Socially Adjusted Vulnerability Assessment for Flood Mitigation in Jefferson Parish Louisiana

Abstract

Federal agencies select the best flood mitigation project based on Benefit-Costs analysis (BCA). These BCAs' calculations of costs and benefits often focus on property values and ignore the distribution of damages across different populations and how this might lead to different outcomes on total social welfare. For effective flood risk management that considers social vulnerability, assessing the property's value at risk and the social factors that influence an affected community's ability to respond to or recover from it is essential. A major driver of this is the income and wealth of at-risk populations. Thus, to address the distributional impacts (i.e., equity), it is important that BCAs are based on social welfare, where individual social vulnerability is considered through relative impacts on income. One of the ways to address equity is through diminishing marginal utility of income, which explains that welfare increases more when $100 goes to low-income people compared to high-income people. This paper aims to use this concept to produce vulnerability-weighted damage impacts for households living in single-family dwellings that make income-informed, tenure-informed estimates of marginal utilities to flood damage. We present a methodology to integrate equity into BCAs with a case study based on Jefferson Parish in Louisiana. This approach will help federal agencies decide who to target while investing and how to put different weightage for low-income communities.

1. Introduction

Floods are the most common hazard causing human suffering, property damage, and loss every year all over the world. Economic flood losses are high and increasing due to many reasons (e.g., population growth, climate change, and soil subsidence) (Mostafiz, Bushra, et al., 2021; Tate et al., 2021). It is estimated that due to socioeconomic development average annual flood damages of US $6 billion for the 136 largest coastal cities will increase to US $52 billion by 2050 (Kind et al., 2017). The increasing number of disaster events, high mitigation costs, and finite resources make flood risk management (FRM) approaches more difficult to implement, where each investment must prioritize maximum social welfare.

Effective flood mitigation management (FMR) will not only assess the value of the property at risk but also the social factors that influence an affected community's ability to respond to or recover from it (Mostafiz, Friedland, et al., 2021). To consider the social factors we must take into account other types of flood damages for humans (i.e., income loss, and health impacts). We also need to consider how flood damage is distributed between people with different incomes, and the capacities of those people to cope with, and recover from, floods. For example, we need to differentiate between damage of US$1,000 for one person with a damage of US$1 each for a thousand persons, and damage of US$1000 for a person who earns US$10,000 annually with that for a person who earns US$100,000. Each of these scenarios will create inequality while they are considered to generate the same impacts. Thus, it is essential to put equity weights to different income groups which will ensure their Social Welfare flood Risk (SWFR). In SWFR, social vulnerability and income inequality are both considered, which ensures that the damages of less vulnerable and high-income people are valued lower than for more vulnerable and low-income people (Kind et al., 2016).

The Social Welfare Flood Risk (SWFR) is also a key part of current federal policy in the Justice40 initiative. Justice40 initiative provides a directive that explains how certain federal investments will be made toward a goal that 40 percent of the overall benefits of such investments flow to disadvantaged communities (The White House, 2022). This initiative is committed to securing environmental justice and spurring economic opportunity for disadvantaged communities that are marginalized and overburdened by pollution and underinvestment in housing, transportation, water and wastewater infrastructure, and health care. This initiative calls for consideration of environmental justice, and recognition of ecosystem co-benefits across multiple agencies ("Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis", EO 13990) (e.g., FEMA and USACE), and using alternative methodologies to evaluate flood control and adaptation projects. In addition, the Biden administration has developed strategies and accelerated policies to advance nature-based solutions to address climate change, nature loss, and inequity. These recent developments have encouraged federal agencies and state agencies to select projects that show consideration for social welfare BCA's, which incorporates equity.

1. Research Question

The objective of this study is to produce vulnerability-weighted damage impacts for households living in single-family dwellings (apartments, or multistoried) that make income-informed, tenure-informed (rental, owner), and insurance-informed estimates of marginal utilities to flood damage. We calculated the social welfare flood risk (SWFR) based on the marginal utility of consumption, risk premium, and equity weights at the neighborhood level (block or block group) based on structure types, and resident characteristics. To implement this study, we focused on the estimation of three parameters,

1. What is the Average Annual Loss (AAL) for each block group in Jefferson Parish?
2. What are the Equity Weights (EW) for a low-income community compared to a high-income community?
3. What is the Social Welfare Flood Risk (SWFR) for each block group in Jefferson Parish?

