NATURE, SOCIOECONOMICS AND FLOOD MORTALITY

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Abstract. We analyze mortality caused by 2,194 large flood events between 1985 and 2008 in 108 countries. Unlike previous studies that looked at natural-disaster mortality, we find that year-to-year changes in income and institutional determinants of vulnerability do not affect flood mortality directly. Income and institutions influence mortality only indirectly, through their impact on the intensity and frequency of floods. Population exposure affects the number of deaths both directly and indirectly. Higher population exposure results in more deaths once the flood has occurred, but it is associated with smaller floods.

INTRODUCTION

Destructive natural events occur regularly across the world, although most do not cause enough damage to be considered natural disasters. Among those that do, floods are the most common. Between 1985 and 2009, floods accounted for 40 percent of the natural disasters recorded by EM-DAT (OFDA/CRED 2010) and another 31 percent were storms (Table 1). Combined, floods and storms represented 44 percent of the deaths, 67 percent of the number of people affected and the bulk of economic damages caused by natural disasters.

Table 1: Immediate impacts of disaster (1985-2009), by disaster type

Panel A	Absolute number			
	# events	People dead	People affected (million)	Damages 2009 (mill.US$)
Floods	2893	175453	2,677	7,723
Storms	2251	414425	722	24,641
E.T.	339	101638	92	1,162
Earthquakes	656	601032	136	6,059
Droughts	352	7512	1,425	29
Other	829	47825	16	1,669
Total	7,320	1,347,885	5,068	41,282
Panel B	**Percentage of total**			
	# events	People dead	People affected	Damages 2009
Floods	40	13	53	19
Storms	31	31	14	60
E.T.	5	8	2	3
Earthquakes	9	45	3	15
Droughts	5	1	28	0
Other	11	4	0	4

Notes: Source: EMDAT, the OFDA/CRED International Disaster Database (www.emdat.be), Universite Catholique de Louvain, Brussels, Belgium (Data version: v12.07, 2010). To be included in the database, an event needs to fulfill at least one of the following criteria: (i) 10 or more people killed, (ii) 100 or more people reported affected (typically displaced); (iii) a declaration of a state of emergency; (iv) a call for international assistance. The "Other" category includes wildfires, wet and dry mass movements (landslides, avalanches, etc.), and volcanoes. People dead include persons confirmed as dead and persons missing and presumed dead. People affected are those requiring immediate assistance during a period of emergency, i.e. requiring basic survival needs such as food, water, shelter, sanitation and immediate medical assistance.

Of all the natural disasters over the last 25 years, floods and storms are becoming more frequent (Figure 1). While part of the observed increase may reflect improved reporting, other types of disasters do not exhibit the same trend. The growth in hydrological disasters is believed to have two causes: increased populations in flood plains and other high-risk areas (Freeman et al. 2003; IPCC 2007, Chapter 3), and an increase in the frequency and intensity of extreme weather events. This second development is associated with climate change and is expected to become more pronounced over this century. A warmer climate, with its increased climate variability, will increase the risk of both floods and droughts (Wetherald and Manabe 2002; IPCC 2007, Table SPM2).

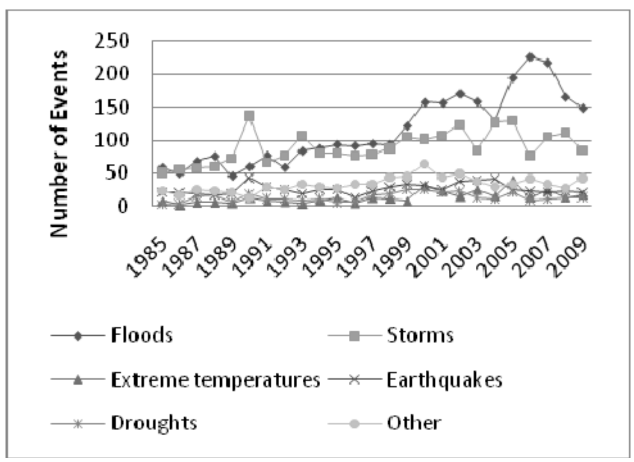

Figure 1: Incidence of natural disasters 1985-2009 (see notes to Table 1)

There is general agreement that the impacts of climate change will be larger in poorer countries (Tol 2008). This is because poorer countries have a greater exposure to climate change, particularly in agriculture and water resources, and have a lower adaptive capacity (Adger 2006;

Smit and Wandel 2006; Tol and Yohe 2007). However, there are few studies that analyze the human cost of floods and how this cost varies across countries and over time.

