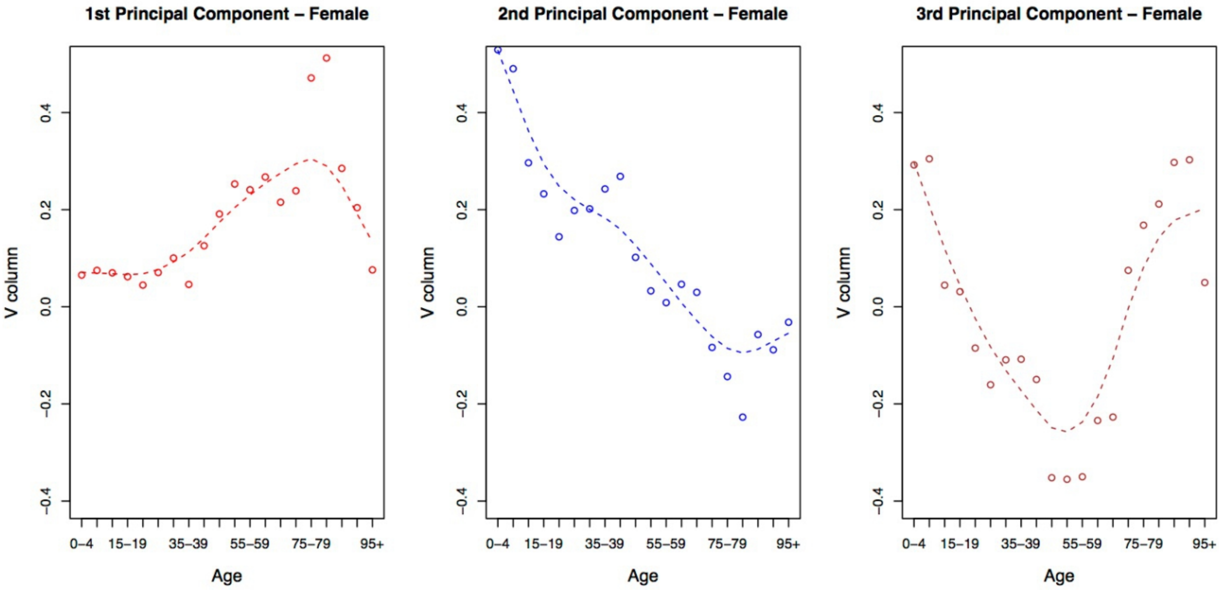
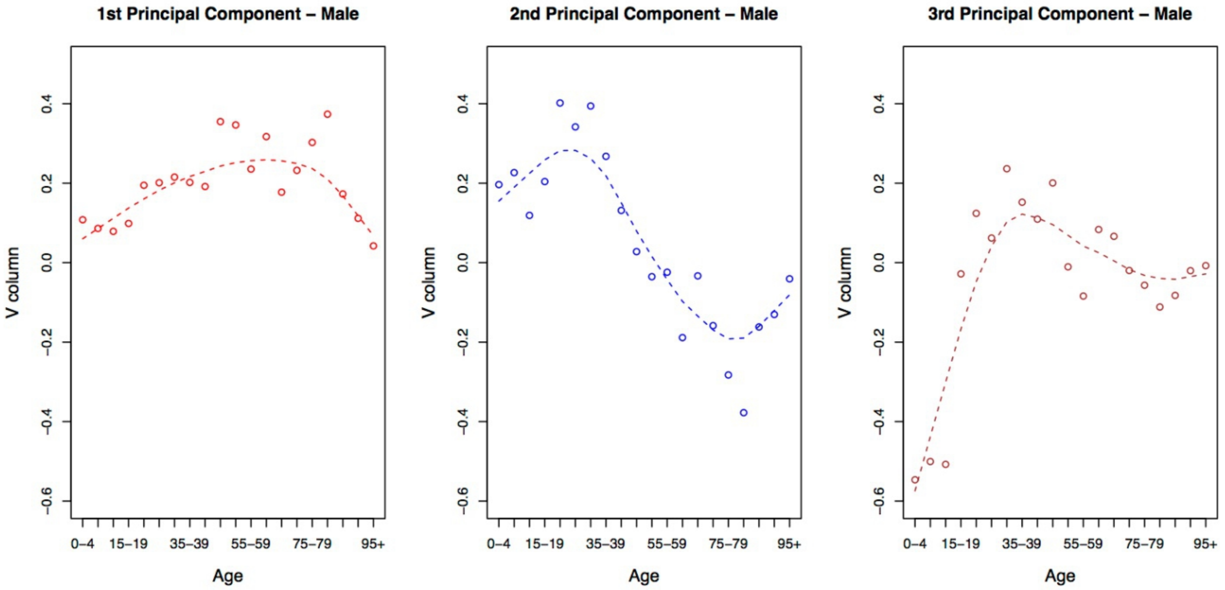


