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Risk Aversion, Inequality and Economic Evaluation of Flood Damages: A Case Study in Ecuador

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Abstract: While floods and other natural disasters affect hundreds of millions of people globally every year, a shared methodological approach on which to ground impact valuations is still missing. Standard Cost-Benefit Analyses typically evaluate damages by summing individuals' monetary equivalents, without taking into account income distribution and risk aversion. We propose an empirical application of alternative valuation approaches developed in recent literature, including equity weights and risk premium multipliers, to a case study in Ecuador. The results show that accounting for inequality may substantially alter the conclusions of a standard vulnerability approach, with important consequences for policy choices pertaining damage compensation and prioritization of intervention areas.

Keywords: natural disasters; flooding; flood vulnerability; inequality; risk premium; expected annual damages; certainty equivalent annual damages; equity weight expected annual damages; equity weight certainty equivalent annual damage

1. Introduction

Flooding, defined by the Intergovernmental Panel on Climate Change (IPCC) [1] as 'the overflowing of the normal confines of a stream or other body of water or the accumulation of water over areas that are not normally submerged', is one of the most common and destructive natural disasters. Estimates of both affected people and economic losses vary widely. According to the Organization for Economic Co-operation and Development (OECD) [2], floods affect up to 250 million people in the world every year. In 2019, floods caused over 5000 casualties worldwide [3].

Population growth is driving an increase in the number of people living in areas susceptible to flooding, with a consequent surge in impacts on lives, properties and productive assets. Urbanization and development reduce the water retention capacity of soils and increase runoff [4]. Climate change is increasing the frequency and intensity of flood disasters throughout the world, which nearly doubled in 2000–2009 compared to the previous decade [5]. This combination of demographic, development and climatic drivers challenges societal resilience to catastrophic flood events. New data released by the World Resource Institute in April 2020 forecast the number of people harmed by floods to double globally by 2030. According to the projections obtained in 2019 by the Aqueduct Floods modeling tool of the World Resource Institute [6], damages to urban property are expected to rise from USD 174 to USD 712 billion per year.

The structure of impacts is not uniform across the world: low-income countries suffer higher fatalities, whereas high-income countries register higher values of damage to properties and infrastructures. Low or lower-middle-income countries accounted for 49 percent of flood events recorded in the International Disaster Database EM-DAT between 1971 and 2015 and for more than 60 percent of all deaths. High and upper-middle-income countries accounted for just under 80 percent of the monetary value of all reported material damages from flood events [2].

The socio-economic significance of the issue and the expectation of an escalating trend stimulated a vast and fast-growing literature on economic impacts of flooding, particularly in urban contexts. McClymont et al. [7] provide a thorough account of the literature on flood risk management and resilience. Hennighausen and Suter [8] explore the impact of flood risk perception in the housing market in the US. Shatkin [9] develops a conceptual framework for assessing the implications of flood risk for urban development, considering issues of property rights, informality, neoliberalization and financialization and the role of the state, with a particular focus on Asian megacities. Goh [10] explores the interrelationships between biophysical factors (ecological scales of the watershed) and socio-political factors (infrastructural scales associated with flood protection, social and spatial marginalization) behind urban flood risk, based on field research in Indonesia. Chen et al. [11] study flooding-migration relationships by combining nationally representative survey data with inundation measures derived from weather stations and satellites. Oosterhaven and Tobben [12] propose a method to estimate the indirect impacts of flood disasters and apply it to the major 2013 flooding event of southern and eastern Germany. Kashyap and Mahanta [13] provide an in-depth review of previous literature.

As both latitude and poverty play a major role in explaining exposure to natural disasters, a number of case studies have focused on developing regions: Ogie et al. [14] on coastal megacities of developing nations, Cobian Alvarez and Resosudarmo [15] on Indonesia, Reynaud et al. [16] on Vietnam, De Silva and Kawasaki [17] on Sri Lanka, Erman et al. [18] on Tanzania, Kurosaki [19] on Pakistan, to cite a few.

A number of studies have also examined the vulnerability and response of different socio-economic groups to natural disasters (e.g., Rasch [20]; Rodriguez-Oreggia et al. [21]; Glave et al. [22]; Lopez-Calva and Ortiz-Juarez [23]; Carter et al. [24]; Brouwer et al. [25]; Masozera et al. [26]) as well as the relationship between poverty and disasters (Tahira and Kawasaki [27]; Borgomeo et al. [28]; Henry et al. [29]; Patnaik and Narayanan [30]; Hallegatte et al. [31]).

There is however, in our view, a yet understudied area of enquiry—the one concerning the methodological aspects of the valuation of economic impacts. Monetary estimates of economic losses from flooding play a crucial role in informing decisions and setting priorities on risk mitigation investments as well as in determining post-disaster compensations. Yet, there are no generally agreed principles on which to ground impact valuations, which partly explains the very large variance across estimates provided even by the most authoritative sources. Particularly lacking, in our view, is a shared methodological approach to account for income inequality in determining the real welfare impact of natural disasters. Simply summing individuals' monetary equivalents is likely to provide a misleading picture of relative impacts and inappropriate policy implications when flooding disproportionately affects the poor, for whom even the loss of everything may amount to small absolute monetary values.

In fact, in standard Cost-Benefit Analyses (CBA), as commonly implemented by governments and international agencies, policies are typically evaluated by summing individuals' monetary equivalents without any distributional concern (e.g. The guidelines for CBA issued by the OECD [32], the European Commission [33], the U.S. Environmental Protection Agency [34]) The same considerations hold generally also for guidelines specific to flood damage assessments (e.g. [35,36]).)

The issue of using distributional weights in CBA dates back to the 1950s [37], but recent literature shows that this discussion has been largely ignored in real world practice (inter alia Drupp et al. [38] and Adler [39]). Kind et al. [40] have suitably tackled the issue and proposed a social welfare approach to CBA for flood and other disaster risk management, showing with a simulation how considering income distribution can lead to different conclusions 'on who to target, what to do, how much to invest and how to share risks' (p. 1). If confirmed, their results would enable decision makers to improve the effectiveness and equitability of flood management policies. However, their methodological approach has not yet been tested in real world studies.

The objective of our work is to contribute to fill this gap. After presenting the methodological options through which we can consider income distribution in the evaluation of flood damages, we offer an illustration based on empirical data from a region of high flood vulnerability and significant income inequality, the Duràn Canton in the Guayas province of Ecuador. The analysis confirms that accounting for inequality substantially alters the ranking of different areas in terms of vulnerability to flood damages and thus provides important insights for policy choices pertaining damage compensation and prioritization of intervention areas.

The paper is organized as follows. In Section 2, we formally describe the four alternative evaluation methodologies proposed in previous studies to estimate flood damages. In Section 3, we present the context of the case study and the data on which the analysis is based. Then we develop the empirical analysis, by calculating (in Section 4) the equity weights and the risk premium multipliers required for the inequality-adjusted evaluation of damages, the results of which are illustrated and discussed in Section 5. Section 6 concludes the paper.

2. Evaluation Methodologies

Following Kind et al. [40], we consider four different methodologies to estimate costs and benefits of flood risk reduction.

The first is the standard estimation of the Expected Annual Damage (EAD). Damages are derived from the stage-damage (or depth-damage) function, which provides estimates of the total damages due to a flood given its depth. Total damages are then divided by the probability of flooding (inverse of the return period). EAD focuses on damages to buildings and it does not take into account diminishing marginal utility of income or risk premia. It is the procedure generally used to evaluate damages in a standard CBA (for applications to flood risk assessment, see for example Skovgård et al. [41], Dupuits et al. [42], Alian et al. [43]). Even though it does not accurately reflect welfare economics theory, it may represent a satisfying proxy in situations where the institutional setting provides compensations for flood damages and the latter do not represent a major share of disposable incomes.