In this paper we analyze mortality caused by floods using new data on 2,194 large flood events in 108 countries between 1985 and 2008. We model the immediate effects of floods as a function of their physical intensity and the vulnerability of the population and infrastructure affected.

Compared to other natural disasters, floods offer more scope for policy intervention, not only for the mitigation of damage once the flood occurs, but for reducing the intensity of a flood or preventing it entirely. Humans have actively managed rivers and their drainage basins (e.g. through dikes, dams, and levees) for millennia. Land use changes, in particular urbanization and the associated increase in impervious surfaces, and human encroachment into flood plains are thought to contribute to the intensity and frequency of floods (IPCC 2007, Chapter 3). Therefore, income and institutional variables capturing the ability and effectiveness of the government to provide public services may affect flood mortality both directly and indirectly. Directly, through the provision of early-warning information systems to keep people out of harm's way, and disaster-relief and emergency services once the flood occurs. Indirectly, by influencing the probability of occurrence and the magnitude of a flood, through, for example, the enactment and enforcement of zoning regulations and relief cuts and other flood-management-related actions (construction and maintenance of dams, levees, bridges). In our paper we consider both channels (Table 2).

Table 2: Effects of vulnerability indicators on flood mortality

	Direct effects Conditional on flood occurrence and magnitude	**Indirect effects** Through flood occurrence and magnitude
Preemptive	• Zoning/Building Regulations • Monitoring and Information Systems	Ex-ante flood management • Zoning Regulations • Infrastructural (e.g. dams)
Reactive	• Emergency services	Ex-post flood management • Infrastructural (e.g. dam release) • Other (e.g. sandbags)

Data. The flood-event related data originates from the publicly accessible Global Archive of Large Flood Events kept by the Dartmouth Flood Observatory (DFO, now at Colorado: http://floodobservatory.colorado.edu). Table 3 shows that the average number of people killed in a flood event, 119, is large, but much smaller than the variance (a first sign of over-dispersion in this variable). DFO reports the magnitude of the flood as the log of the product of flood duration (in days)* area affected by the flood * flood severity (Class 1 = 10-20, Class 1.5 = 20-100, Class 2 = 100 + year recurrence interval).

Table 3: Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
Flood events between 1985 and 2008 (N=2,194)				
Number of deaths	119	2961	0	138,000
Flood magnitude	5.17	1.10	1.30	8.37
Pop. dens. flood area	394.5	1275.0	0.02	30,823
Country-year statistics (n=108 countries)				
GDP pc (PPP 2005$)	9,375	10,190	203	47,996
Corruption	2.88	1.21	0.00	6.00
Ethnic tensions	3.82	1.46	0.00	6.00
Total area (sq.km)	1.9E+06	3.2E+06	1.0E+03	1.6E+07
Urban pop.growth(%)	2.60	1.68	-2.77	12.83
Latitude (abs.value)	24.25	15.68	0.42	67.47
Elevation (meters)	649	423	18	1,871
Coastal (% total area)	0.37	0.34	0	1
Forest (% total area)	0.30	0.19	0.00006	0.95
Count of floods	1.12	2.55	0	32

We overlaid flood maps with population maps from the Gridded Population of the World v3 (CIESIN-CIAT 2005) using GIS, to obtain estimates of the population exposed to a flood event. For vulnerability indicators we use GDP per capita (in 2005 PPP international dollars from WDI, 2010), a corruption index and an ethnic tensions index, from the International Country Risk Guide of Political Risk Services (www.prsgroup.com). Anbarci et al. (2005) highlight the ability of a country to pursue collective action, captured by lower corruption and ethnic tensions, as an important factor to fight mortality from natural disasters, earthquakes, in particular.

We hypothesize that socioeconomic and institutional factors have not only a direct effect but also an indirect effect on flood mortality through their impact on the magnitude and number of floods. To explain magnitude and flood frequency, we also account for a number of physical factors, at the country level: country's total land area (squared km.), latitude (in absolute value), mean elevation (meters above sea level), percentage of land area within 100 km of ice-free coast, from WDI (2010) and Gallup et al. (1999). To capture land-use change effects we use urban population growth and total forest area from FAO (2001, 2005, 2007) and WDI (2010).

Models. We first estimated the number of deaths as a function of the intensity of the flood event, measured by its magnitude; the exposure of the population, measured as the log of the population living in the affected area; and the socioeconomic and institutional indicators of vulnerability.

Direct effects on number of deaths. The dependent variable is the non-negative count of deaths in a flood event. Because of over-dispersion we use a Negative Binomial Regression, and add country-specific effects to the regressions. We report robust standard errors clustered at the country level. Finally, we lag all explanatory variables by one year to mitigate endogeneity bias.