Figure 1: Map of countries where data on causes of death related to “cataclysmic storm” (X37) and “flood” (X38) are available in WHO ICD-10 (1995 – 2011)



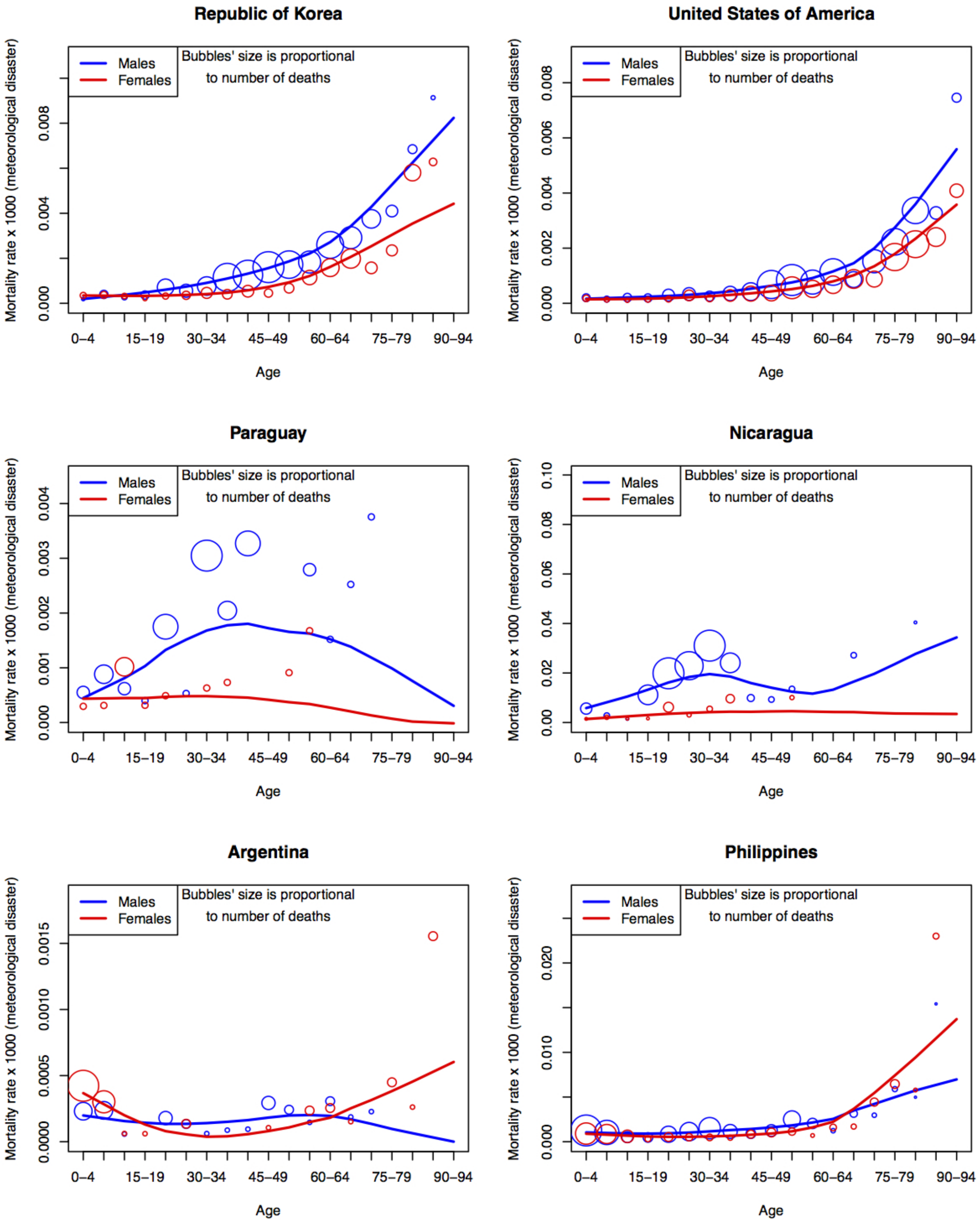
Source: own calculations based on ICD-10, WHO mortality database.