A first factor neglected in standard valuations of expected damages, as already discussed in Schulze and Kneese [44], is risk aversion. Risk-averse people, in order to protect themselves from adverse events, are willing to pay an amount larger than the expected damage (ED)—which is what makes insurance markets feasible. Additional Willingness to Pay (*WTP*) above the reduction of ED is the risk premium. We assume a typical [45] risk-averse utility function—a concave curve that becomes flatter as income increases—with constant elasticity:

$$U(Y) = \frac{Y^{1-\gamma}}{1-\gamma} \tag{1}$$

where Y is income and γ is the elasticity of marginal utility of income—the variation of utility in response to changes in income. For this utility function we can express the risk premium multiplier (*RM*), following the European Commission's guidelines to CBA [33], as:

$$RM = \frac{WTP}{EAD} = \frac{1-\left\{1+P\left[(1-Z)^{(1-\gamma)}-1\right]\right\}^{\frac{1}{(1-\gamma)}}}{PZ} \tag{2}$$

where the numerator is the *WTP* for flood risk reduction, the denominator is the expected damage, P is the probability of flood occurrence (inverse of the return period) and Z is the share of income eroded by the flood—the commonly adopted measure of vulnerability. The multiplier increases more than proportionally with vulnerability.

One possible monetary evaluation approach accounting for risk aversion consists in evaluating costs and benefits of disaster prevention or remediation policies on the ground of a certainty equivalent, calculated by multiplying the expected damage by the risk premium multiplier defined above. The resulting measure, called by Kind et al. [40] Certainty Equivalent Annual Damages (CEAD), weighs *WTP* by a factor that increases more than proportionally with the fraction of household income lost, so as to account for the fact that economic theory and empirical evidence make us expect more socio-economically vulnerable individuals to be more risk averse. When compensation programs are insufficient to cover actual damages and these damages may erode a significant portion of incomes, adopting CEAD in CBA is a useful improvement over EAD.

The two approaches above do not take into account that marginal disutility of losses may vary substantially with the income of affected households, as predicted by welfare economics (and estimated in over 50 countries by Layard et al. [46]). The limits of CBAs weighing all benefits and costs equally regardless to whom they accrue—an issue thoroughly discussed in theory, besides Adler [39], also by Fleurbaey and Abi-Rafeh [47], Anthoff et al. [48] and the UK Greenbook [49]—become increasingly relevant in contexts where compensation is negligible, socio-economic vulnerability is high and income distribution is strongly unequal.

Given a standard utilitarian welfare function $W = f(U_1, U_2, \ldots, U_N)$, a change in social welfare can be written as the sum of the marginal contribution to social welfare of the variation in utility of each individual:

$$\partial W = \left(\frac{\partial W}{\partial U_1}\partial U_1 + \frac{\partial W}{\partial U_2}\partial U_2 + \cdots + \frac{\partial W}{\partial U_N}\partial U_N\right) \tag{3}$$

If we consider a change in income:

$$\partial W = \left(\frac{\partial W}{\partial U_1}\frac{\partial U_1}{\partial Y_1}\partial U_1 + \frac{\partial W}{\partial U_2}\frac{\partial U_2}{\partial Y_2}\partial U_2 + \cdots + \frac{\partial W}{\partial U_N}\frac{\partial U_N}{\partial Y_N}\partial U_N\right) \tag{4}$$

Equity weights can be derived, as done, for example, in Fleurbaey and Abi-Rafeh [47] and the European Commission [33], by summing one monetary unit to a person's annual income and calculating the variation in utility:

$$\partial W = \left(\omega_{U_1}\cdot\omega_{Y_1}\cdot\partial Y_1 + \omega_{U_2}\cdot\omega_{Y_2}\cdot\partial Y_2 + \cdots + \omega_{U_N}\cdot\omega_{Y_N}\cdot\partial Y_N\right) \tag{5}$$

where $\omega_{U_i} = \frac{\partial W}{\partial U_i}$ and $\omega_{Y_i} = \frac{\partial U}{\partial Y_i}$. According to the approximation suggested by OECD [50], the equity weight ω for a marginal increase in income for a person with income Y_i can be computed as:

$$\omega_{Y_i} = \left({}^{Y_i}/_{Y_{avg}}\right)^{-\gamma} \tag{6}$$

By introducing this equity weight in the calculation of EADs, one obtains an alternative measure, named by Kind et al. [40] Equity Weight Expected Annual Damages (EWEAD). EWEADs are obtained as the product of EAD and the equity weight, and they represent the weight assigned to a dollar loss by the affected individual.

A further alternative measure can be obtained by combining the three approaches above, so as to include both considerations of varying marginal disutility of losses, which may be important when damages are a significant share of incomes and these incomes are unfairly distributed, and of risk aversion, relevant when available compensations are insufficient and, again, distribution of income is significantly unequal. The resulting measure, called Equity Weight Certainty Equivalent Annual Damage (EWCEAD) [40], can be calculated by multiplying the EAD by the equity weight and the risk premium multiplier.

To sum up, the four alternative evaluation methodologies can be expressed as:

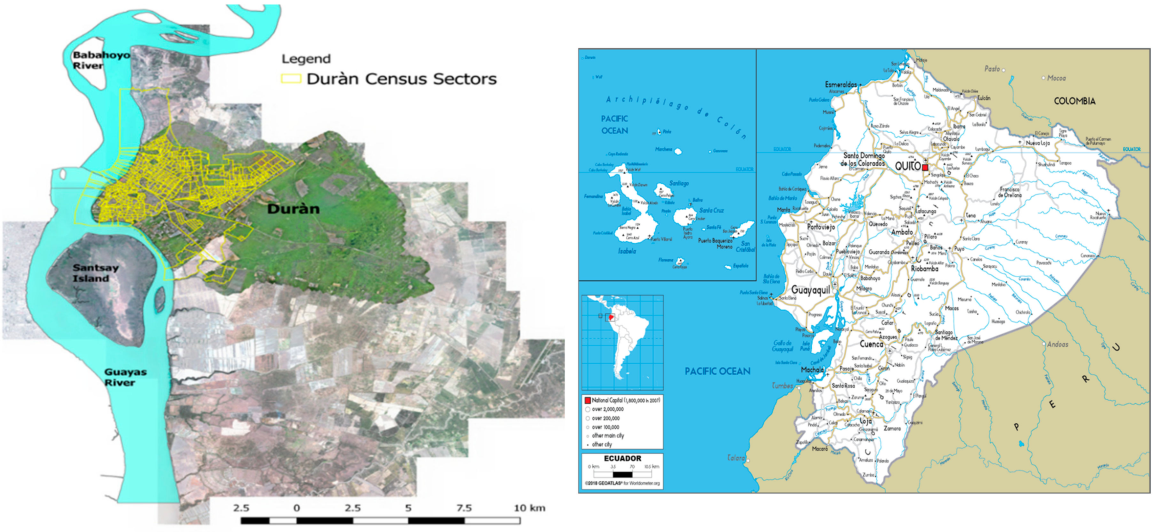
(i) Expected Annual Damage (EAD) = TD/Pr(e)
(ii) Certainty Equivalent Annual Damage (CEAD) = EAD × Risk Premium Multipliers
(iii) Equity Weights Expected Annual Damage (EWEAD) = EAD × Equity weights
(iv) Equity Weights Certainty Equivalent Annual Damage (EWCEAD) = EAD × Equity weights × Risk Premium Multipliers.