2. Methods

We derived the flood depth data (pluvial, fluvial, and coastal) for Louisiana from the Fathom dataset. Flood hazard for the 100- and 500-year return periods was represented using flood depth grids, which cover a horizontal resolution of 1 arc-second (~30m). We followed the (Wing et al., 2017) methodology to remove cells from the pluvial grid with a depth of less than 15 cm, as it represents the ground flood elevation. Later we used flood depth data and structure type data to understand the flood risk at each block group.

We collected variables related to income parameters from the 2016–2020 release of the American Community Survey (ACS), for each census tract (n=4294) in Louisiana. We used the variable B19013_001 for median household income data at the block group level and variable B06011_001 for median income data for Louisiana at the tract level. Table 1 represents different data sources we used for this study.

Table 01: Different data Sources

Data Type	Source
Building Data (2010)	INCORE & NSI data: (https://incore.ncsa.illinois.edu/)
Fluvial and Coastal Flood Depth Data (2023)	Fathom US Flood Map (Wing et al 2018)
Depth-Damage Function	Hazus/FAST database
Demographic Data for Jefferson Parish	Census and ACS 2010
Insurance (estimated coverages for renters and homeowners)	Single family home (National Flood Insurance Program) NFIP Policies

We also derived the building structure data (building heights, ground floor elevation, area, and number of stories) and data related to tenure status and flood insurance from the INCORE Dataset. For the Annual Average Loss (AAL) calculation, we followed the (Al Assi et al., 2022) methodology. The AAL (Eq. 1) values were calculated here by numerically integrating loss-exceedance probability distributions to represent the economic annual flood risk to the building.

$$AAL = P\ x\ D \ldots\ldots\ldots\ldots\ldots(1)$$

Here P is the probability of a flood event and D is the total damage due to the flood event. The damage (D) was calculated based on the flood depth and structure types. Figure 1 represents the AAL at household level for Jefferson Parish.

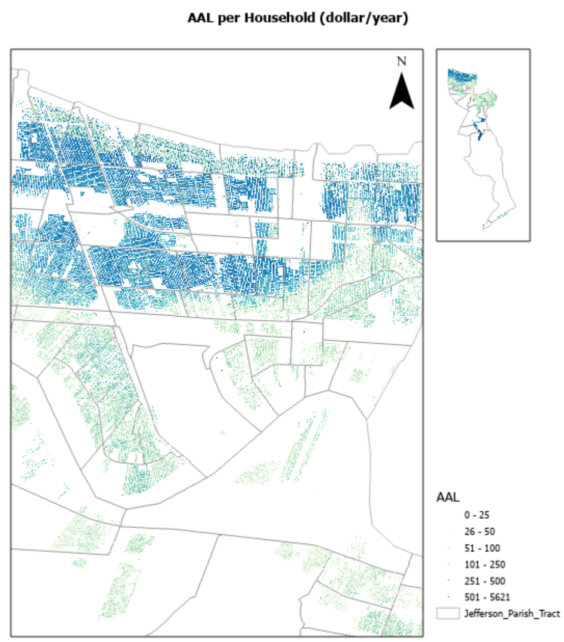


Figure 01: AAL at household level for Jefferson Parish, LA.

The utility function is governed by the law of diminishing marginal utility of consumption, it is non-linear and has a concave shape (Figure 01). This indicates that with decreasing consumption, the marginal utility or well-being increases (Kind et al., 2017). We assumed that the annual income of an individual is consumed in the same year. Annual consumption is therefore equal to annual income. Diminishing the marginal utility of consumption is essential to social welfare in two ways. First, it provides an explanation of why people tend to be risk averse: that is an additional unit of consumption has a greater value during periods when there is a flood event than when there is no flood event. Second, it justifies the use of equity weights in BCAs (Benefit Cost Analysis) where an additional unit of consumption is valued higher for low-income communities than for high-income communities (Kind et al., 2019). Similarly, the AAL will have different impacts on different income groups, with similar structural damages having disparate economic welfare effects. The utility function is described in Eq. 2.

$$\boldsymbol{U(C)} = \frac{\boldsymbol{C^{(1-\gamma)}}}{\boldsymbol{(1-\gamma)}} \ldots\ldots\ldots\ldots(2)$$

For $\gamma \geq 0$ and $\gamma \neq 1$, where U is the utility, C is the consumption, and γ the elasticity of marginal utility of consumption. The well-being, defined by the utility, is linear if $\gamma = 0$. For $\gamma \geq 0$, the marginal utility of consumption diminishes, resulting in a concave shape of the utility function (see Figure 01).