Figure 2: First three principal components of demeaned number of deaths related to floods and cataclysmic storms for females. Dashed lines represent smoothed values.



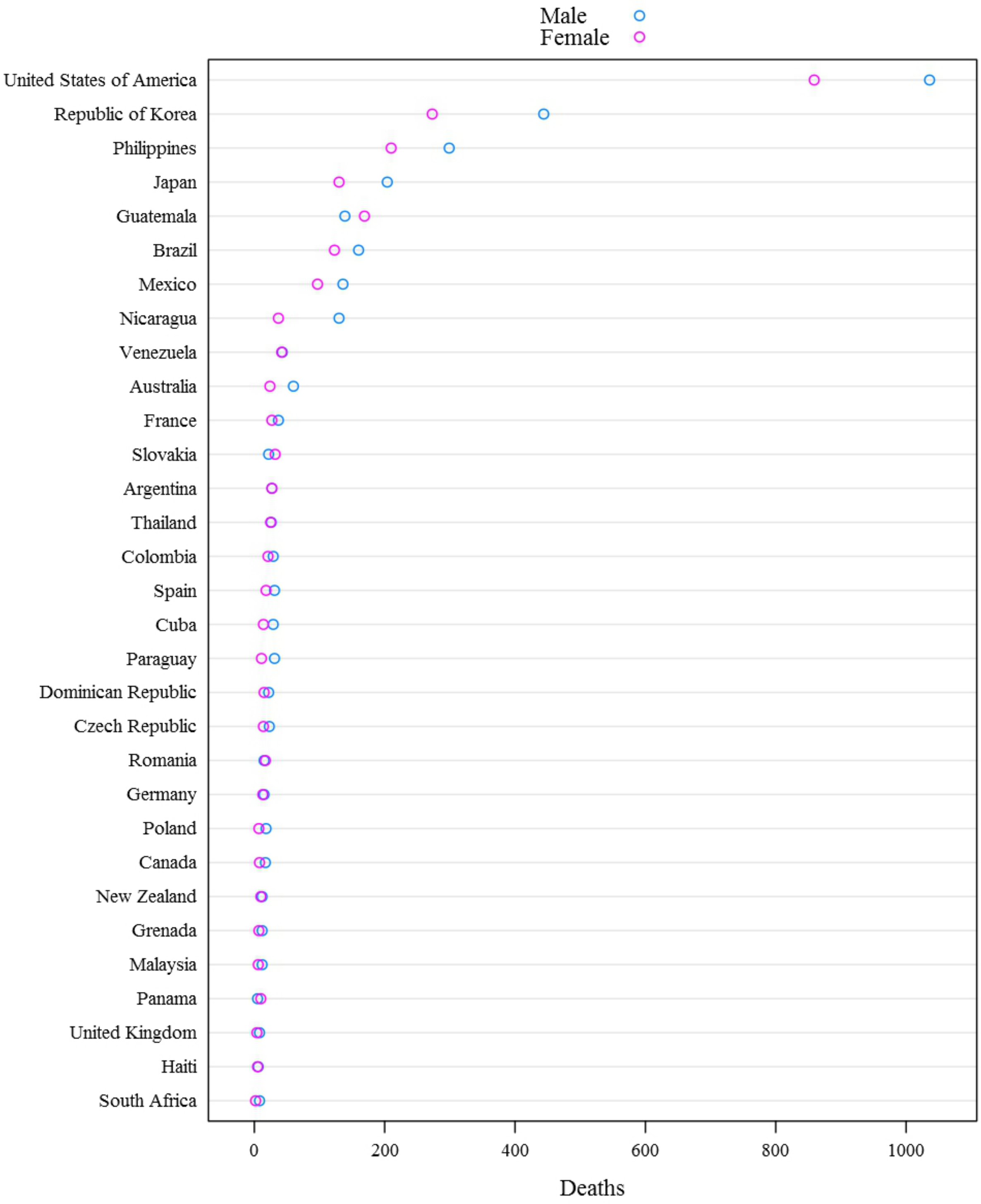
Source: own calculations based on ICD-10, WHO mortality database.