In the following sections, we implement them in an empirical valuation of flood damages in our case study, we analyze and compare the results obtained and we highlight the implications of alternative methodological choices.

3. Data

3.1. The Research Context

This research was developed in connection with the project "Climatic Resilience of Duran" (RESCLIMA DURAN), to which the University of Turin contributed with a study on the economic valuation of damages complementing the hydrological, geotechnical and community perception analyses developed by local experts (e.g., Tauzer et al. [51]) and by several other European and North American universities and research institutes (a project description is available at: https://www.researchgate.net/project/CLIMATE-RESILIENCE-FOR-CITIES-IN-ECUADOR-Case-of-Duran-RESCLIMA). The Duràn Canton, our study area, is part of the Guayas province in Ecuador, in the estuarine region of the Guayas River (Figure 1). The total area is 331.22 km^2, of which 58.14 km^2 of urban area and 273.08 km^2 of rural area. 97.91 percent of the about 272,000 inhabitants are urbanized. It represents a growing municipality within the largest urban center in Ecuador, Guayaquil, characterized by demographic and socio-economic dynamics—in terms of urbanization trends, segregation between modernized sectors and marginal areas, insecurity, high inequality [52]—typical of large cities in tropical areas.



(**a**) (**b**)

Figure 1. Duràn Canton, Ecuador. (**a**) Map of Duràn urban area; (**b**) Map of Ecuador.

The Canton is composed of 531 census sectors, but the latest Ecuador census (Encuesta Naciònal de Ingresos y Gastos de los Hogares Urbanos y Rurales; Instituto National de Estadistica y Censos (INEC) 2011 [53]) covers only 18 of them. In these sectors, between 10 and 13 families per sector were surveyed, for a total of 213 household observations, which constitute our sample. The survey contains data on population, education level, persons employed, monthly income, monthly expenditure on food and house typology. Houses are classified into four main typologies: villas, independent houses (smaller than villas), apartments in buildings, and houses made of wood or canes. Considering the predominant construction material, houses are further divided in concrete houses, brick-only houses, wooden houses, and cane houses (Table 1).

The average households' annual income is around USD 8000. The sampled houses measure, on average, 68 m^2 and are mostly built with concrete (81 percent), although 16 percent of the houses is still made of wood or canes. Out of the 213 household observations, 153 are house owners (72 percent) and the remaining 60 (28 percent) are tenants.

Latitude and the combination of the cold Humboldt current with the hot currents in Gulf of Panama and the El Niño Southern Oscillation (ENSO) phenomenon give Ecuador, with the exception of the Andean regions, a tropical climate, with heavy precipitations between January and May leading to frequent overflows of the Guayas river and the region's inner waterways. Coastal Ecuador is one of the highest hydraulic risk locations in Latin America, and cities along the mouth of the Guayas river rank among the most vulnerable areas to flooding worldwide [54]. The urban area of Duràn Canton is at an altitude varying between 0 and 88 meters above sea level. Unstructured urbanization has pushed the poor into the risk prone lowest-lying areas [51,55].

Table 1. Descriptive Statistics (Source: our elaboration on [53]).

		Mean	**St.Dev**
Average Annual Income ($/2011)		8153	3490
Gender			
	Female	0.506	
	Male	0.494	
Age Group			
	0–14	0.309	
	15–64	0.647	
	65+	0.043	
House Dimension (sqm)		68.13	48.68
House typology			
	Villas	0.633	
	Independent houses	0.061	
	Apartments in buildings	0.140	
	Wood and cane houses	0.164	
Construction material			
	Concrete	0.817	
	Brick-only	0.014	
	Wood	0.014	
	Cane	0.156	
House ownership			
	Owner	0.718	
	Tenant	0.282	

3.2. Return Period, Stage-Damage Function and Flood Inundation Map

According to hydrological models developed by the local government [56], the largest part of the Duràn Canton territory experiences extremely frequent flooding, with estimated return periods of five years (blue area in Figure 2). The most urbanized census sectors are mainly subject to return periods of up to 25 years. Arnell et al. [57] report that the frequency of river flooding in the period 1961–1990 will likely double by 2050 in Central and Eastern Europe, Central America, Brazil and some parts of Western and Central Africa. According to data reported in the EM-DAT database, the average annual number of flood events worldwide has increased from under 30 between 1971–1980 to almost 50 between 1981–1990 to over 140 between 2011 and 2015.

The stage-damage (or depth-damage) function, as mentioned above, is a function that connects damages to the depth of flood water. The database of the Joint Research Center of the European Commission (JRC) created by Huizinga et al. [58] contains damage factors of the function for all Latin American countries. The maximum damage value is estimated for Ecuador in USD 436 per square meter. This value—the highest in Latin America—represents the sum of structural and house or other building content damages, with structural damages estimated at USD 291/sqm and content damages at USD 145/sqm. We have adjusted damage values, as suggested by the JRC guidelines [58], considering rural versus urban context and the predominant material of buildings. The stage-damage function for Latin America is reported in Figure 3.

The values of flood depth in Duràn Canton for a return period of five years, described by the color gradient in Figure 4, were obtained from maps developed by Tapia [59].

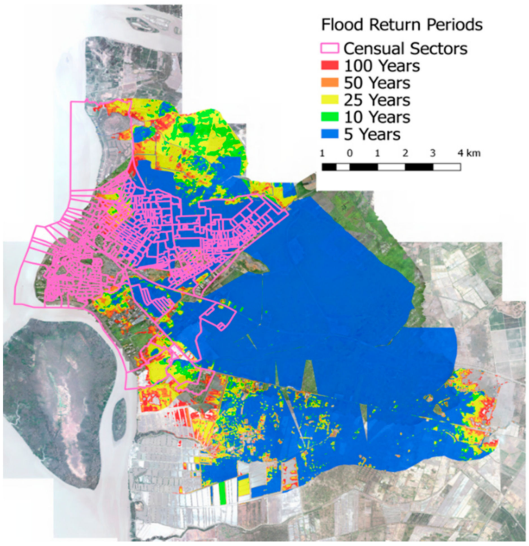


Figure 2. Return period map for Duràn Canton. (Source: our re-elaboration on [56]).

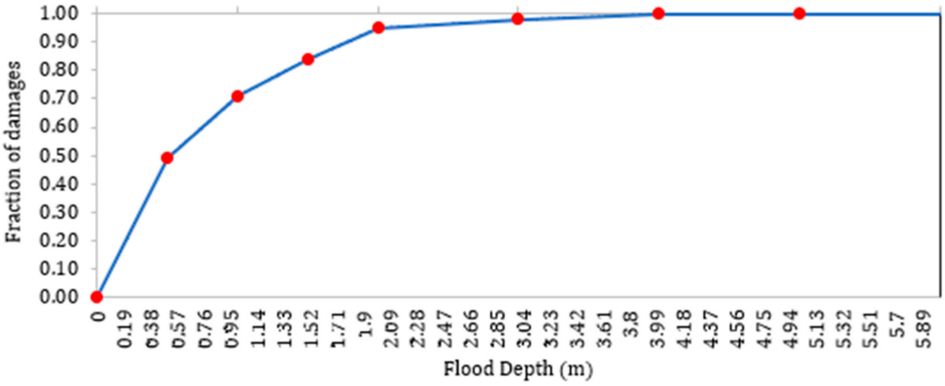


Figure 3. Stage-damage function for Latin America (Source: our adaptation on [58]).