The first column in Table 4 corresponds to a standard negative binomial regression similar to those used to explain earthquake mortality (e.g. Anbarci et al. 2005, Keefer et al. 2010). Observations are pooled and the regression includes continent dummies. Coefficients for all the variables but ethnic tensions are statistically significant at a 5 percent significance level or better.

The results conform to intuition. A one unit increase in magnitude is associated with a 55 percent increase in the number of deaths. To give an indication of the (large) size of this effect, at the predicted number deaths of 31, increasing the magnitude of the flood by one would result in 17 additional deaths. Similarly, the more population living in the affected area and exposed to the flood, the larger the death toll; a one percent increase is associated with 7.7 more deaths (25 percent of 31). An increase of one percent in income reduces the death toll by 13 people (44 percent of 31). Corruption is associated with an increases in the number of deaths; an improvement in the corruption index by one reduces the number of deaths by 20 percent. (The corruption index takes values between 0 and 6 with higher values indicating lower corruption). Finally, over time the number of deaths has been falling at a rate of 7 percent (or 2.2 deaths) per year.

Because the sample is restricted to large-flood-event observations, and we are controlling for the magnitude of the flood, results in Table 4 capture the direct effects of the variables, once the shock has taken place. The coefficient on income may capture availability of better medical care, emergency treatment and crisis management (Athey and Stern, 2002). In addition, richer nations typically have better forecasting and warning systems. Investment in computer modelling of storms and early warning systems can facilitate mass evacuations and save lives (Sheets & Williams, 2001). The coefficient on corruption may capture better provision of public services, including disaster relief but also the creation and enforcement of rigorous building codes, and maintenance and retrofitting of infrastructure such as bridges, dams and levees.

The second column of Table 4 presents results from the estimation including country fixed effects. Magnitude remains significant and positive, although its size is reduced. A one unit increase in the magnitude of the flood is associated with a 26 percent increase in the number of deaths. Similarly, the larger the population affected, the larger the number of deaths; a one percent increase raises the death toll, now by 6.6 percent. In this specification, neither income nor governance indicators are significant. This suggests that it is the differences in these variables across countries, rather than within country what were driving the results in column (1). That is, once we control for country-specific unobserved factors that are constant over time, the annual change in a country's GDP does not have a statistically significant impact on the number of deaths. Finally, the coefficient on the time variable indicates that the number of deaths is decreasing over time for all the countries, at a rate of 2.6 percent per year. This may reflect faster and better international aid channels over the period considered.

In regressions not reported but available upon request, the results in Table 5 were robust to (i) the inclusion of variables capturing flood frequency; (ii) restricting the sample to events caused by "heavy rain" so that we exclude instances of "mal-adaptation" due for example to dam breaks. This sample also excludes floods caused by ice-melt, cyclones (such as the 1991 Bangladesh cyclone), tidal surges and tsunamis; (iii) restricting the sample to the most recent 10 years with more accurate information. When restricting the sample to developing countries, however, higher income was associated with more deaths (perhaps because of better reporting).

Table 4: Determinants of flood mortality

VARIABLES	Pooled (1)	Country fixed effects (2)
Magnitude	0.554***	0.255***
	(0.0540)	(0.0335)
Ln(population)	0.250***	0.0657**
	(0.0490)	(0.0264)
Ln(GDP per capita PPP)	-0.437***	0.0755
	(0.0953)	(0.0980)
Corruption	-0.202**	0.0381
	(0.0967)	(0.0682)
Ethnic tensions	-0.0127	0.0250
	(0.0638)	(0.0328)
Year	-0.0707***	-0.0261***
	(0.0133)	(0.00703)
Continent dummies	Yes	No
Observations	2194	2178
Number of id	108	93

Notes: Negative binominal regressions. Dependent variable is number of people dead in flood event. Cluster-robust standard errors (country-level) in all specifications. *** p<0.01, ** p<0.05, * p<0.1.

Flood magnitude. The number of people killed in a flood is conditional on the magnitude of the flood, and on its actual occurrence. In turn, magnitude and the number of floods are modeled as a function of the natural characteristics of the country, and socioeconomic and institutional variables believed to be related to land use and flood management.

Flood magnitude is a continuous variable, and linear regression analysis techniques are appropriate. We present results from the pooled as well as country-specific random effects models (Table 5)

The results of the pooled model are presented in column (1). In column (2) we introduce country-specific effects. More population reduces the magnitude of the flood. A one percent increase in population is associated with a reduction in magnitude of 0.14 percentage points. This is a modest impact, but it is highly significant, robust across specifications, and of the expected sign. More people means more hands to fight a flood. More people also means a higher exposure and potential for damage and deaths (as shown in Table 4). This increases the payoffs of investments in flood mitigation and management.