Figure 3: First three principal components of demeaned number of deaths related to floods and cataclysmic storms for males. Dashed lines represent smoothed values.



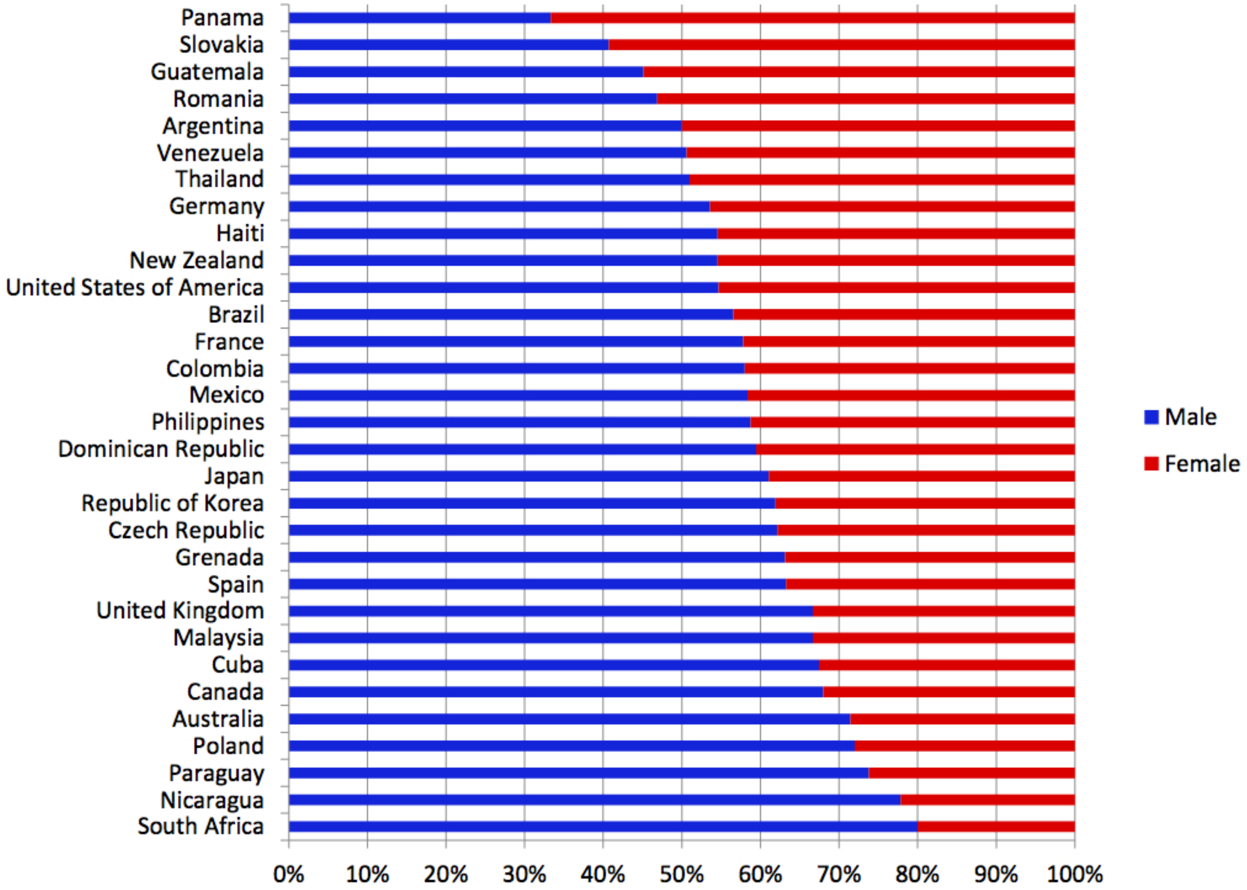
Source: own calculations based on ICD-10 WHO mortality database (for death counts) and UN WPP 2012 (for population counts).