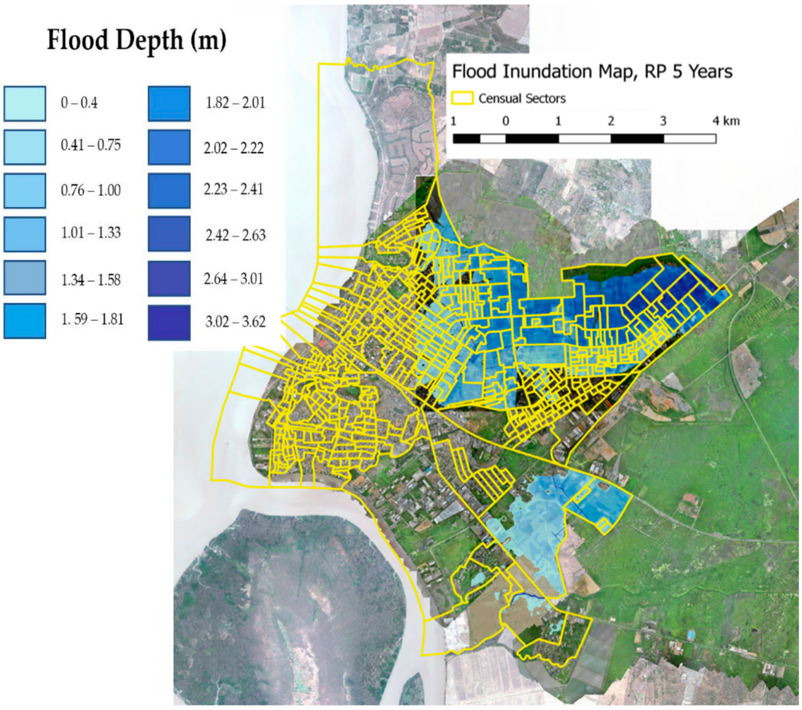


Figure 4. Flood inundation map for five years return period (Source: Our elaboration on [43]).

Total damages were derived from the stage-damage function and the inundation maps, for each censual sector and for each return period. Total damages were calculated dividing the house dimensions (square meters) by the return period of floods. The result is the Expected Annual Damage.

4. Empirical Equity Weights and Risk Premium Multipliers

In order to compute the risk premium multipliers of Equation (2) and the equity weights of Equation (6), we need empirical values for the elasticity of marginal utility (γ) and for the standard vulnerability (Z). We compute the equity weights, starting from the annual income per census sector, considering also risk aversion and income distribution. The elasticity of marginal utility, which must be $\gamma > 0$ and $\gamma \neq 1$, varies across countries and with the level of development. An estimated value for Ecuador is not available in the literature. Existing empirical estimates include Evans [60], who provides an average value of 1.4 in 20 OECD countries; Kula [61], who estimates a value of 1.64 for India; and Lopez [62], who computes the elasticity of marginal utility for nine Latin American countries with values between 1.1 and 1.9, as shown in Table 2.

Table 2. Elasticity of marginal utility in Latin American countries (Source: [62], p. 12).

Countries	γ
Argentina	1.3
Bolivia	1.5
Brazil	1.8
Chile	1.3
Colombia	1.9
Honduras	1.1
Mexico	1.3
Nicaragua	1.4
Peru	1.9

In order to select a value of γ appropriate for Ecuador, we conduct a sensitivity analysis by varying γ in the range 1.1–1.9, the interval of values estimated for Latin American countries by Lopez [62]. The results of the sensitivity analysis are available on request from the corresponding author. The results, in terms of expected damages, remain almost unchanged as the value of γ increases. Then we assume a value of $\gamma = 1.5$, considering that the income distribution and the Gini Index in Ecuador are comparable to the ones reported for other countries in South America (e.g., Bolivia, Nicaragua, Mexico) that show elasticities of marginal utility in the range 1.3–1.5 [62]. The resulting equity weights for each census sector are reported in Table 3.

From the latest Ecuador National Survey of Income and Expenditure of Urban and Rural Homes (2011) [53], we retrieved information also on each household status of house owner or tenant, whose descriptive statistics were reported in Table 1.

An important methodological issue highlighted by our Duràn Canton case study, but of high general significance particularly for natural disasters in developing countries, is that standard vulnerability, computed as share of income eroded by annual flood damages (however computed), $Z = \mathit{Flood\ damages}/Y_i$, is unable to account for damages higher than the annual income. Indeed, in our empirical analysis we find that, in poor neighborhoods, the case of households hit by flood damages to their properties (houses or their contents) higher than the family's annual income is all but infrequent. This implies a term $Z > 1$ and hence a negative risk multiplier: in this way, standard analytical tools truncate the accounting of fractional losses suffered by the poorest.

In order to overcome this limitation, we substitute the share of income lost due to the flood with the fractional value of flood damages over total wealth (TW), $Z = \mathit{Flood\ damages}/TW_i$. If the house is owned, the total wealth includes both income and the damageable value of the house, and potential flood damages are relative both to the structure and the contents. If the house is not owned, potential flood damages can only reach the maximum damage value for the contents, and total wealth is given by the sum of income and the damageable part of the contents. As a proxy of total wealth, therefore, we use the sum of annual income and the maximum value of potential flood damage obtained from the stage-damage function. In the case of households owning their house, the maximum value includes both structural and contents damage (USD 436/sqm); tenant households can only suffer contents damage (the maximum value of which is estimated in USD 145/sqm).

Table 3. Empirical equity weights.

Census Sector	Equity Weight
2002	1.388
4002	1.188
6011	0.798
9003	1.647
11006	1.111
11007	1.566
14004	1.359
17007	1.865
18002	1.785
20007	1.503
22005	1.997
28008	1.568
35004	1.103
39002	0.405
41001	1.146
42010	0.731
49009	0.345
55012	0.408

The substitution of income lost to flood damages with the share of total wealth lost is an innovation with respect to standard approaches, which allows us to have a value of vulnerability Z always between 0 and 1, obtaining valid values for the risk multiplier also for the poorest population quantiles.

The average risk premium multipliers present a slightly rising trend as the return time increases (Figure 5) due to more intense flooding and greater damages to buildings. However, given the peculiarities of our case study, the variability of average risk premium is limited. Figure 5 also shows the census sectors not impacted at low return times (sectors 39002 and 09003), in which the average risk premium is zero.

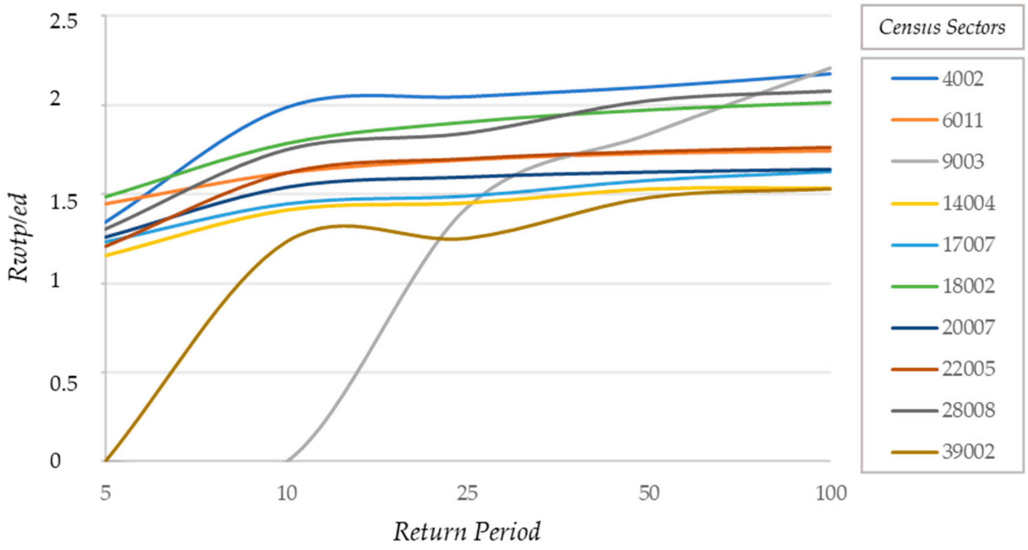


Figure 5. Average risk premium multipliers for census sectors presenting damages. Return periods between 5 and 100 years and $\gamma = 1.5$.