Table 5: Determinants of flood magnitude

VARIABLES	Pooled (1)	Country specific (random) effects (2)
Ln(population)	-0.141***	-0.138***
	(0.0270)	(0.0164)
Ln(GDP per capita PPP)	-0.249***	-0.183***
	(0.0510)	(0.0547)
Corruption	0.0720**	0.0812***
	(0.0343)	(0.0275)
Ethnic tensions	0.0449	0.0400*
	(0.0306)	(0.0239)
Year	-0.00965	-0.00464
	(0.00852)	(0.00411)
Natural characteristics	Yes	Yes
Continent dummies	Yes	No
Observations	2188	2188
Number of id	108	108

Notes: Linear regressions. Dependent variable is flood magnitude. Cluster-robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Income also has a negative impact on flood magnitude (a one percent increase in income is associated with around 0.2 percentage points lower magnitude) possibly reflecting more resources available for flood control. Interestingly, the indices of corruption and ethnic tensions exhibit a positive sign. A reduction in the obstacles for collective action and efficient provision of public services associated with an increase of the magnitude of the flood. At first sight this may seem counterintuitive, but it might reflect a different approach to flood management: "learning to live with the floods" rather than "fighting the floods" through infrastructural solutions. For example, flood storage could become a recognized land use in development plans, which could be encouraged and compensated through government incentives. This kind of arrangement is more likely, ceteris paribus, in less corrupt and less fractioned societies. Galloway (1999) reports that over 25,000 homes have been relocated from the Mississippi floodplain since the large floods of 1993, and thousands of hectares of marginally productive low-lying areas have been reconverted from agriculture to natural areas. These actions seek to reduce the impacts on a population, but translate into large areas being flooded which, in turn, increase our measure of the magnitude of a flood.

Flood frequency. To measure flood frequency, we use the yearly count of floods in a country. The same estimation techniques discussed for Table 4 are relevant for Table 6. Population has a significant, positive impact on the number of floods recorded, according to column (1). Larger countries in terms of population experience more floods. Income exhibits a negative and statistically significant coefficient. Inter-annual increases in income within a country are associated with a decrease in the number of floods, possibly due to increased availability of resources for flood management. The number of floods is increasing over time at a rate of around 5 percent per year.

Table 6: Explaining number of floods

VARIABLES	Pooled (1)	Country specific (random) effects (2)
Ln(population)	0.570***	-0.182
	(0.0642)	(0.176)
Ln(GDP per capita PPP)	0.0605	-0.225*
	(0.0716)	(0.134)
Corruption	0.0103	-0.0533
	(0.0508)	(0.0361)
Ethnic tensions	-0.112***	-0.0109
	(0.0323)	(0.0310)
Year	0.0426***	0.0585***
	(0.00635)	(0.00744)
Natural characteristics	Yes	Yes
Continent dummies	Yes	No
Country Specific Fixed Effects	No	Yes
Observations	2292	2292
Number of id	107	107

Notes: Negative binominal regressions. Dependent variable is number of people dead in flood event. Cluster-robust standard errors (country-level) in all specifications. *** p<0.01, ** p<0.05, * p<0.1.

CONCLUSIONS

In this paper we use new data on large flood events between 1985 and 2008 in over 100 countries to investigate the relative contribution of natural and socioeconomic factors to explain the number of people killed by floods.

The physical magnitude of a flood has a large, positive and robust impact on the number of deaths. This is hardly surprising; larger floods kill more people. More surprising is that, conditional on flood occurrence and controlling for flood magnitude, year-to-year changes in income, and in two indices of corruption and ethnic tensions do not significantly affect the number of deaths.

Higher incomes enable investment in better monitoring and early warning systems, in infrastructural solutions for flood management, and, once the flood has occurred, in faster and better emergency assistance. Lower corruption and more social cohesion facilitate the provision of those public services more effectively, and the creation and enforcement of rigorous building codes and land zoning restrictions. Our results suggest that these factors help explain differences in deaths between countries, as previous research has shown for other natural disasters. Within a country, however, after controlling for flood occurrence and intensity, annual changes in incomes or institutions do not directly affect the death toll.