Figure 4: Profiles of flood and cataclysmic storm mortality for selected countries, by age and sex. The bubbles indicate mortality rates (x 1000). The size of the bubbles is proportional to actual number of deaths. The size of bubbles has been rescaled for each country, separately. Thus, comparisons of number of deaths across countries, based on the size of the bubbles, are not possible. The solid lines are the smoothed values.



Source: own calculations based on ICD-10 WHO mortality database

Figure 5: Total number of deaths from floods and storms by gender for selected countries with ≥ 10 deaths over the period 1995 – 2011



Source: own calculations based on ICD-10 WHO mortality database

Figure 6: Percentages of deaths from floods and storms by gender for selected countries with ≥ 10 deaths over the period 1995 – 2011

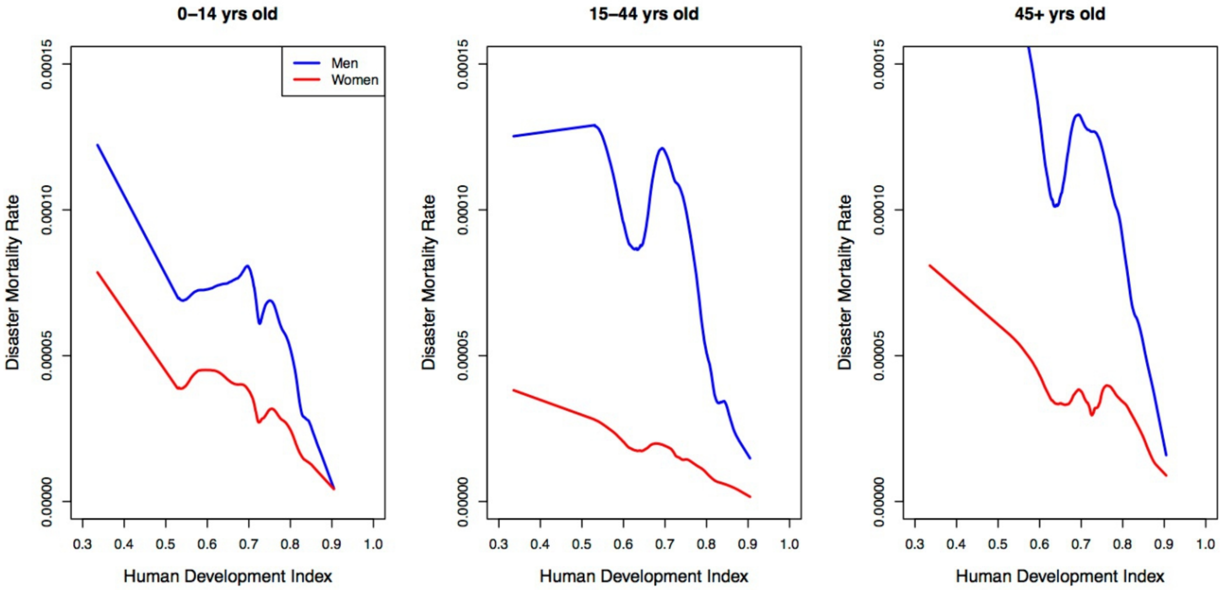


Figure 7: Relationship between meteorological disaster mortality and Human Development Index, by age and sex.