5. Results

To summarize, our empirical analysis combines information on (i) income and house owner or tenant status for the 213 household observations in the Duràn Canton covered by the INEC 2011 census; (ii) damage factors from Arnell and Lloyd-Hughes [57]'s Latin America stage-damage function; and (iii) values of flood depth in Duràn Canton for a return period of five years, from the inundation maps [59]. We compare the resulting evaluation of flood damages obtained with the four alternative methodologies discussed in Section 2, for return periods of 10, 25, 50 and 100 years and under the assumption of a constant elasticity of marginal utility of income of 1.2.

Figures 6–9 display the damage profiles for Expected Annual Damages, Certainty Equivalent Annual Damages, Equity Weights Expected Annual Damages and Equity Weights Certainty Expected Annual Damages, respectively.

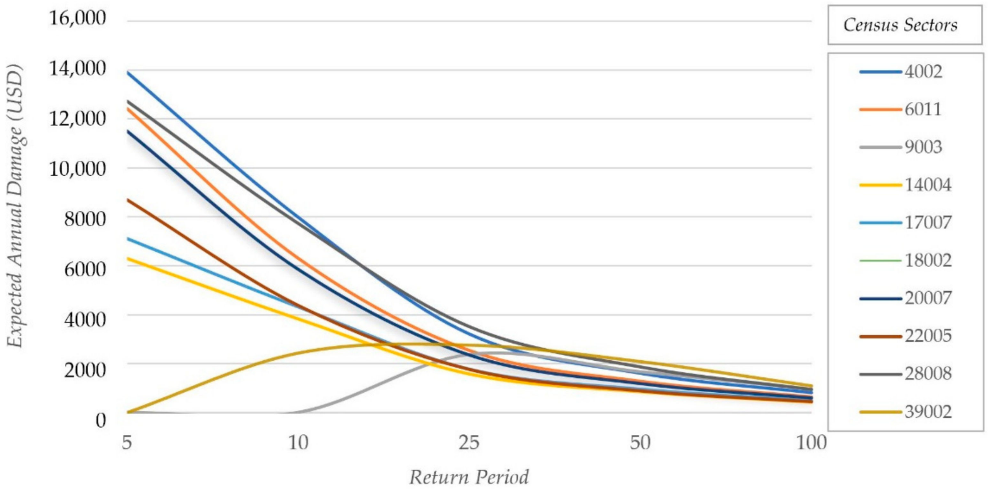


Figure 6. Damage profile evaluated with Expected Annual Damage (EAD), by census sector and return period.

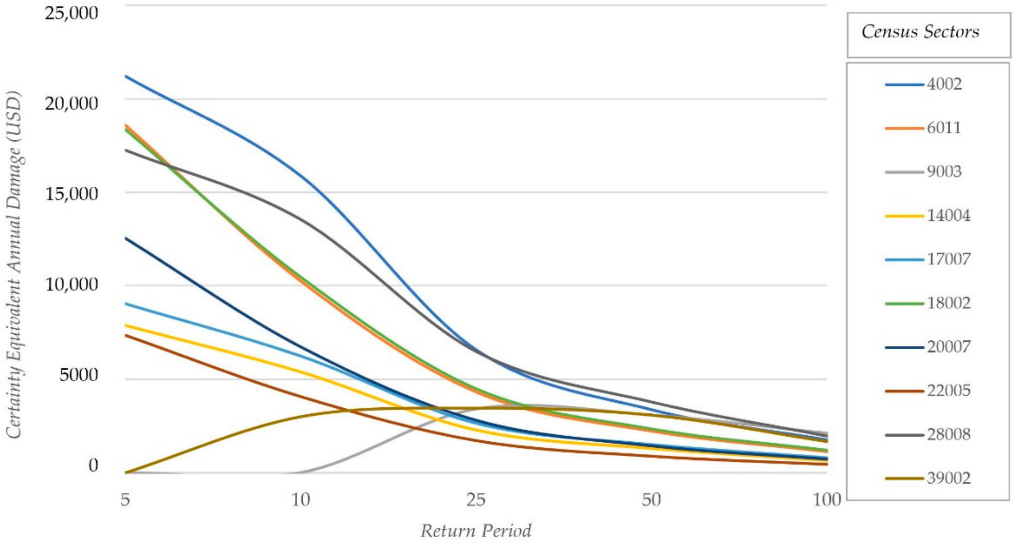


Figure 7. Damage profile evaluated with Certainty Equivalent Annual Damage (CEAD), by return period.

Figures 6–9 show a rapid reduction in the estimated damages as return times lengthen, regardless of the calculation method used. This happens because, in the specific context of the Duràn Canton, flood events are already particularly severe with low return times and they decrease with longer times. In particular, if we look at the case of EAD, which is the ratio between total damages and the probability of occurrence (Figure 6), it becomes clear that if damages do not increase as the return time increases, the ratio of these two measures will tend to decrease. This result is definitely site-specific and it depends on both the orographic characteristics of the case study and the simulated inundation maps. We also observe that some census sectors are not affected by inundations for return periods of 5 and 10 years but they are with longer periods (i.e., 39002 and 09003).

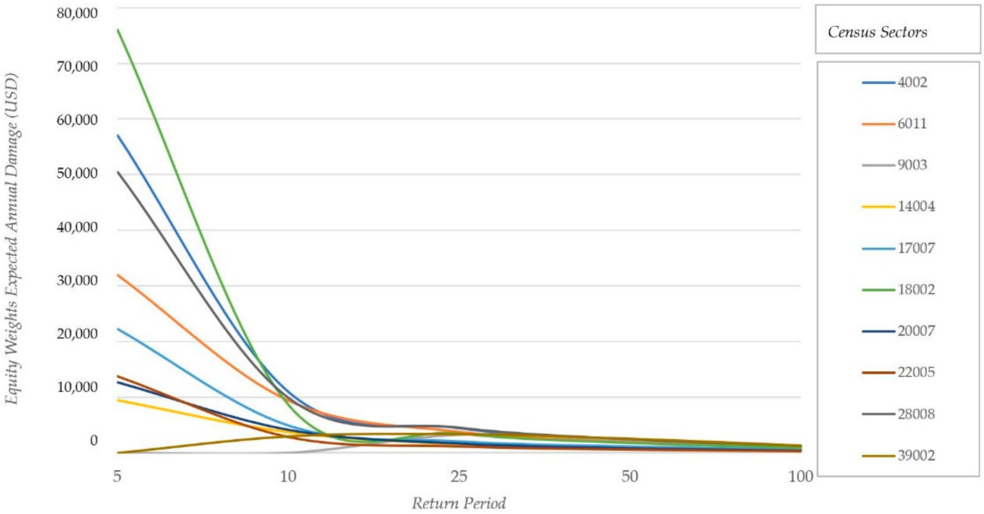


Figure 8. Damage profile evaluated with Equity Weights Expected Annual Damage (EWEAD), by return period.