This does not mean that socioeconomic factors do not matter. Income and institutions influence flood mortality indirectly, through their impact on the intensity and frequency of floods. For millennia, humans have settled close to water bodies and in flood plains, and actively managed rivers and their drainage basins, willingly (e.g. through dikes, dams, and levees), or unwillingly. Inter-annual increases in income within a country are associated with a lower flood magnitude and a decrease in the number of floods, possibly reflecting more resources available for flood control and management. Interestingly, a reduction in the obstacles for collective action and efficient provision of public services (as measured by the corruption and ethnic tensions indices) are associated with an increase of the magnitude of the flood. We hypothesize that this could be due to a "learning-to-life-with-the-flood" management approach, in which development plans result in the creation of large flood storage areas as an alternative land use. These actions seek to reduce the impacts of a flood on a population, and are often accompanied with the relocation of homes, but translate into large areas being flooded which, in turn, increase the measure of the magnitude of a flood.

Population exposure affects the number of deaths both directly and indirectly. We obtain estimates of the population exposed to a flood event by overlying maps of the areas affected by floods with global population maps using GIS. Higher population exposure is associated with more deaths once the flood has occurred. However, precisely because more people increase the potential for damage and deaths, this increases the payoffs of investments in flood mitigation and management, resulting in smaller floods. In developing countries more population exposure is also associated with fewer floods.

Our paper also contributes, albeit tangentially, to the debate of the role of forests on the prevention and reduction of large flood events. We do not find evidence that forests reduce the magnitude of large flood events. Year-to-year changes in forested area do not significantly affect the number of floods experience by the countries in our sample either.

Finally, our results suggest that the number of deaths is decreasing over time for all the countries, at a rate of 2.6 percent per year, which may reflect faster and better international aid channels. Unfortunately, results also show that the number of floods is increasing over time, and that, over the last 10 years, floods are becoming larger.

REFERENCES

Adger, W. (2006) "Vulnerability" *Global Environmental Change*, 16: 268–281.

Anbarci, N., M. Escaleras, and C. A. Register (2005) “Earthquake fatalities: the interaction of nature and political economy” *Journal of Public Economics* 89 (9-10): 1907-1933.

Athey, Susan, and Scott Stern (2002) “The Impact of Information Technology on Emergency Health Care Outcomes” *Rand Journal of Economics* 33(3): 399–432.

Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT) (2005) Gridded Population of the World Version 3 (GPWv3): Population Grids. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw. (Accessed August 7 2010).

DFO (Dartmouth Flood Observatory) (2010) http://floodobservatory.colorado.edu -Accessed July 2010.

FAO (2001) Global forest resources assessment 2000. Rome.

FAO (2005) Global forest resources assessment 2005. Rome.

FAO (2007) State of the world’s forests 2007. Rome.

Freeman, P.K., M. Keen, and M. Mani, 2003, “Dealing with Increased Risk of Natural Disasters: Challenges and Options,” IMF Working Paper WP/03/197.

Galloway J. G.E. 1999. Two hundred and eighty years of river management and flood control along the Mississippi. In: Regional Cooperation in the Twenty-first Century on Flood Control and Management in Asia and the Pacific. Economic and Social Commission for Asia and the Pacific, Bangkok. pp. 190-204.

Gallup, John L. Sachs, Jeffrey and Andrew Mellinger (1999) "Geography and Economic Development" *International Regional Science Review* 22(2): 179-232

IPCC (Intergovernmental Panel on Climate Change). 2007. *Impacts, Adaptation and Vulnerability*, Cambridge University Press: Cambridge, UK.

Keefer, P., E. Neumayer, T. Plümper (2010) "Earthquake Propensity and the Politics of Mortality Prevention" Policy Research working paper , WPS 5182, The World Bank.

OFDA/CRED (Office of Foreign Disaster Assistance, USAID / Center for Research of the Epidemiology of Disasters) 2010. International Disaster Database - www.emdat.be- Universite Catholique de Louvain, Brussels, Belgim (Data version: v12.07, 2010).

O'Keefe, P., K. Westgate, and B. Wisner. 1976. Taking the naturalness out of natural disasters. *Nature* 260:566–67.

Sheets, Bob, and Jack Williams (2001) *Hurricane Watch: Forecasting the Deadliest Storms on Earth*, Vintage Books at Random House

Smit, B. and J.Wandel. 2006. "Adaptation, adaptive capacity and vulnerability" *Global Environmental Change* 16: 282–292.

Tol, R.S.J. and G.W. Yohe. 2007. "The weakest link hypothesis for adaptive capacity: an empirical test" *Global Environmental Change* 17: 218–227

Tol R.S.J. 2008 "Why Worry About Climate Change? A Research Agenda" *Environmental Values* 17: 437-70.

Wetherald Richard T., and Syukuro Manabe (2002) "Simulation of hydrologic changes associated with global warming" *Journal of Geophysical Research*, 107(4379), 15 PP.

Word Development Indicators (2010) available online at http://databank.worldbank.org/ddp/home.do (accessed August 2010).