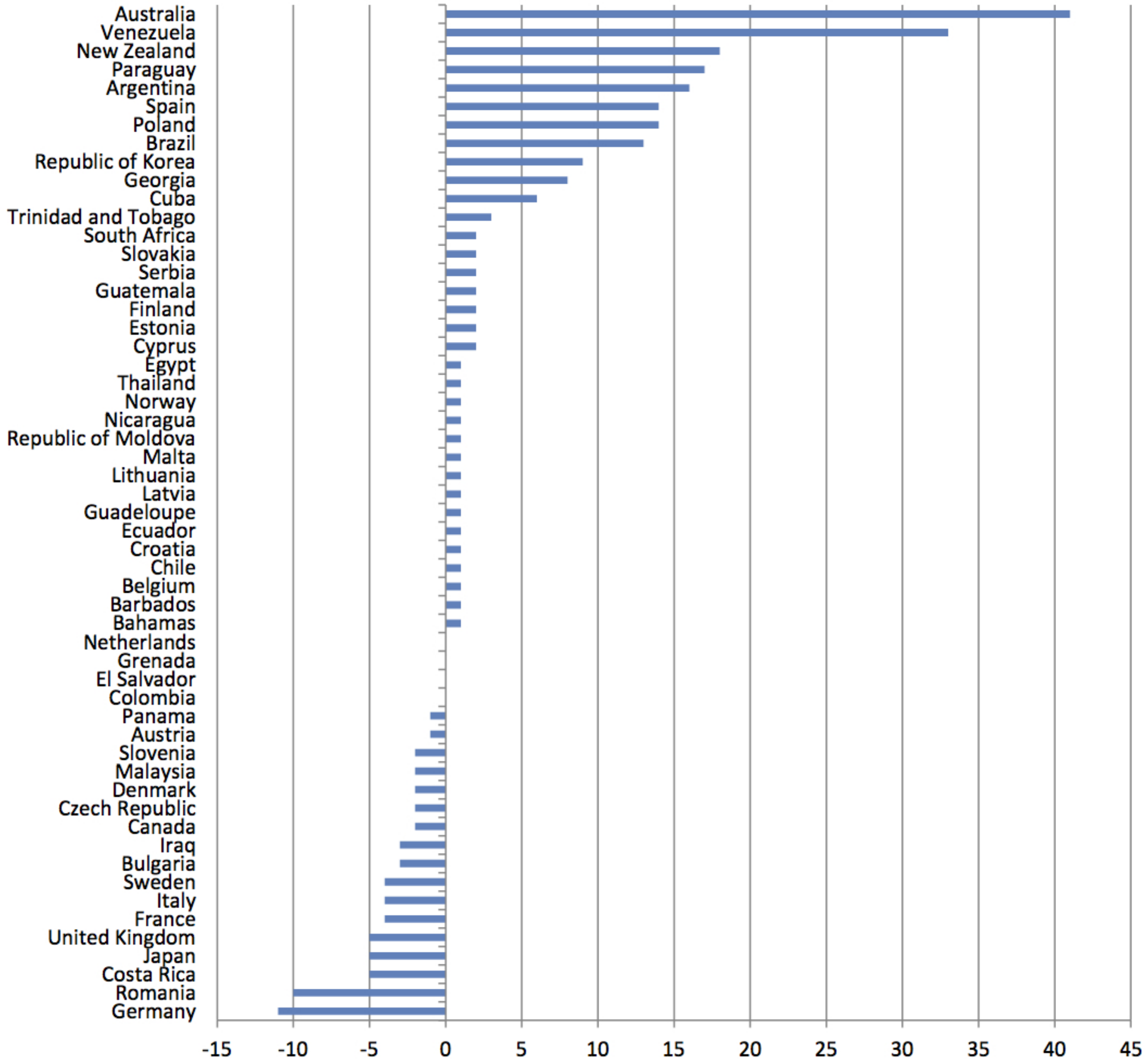


Figure 8: Absolute differences in the number of meteorological deaths reported by WHO and EM-DAT when there were <10 deaths per a single disaster event.