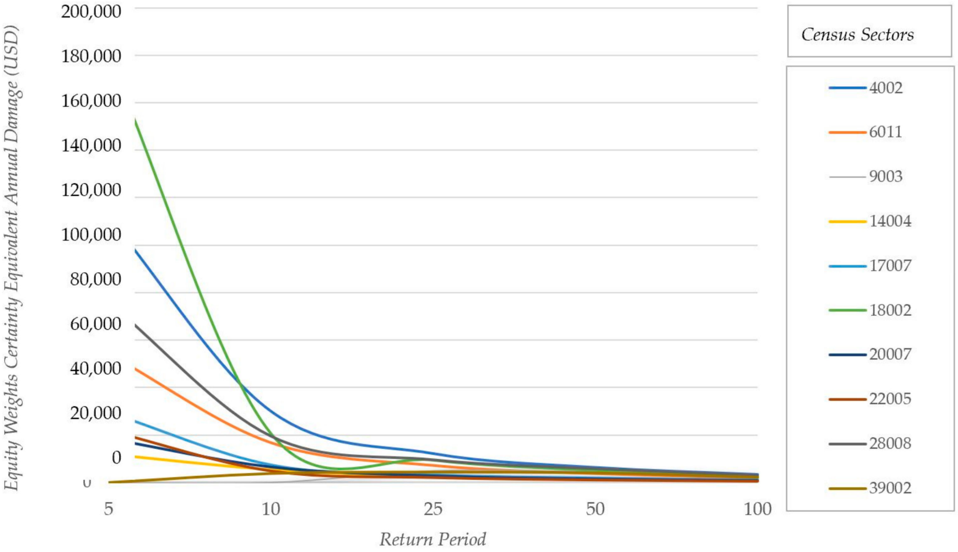


Figure 9. Damage profile evaluated with Equity Weights Certainty Equivalent Annual Damage (EWCEAD), by return period.

Finally, we can notice two main differences among the methods used to compute expected damages. When we take into account income distribution and risk premium, the ranking of sectors by intensity of damage is significantly altered by the choice of evaluation methodology. Moreover, the shape of the curves tends to be more complex when only risk premium multipliers are considered (CEAD in Figure 7) because risk premium multipliers are more heterogeneous among return times and they tend to be more clearly traced when we introduce the distribution of income through equity.

In order to allow an explicit comparison of damage evaluations conducted with the four alternative methodologies, in Table 4 we report the results for all sectors for a return period of five years. Out of the 18 sectors of Duràn Canton, eight are inundated with a return period of five years. The other sectors are never inundated or are inundated for longer return periods: a return period of five years maximizes the area interested by floods (Figure 2).

Table 4. Ranking of sectors by flood damages, for each estimation methodology.

Sector	Average Household Income (*USD*)	EAD (*USD*)	Average EAD (*USD*)	Median EAD (*USD*)	Sector	Average Household Income (*USD*)	EWEAD (*USD*)	Average EWEAD (*USD*)	Median EWEAD (*USD*)
4002	7153	13,901	1263	447	18002	5452	76,014	6334	1421
28008	5943	12,723	1060	980	4002	7153	57,056	5186	841
6011	9324	12,433	1130	1177	28008	5943	50,473	4206	1328
18002	5452	11,502	958	1166	6011	9324	31,884	2898	1751
20007	6113	8695	724	556	17007	5295	22,235	1853	1164
17007	5295	7106	592	560	22005	5058	13,775	1147	397
14004	6538	6297	524	210	20007	6113	12,618	1051	543
22005	5058	4953	413	177	14004	6538	9456	788	467
Sector	**Average Household Income (*USD*)**	**CEAD (*USD*)**	**Average CEAD (*USD*)**	**Median CEAD (*USD*)**	**Sector**	**Average Household Income (*USD*)**	**EWCEAD (*USD*)**	**Average EWCEAD (*USD*)**	**Median EWCEAD (*USD*)**
4002	7153	21,223	1929	535	18002	5452	180,015	15,001	1944
6011	9324	18,592	1690	1728	4002	7153	111,872	10,170	1065
18002	5452	18,361	1530	1571	28008	5943	76,053	6337	1731
28008	5943	17,262	1438	1390	6011	9324	54,220	4929	2592
20007	6113	12,541	1045	662	17007	5295	29,487	2457	1458
17007	5295	9043	753	720	22005	5058	21,903	1825	432
14004	6538	7889	657	226	20007	6113	18,374	1531	664
22005	5058	7359	613	189	14004	6538	11,816	984	526

The area suffering the highest damages is Sector 4002, with total EAD of USD 13,901 and average EAD of USD 1263. Sector 4002 is not the most frequently and severely inundated sector, but it is the sector, along with 6011, with the highest average annual per household income, larger houses and where a bigger share of families are house owners. The predominant construction material is concrete, which makes for houses of higher value with respect to brick-only, wooden or cane constructions more frequent in lower income sectors. Due to the very high value of Expected Annual Damages, Sector 4002 ranks as the most damaged sector also under the CEAD methodology, even though it does not have the highest risk premium multiplier.

However, when equity weights are considered, Sector 4002 is no longer the most impacted sector.

Sectors 28008 and 18002, areas with high equity weights and risk premium multipliers, which rank second and fourth respectively under the Expected Annual Damage framework, become the first and third most severely affected areas if equity weights and risk premium multipliers are accounted for in the evaluation of damages (EWEAD and EWCEAD). Conversely, Sector 6011 (the sector with the highest average income per household), which would be considered the second most damaged area under a standard EAD approach, slides down to fourth position in the ranking if damages are evaluated with equity weights. The adoption of methodologies that incorporate information on income distribution does alter significantly the outcome of evaluations and the ranking of target areas for compensation and reconstruction.

In Table 4, we report also the median value for each of the alternative methodologies used to compute expected damages. This measure of central tendency helps us to identify the census sectors presenting low-income households suffering severe damages and, in general, more unequal income distributions. This is the case for Sector 4002, which presents the highest average EAD but is among the sectors with the lowest median EAD; in this sector, the presence of few households with very low annual income exerts a strong effect on the mean which is instead mitigated by the median.

6. Conclusions

The EAD framework represents the procedure to evaluate damages from natural disasters in a typical CBA. Indeed, standard CBA is a satisfying procedure when adequate schemes are in place for the compensation of damages, income distribution is fair and damages are moderate. However, this is not the case in many instances—particularly in urban areas with low average income and marked inequality. By testing EAD and three alternative evaluation methodologies on data from a particularly significant case study—a coastal tropical urban area among the most vulnerable to flooding worldwide—we provide evidence of general value and a framework replicable in any other relevant context. Our results show that alternative measures of monetary damages from natural disasters, more coherent with economic theory of individual preferences and a social welfare perspective, can substantially modify both compensations and the ranking of priority areas of intervention. Our empirical implementation of the theoretical framework proposed in Adler [39] and Kind et al. [40] shows that the observation of income distribution, specifically via its reflection on marginal utility of income and on risk aversion, may provide a different view from the commonly adopted approach and it allows decision makers to pursue mitigation, adaptation and compensation policies more closely, reflecting a social welfare objective.

Obviously, this study also leaves room for further improvements. We have used a general stage-damage function fitted to Latin American countries, whereas more sophisticated, ad hoc studies could develop specific stage-damage functions fitted to the specific evaluation area—Ecuador or Duràn Canton data, in this case. We have used the latest available census, published in 2011 [53]; the study could be validated and updated by using the new census data which will become available in 2021-22. The sensitivity analysis could be enriched: particularly (i) a specific value of the γ parameter for the area of interest could be calculated from original data; and (ii) the analysis could be repeated with different utility functions. Further studies, replicating the analysis in other contexts and perhaps refined along these lines, would contribute to strengthening the case for revisiting the way CBA is performed in the presence of high-income inequality. We hope this first empirical investigation will spur further research interest on alternative approaches for the monetary valuation of the impacts of floods and other natural disasters on people's livelihoods.

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References

1. IPCC. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2012.
2. OECD. *Financial Management of Flood Risk*; OECD Publishing: Paris, France, 2016. [CrossRef]
3. CRED—Centre for Research on the Epidemiology of Disasters. *Disaster Year in Review 2019*; CRED: Brussels, Belgium, 2020; Available online: https://www.cred.be/publications (accessed on 2 September 2020).
4. Pereira, P.; Barcelò, D.; Panagos, P. Soil and water threats in a changing environment. *Environ. Res.* **2020**, *186*, 109501. [CrossRef]
5. Keating, A.; Campbell, K.; Mechler, R.; Michel-Kerjan, E.; Mochizuki, J.; Kunreuther, H.; Bayer, J.; Hanger, S.; McCallum, I.; See, L.; et al. *Operationalizing Resilience against Natural Disaster Risk: Opportunities, Barriers, and a Way forward*; Zurich Flood Resilience Alliance; IIASA: Zurich, Switzerland, 2014.
6. World Resource Institute. *Aqueduct Water Risk Atlas (Aqueduct 3.0)*; WRI: Washington, DC, USA, 2019; Available online: https://wriorg.s3.amazonaws.com/s3fs-public/uploads/aqueduct-whats-new.pdf (accessed on 18 November 2020).
7. McClymont, K.; Morrison, D.; Beevers, L.; Esther, C. Flood Resilience: A Systematic Review. *J. Environ. Plan. Manag.* **2020**, *63*, 1151–1176. [CrossRef]
8. Hennighausen, H.; Suter, J.F. Flood Risk Perception in the Housing Market and the Impact of a Major Flood Event. *Land Econ.* **2020**, *96*, 366–383. [CrossRef]
9. Shatkin, G. Futures of Crisis, Futures of Urban Political Theory: Flooding in Asian Coastal Megacities. *Int. J. Urban Reg. Res.* **2019**, *43*, 207–226. [CrossRef]
10. Goh, K. Urban Waterscapes: The Hydro-Politics of Flooding in a Sinking City. *Int. J. Urban Reg. Res.* **2019**, *43*, 250–272. [CrossRef]
11. Chen, J.J.; Mueller, V.; Jia, Y.; Tseng, S.K.-H. Validating Migration Responses to Flooding Using Satellite and Vital Registration Data. *Am. Econ. Rev.* **2017**, *107*, 441–445. [CrossRef]
12. Oosterhaven, J.; Tobben, J. Wider Economic Impacts of Heavy Flooding in Germany: A Non-linear Programming Approach. *Spat. Econ. Anal.* **2017**, *12*, 404–428. [CrossRef]
13. Kashyap, S.; Mahanta, R. Vulnerability Aspects of Urban Flooding: A Review. *Indian J. Econ. Dev.* **2018**, *14*, 578–586. [CrossRef]
14. Ogie, R.I.; Adam, C.; Perez, P. A Review of Structural Approach to Flood Management in Coastal Megacities of Developing Nations: Current Research and Future Directions. *J. Environ. Plan. Manag.* **2000**, *63*, 127–147. [CrossRef]
15. Cobian Alvarez, J.A.; Resosudarmo, B.P. The Cost of Floods in Developing Countries' Megacities: A Hedonic Price Analysis of the Jakarta Housing Market, Indonesia. *Environ. Econ. Policy Stud.* **2019**, *21*, 555–577. [CrossRef]

16. Reynaud, A.; Nguyen, M.-H.; Aubert, C. Is There a Demand for Flood Insurance in Vietnam? Results from a Choice Experiment. *Environ. Econ. Policy Stud.* **2018**, *20*, 593–617. [CrossRef]
17. De Silva, M.M.G.T.; Kawasaki, A. Socioeconomic Vulnerability to Disaster Risk: A Case Study of Flood and Drought Impact in a Rural Sri Lankan Community. *Ecol. Econ.* **2018**, *152*, 131–140. [CrossRef]
18. Erman, A.E.; Tariverdi, M.; Obolensky, M.A.B.; Chen, X.; Vincent, R.C.; Malgioglio, S.; Maruyama Rentschler, J.E.; Hallegatte, S.; Yoshida, N. *Wading Out the Storm: The Role of Poverty in Exposure, Vulnerability and Resilience to Floods in Dar Es Salaam*; Policy Research Working Paper Series 8976; World Bank: Washington, DC, USA, 2017.
19. Kurosaki, T. Vulnerability of Household Consumption to Floods and Droughts in Developing Countries: Evidence from Pakistan. *Environ. Dev. Econ.* **2015**, *20*, 209–235. [CrossRef]
20. Rasch, R. Income Inequality and Urban Vulnerability to Flood Hazard in Brazil. *Soc. Sci. Q.* **2017**, *98*, 299–325. [CrossRef]
21. Rodriguez-Oreggia, E.; De La Fuente, A.; De La Torre, R.; Moreno, H.A. Natural Disasters, Human Development and Poverty at the Municipal Level in Mexico. *J. Dev. Stud.* **2013**, *49*, 442–455. [CrossRef]
22. Glave, M.; Fort, R.; Rosemberg, C. *Disaster Risk and Poverty in Latin America: The Peruvian Case Study*; Group for the Analysis of Development (GRADE): Lima, Peru, 2009.
23. Lopez-Calva, L.F.; Ortiz-Juarez, E. *Evidence and Policy Lessons on the Links between Disaster Risk and Poverty in Latin America*; MDG-01-2009; UNDP Regional Bureau for Latin America and the Caribbean: New York, NY, USA, 2009.
24. Carter, M.R.; Little, P.D.; Mogues, T.; Negatu, W. Poverty traps and natural disasters in Ethiopia and Honduras. *World Dev.* **2007**, *35*, 835–856. [CrossRef]
25. Brouwer, R.; Akter, S.; Brander, L.; Haque, E. Socioeconomic vulnerability and adaptation to environmental risk: A case study of climate change and flooding in Bangladesh. *Risk Anal.* **2007**, *27*, 313–326. [CrossRef]
26. Masozera, M.; Bailey, M.; Kerchner, C. Distribution of impacts of natural disasters across income groups: A case study of New Orleans. *Ecol. Econ.* **2007**, *63*, 299–306. [CrossRef]
27. Tahira, Y.; Kawasaki, A. The impact of the Thai flood of 2011 on the rural poor population living on the flood plain. *J. Disaster Res.* **2017**, *12*, 147–157. [CrossRef]
28. Borgomeo, E.; Hall, J.W.; Salehin, M. Avoiding the water-poverty trap: Insights from a conceptual human-water dynamical model for coastal Bangladesh. *Int. J. Water Resour.* **2017**, *34*, 1–23. [CrossRef]
29. Henry, M.; Kawasaki, A.; Takigawa, I.; Meguro, K. The impact of income disparity on vulnerability and information collection: An analysis of the 2011 Thai flood. *Flood Risk Manag.* **2015**, *10*, 339–348. [CrossRef]
30. Patnaik, U.; Narayanan, K. Vulnerability and Coping to Disasters: A Study of Household Behaviour in Flood Prone Region of India. *Munich Pers. RePEc Arch.* **2010**, *21992*, 1–22.
31. Hallegatte, S.; Henriet, F.; Patwardhan, A.; Narayanan, K.; Ghosh, S.; Karmakar, S.; Patnaik, U.; Abhayankar, A.; Pohit, S.; Corfee-Morlot, J. *Flood Risks, Climate Change Impacts and Adaptation Benefits in Mumbai: An Initial Assessment of Socio-Economic Consequences of Present and Climate Change Induced Flood Risks and of Possible Adaptation Options*; OECD Publishing Office: Paris, France, 2010.
32. OECD. *Cost-Benefit Analysis and the Environment: Further Developments and Policy Use*; OECD Publishing: Paris, France, 2018. [CrossRef]
33. European Commission. *Guide to Cost-Benefit Analysis of Investment Projects*; European Commission: Brussels, Belgium, 2015. Available online: https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf (accessed on 15 February 2020).
34. U.S. Environmental Protection Agency, National Center for Environmental Economics. *Guidelines for Preparing Economic Analyses*; EPA 240-R-00-003; U.S. Environmental Protection Agency, National Center for Environmental Economics: Washington, DC, USA, 2000. Available online: https://nepis.epa.gov/Exe/ZyPDF.cgi/P1004DN9.PDF?Dockey=P1004DN9.PDF (accessed on 18 November 2020).
35. European Commission. *Floods and Economics: Appraising, Prioritising and Financing Flood Risk Management Measures and Instruments*; Working Group F on Floods, Thematic Workshop 25-26/10/2010; European Commission: Ghent, Belgium, 2011. Available online: https://ec.europa.eu/environment/water/water-framework/economics/pdf/WGF11-3-BE-Floods_and_economics_workshop.pdf (accessed on 15 February 2020).
36. European Commission. *Directorate General Humanitarian Aid and Civil Protection (DG-ECHO). Integrating CBA in the Development of Standards for Flood Protection & Safety (FLOOD-CBA2)*; Final Report; European Commission: Ghent, Belgium, 2017. Available online: http://www.floodcba2.eu/site/ (accessed on 18 November 2020).