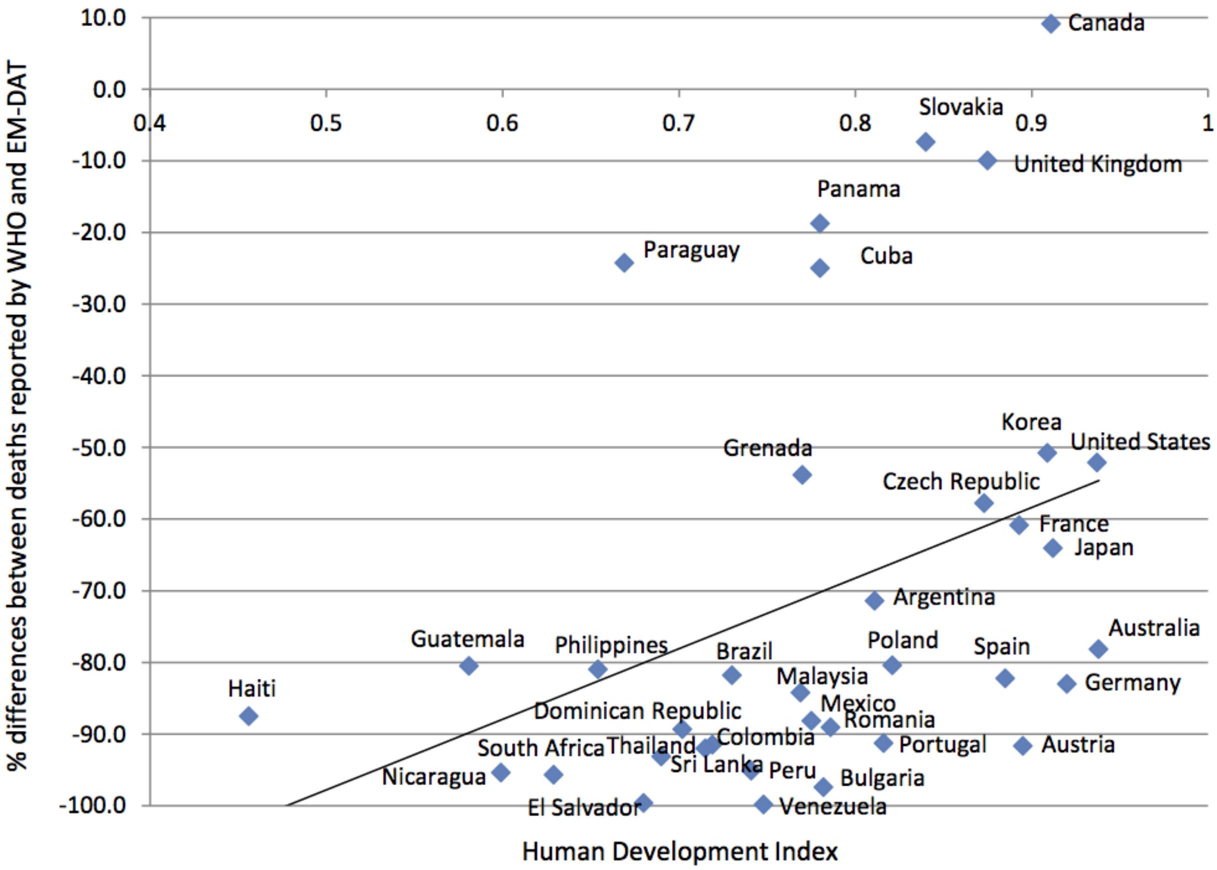


Figure 9: Relationships between percentage differences in hydro-meteorological deaths reported by WHO and EMDAT when deaths were ≥ 10 per single disaster event and HDI. Pearson's r=0.374, p=0.025.