37. Meade, J.E. *Trade and Welfare: Mathematical Supplement*; Oxford University Press: Oxford, UK, 1955.
38. Drupp, M.A.; Meyac, J.N.; Baumgärtner, S.; Quaas, M.F. Economic Inequality and the Value of Nature. *Ecol. Econ.* **2018**, *150*, 340–345. [CrossRef]
39. Adler, M.D. Benefit–Cost Analysis and Distributional Weights: An Overview. *Rev. Environ. Econ. Policy* **2016**, *10*, 264–285. [CrossRef]
40. Kind, J.; Botzen, W.J.W.; Aerts, J.C.J.H. Accounting for risk aversion, income distribution and social welfare in cost-benefit analysis for flood risk management. *WIREs Clim. Chang.* **2017**, *8*, e446. [CrossRef]
41. Skovgård, O.A.; Zhou, Q.; Linde, J.J.; Arnbjerg-Nielsen, K. Comparing Methods of Calculating Expected Annual Damage in Urban Pluvial Flood Risk Assessments. *Water* **2015**, *7*, 255. [CrossRef]
42. Dupuits, E.J.C.; Diermanse, F.L.M.; Kok, M. Economically optimal safety targets for interdependent flood defences in a graph-based approach with an efficient evaluation of expected annual damage estimates. *Nat. Hazards Earth Syst. Sci.* **2017**, *17*, 1893–1906. [CrossRef]
43. Alian, N.; Ahmadi, M.M.; Bakhtiari, B. Uncertainty Analysis of Expected Annual Flood Damage for Flood Risk Assessment (A Case Study: Zayande Roud Basin). *J. Water Soil Sci.* **2019**, *23*, 141–152.
44. Schulze, W.D.; Kneese, A.V. Risk in Benefit-Cost Analysis. *Risk Anal.* **1981**, *1*, 81–88. [CrossRef]
45. Arrow, K.J. *The Theory of Risk Aversion. Aspects of the Theory of Risk Bearing*; Yrjo Jahnssonin Saatio: Helsinki, Finland, 1965; Reprinted in: *Essays in the Theory of Risk Bearing*; Markham: Chicago, IL, USA, 1971; pp. 90–109.
46. Layard, R.; Mayraz, G.; Nickell, S. The marginal utility of income. *J. Public Econ.* **2008**, *92*, 1846–1857. [CrossRef]
47. Fleurbaey, M.; Abi-Rafeh, R. The use of distributional weights in benefit–cost analysis: Insights from welfare economics. *Rev. Environ. Econ. Policy* **2016**, *10*, 286–307. [CrossRef]
48. Anthoff, D.; Hepburn, C.; Tol, R.S. Equity weighting and the marginal damage costs of climate change. *Ecol. Econ.* **2009**, *68*, 836–849.
49. Her Majesty's Treasury (HMT). *The Green Book. Appraisal and Evaluation in Central Government*; TSO: London, UK, 2011.
50. OECD. *Cost-Benefit Analysis and the Environment: Recent Developments*; OECD Publishing: Paris, France, 2006. [CrossRef]
51. Tauzer, E.; Borbor-Cordova, M.J.; Mendoza, J.; De La Cuadra, T.; Cunalata, J.; Stewart-Ibarra, A.M. A participatory community case study of periurban coastal flood vulnerability in southern Ecuador. *PLoS ONE* **2019**, *14*, e0224171. [CrossRef]
52. Moser, C. *Ordinary Families, Extraordinary Lives: Assets of Poverty Reduction in Guayaquil, 1978–2004*; Brookings Institution Press: Washington, DC, USA, 2009.
53. INEC. *Encuesta Naciònal de Ingresos y Gastos de los Hogares Urbanos y Rurales*; Instituto Nacional de Estadística y Censos, Gobierno de la Republica del Ecuador: Quito, Ecuador, 2011. Available online: https://www.ecuadorencifras.gob.ec/encuesta-nacional-de-ingresos-y-gastos-de-los-hogares-urbanos-y-rurales/ (accessed on 15 February 2020).
54. Calil, J.; Reguero, B.G.; Zamora, A.R.; Losada, I.J.; Méndez, F.J. Comparative Coastal Risk 719 Index (CCRI): A multidisciplinary risk index for Latin America and the 720 Caribbean. *PLoS ONE* **2017**, *12*, e0187011. [CrossRef]
55. Hardoy, J.E.; Mitlin, D.; Satterthwaite, D. *Environmental Problems in an Urbanizing World: Finding Solutions in Cities in Africa, Asia and Latin America*; Routledge: London, UK, 2013. [CrossRef]
56. Gobierno Autonomo Descentralizado Durán (GAD-Durán). Mapa de Amenazas por Inundaciones: Durán, Ecuador; 2014. Available online: http://preventionweb.net/go/40953 (accessed on 15 February 2020).
57. Arnell, N.W.; Lloyd-Hughes, B. The global-scale impacts of climate change on water resources and flooding under new climate and socio-economic scenarios. *Clim. Chang.* **2014**, *122*, 127–140. [CrossRef]
58. Huizinga, J.; de Moel, H.; Szewczyk, W. *Global Flood Depth-Damage Functions: Methodology and the Database with Guidelines*; JRC Working Papers JRC105688; Joint Research Centre of the European Commission (JRC): Seville, Spain, 2017.
59. Tapia, A.J.C. *Hydrologic Modelling of an Experimental Area in the Guayas River Basin to Quantify Liquid and Solid Flow Production*; Universidad Nacional de La Plata: Quito, Ecuador, 2012.
60. Evans, D.J. The Elasticity of Marginal Utility of Consumption: Estimates for 20 OECD Countries. *Fisc. Stud.* **2005**, *26*, 197–224. [CrossRef]
61. Kula, E. Estimation of a Social Rate of Interest for India. *J. Agric. Econ.* **2004**, *55*, 91–99. [CrossRef]

62. Lopez, H. *The Social Discount Rate: Estimates for Nine Latin American Countries*; Policy Research working paper WPS 4639; World Bank: Washington, DC, USA, 2008. Available online: http://documents.worldbank.org/curated/en/135541468266716605/The-social-discount-rate-estimates-for-nine-Latin-American-countries (accessed on 2 September 2020).