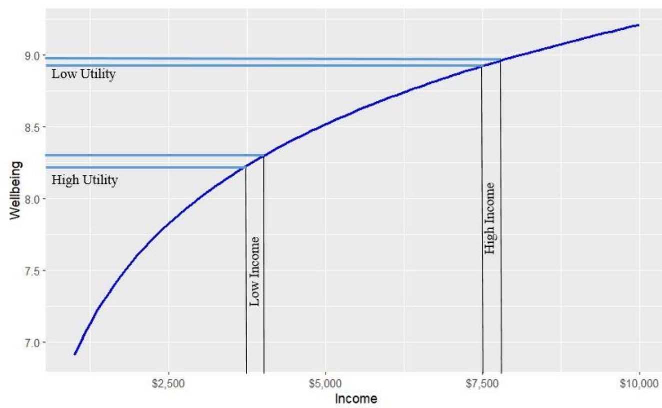


Figure 01: This graph illustrates how a person with a monthly salary of $60,000 would experience greater well-being with a $ 1,000 increase in income compared to a person with a $200,000 yearly income.

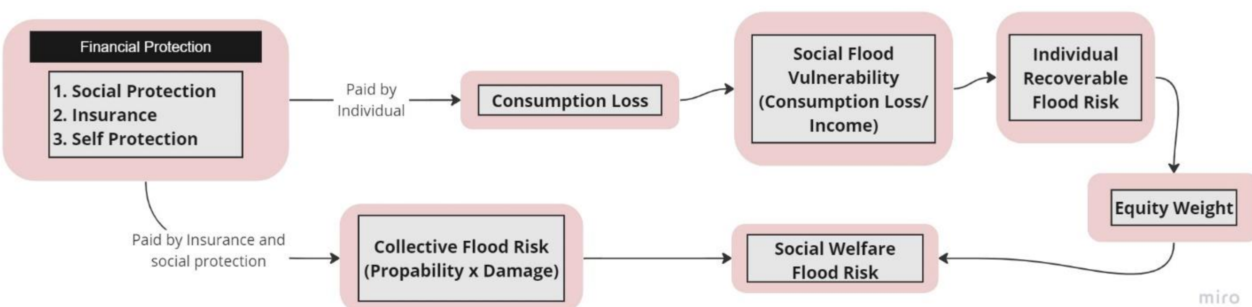


Figure 02: Conceptual pathway of calculating Equity Weights using financial protection.

In this study, consumption loss is the damage that are not covered through financial protection. Without any form of financial protection, we assume that flood events lead to an immediate reduction of consumption and hence affect well-being. This consumption loss is important as the repair or replacement of damaged assets or goods is financed at the cost of consumption (Adler, 2016). Three forms of financial protection can mitigate the immediate impact of floods on consumption or smooth it over time: insurance, social protection, and self-protection (Figure 02). Here Figure 02 represents how different financial protections can be used in the equity weight (EW) estimation.

Insurance is a form of financial protection in which individuals can smooth the impact of a flood over time by paying an annual insurance fee. In case of a flood, damage repairs are paid for by the insurer. Social protection is a form of financial protection that is provided by the national government, international community, NGOs, philanthropists, relatives, and/or friends. It comes in the form of social assistance, wealth, and compensation for emergency aid (Kind et al., 2017). Self-protection is a form of financial protection (i.e., salary) in which an individual can smooth the impact of a flood over time by using savings, borrowing money, or selling goods or assets. Here self-protection is the amount of money paid by the individual and it is directly related to the consumption loss. Social protection and insurance is covered by other sources which leads to the calculation of AAL. We used all three of these financial protections to calculate the SWFR.

Here Risk premium (Eq.3), R can be derived from the following equation, where p is the probability for flood events, Z is the social vulnerability and ϒ is the marginal utility of income.

$$R = \frac{WTP}{AAL} = \frac{1-\left[1+\left\{P\left(1-Z_{i,t}\right)^{1-\gamma_1}-1\right\}\right]^{\frac{1}{1-\gamma}}}{PZ_{i,t}} \text{ ………….(3)}$$

Here, the numerator is the WTP for flood risk reduction and the denominator is the expected damage. Also, 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 while accounting for risk aversion consists of evaluating the costs and benefits (BCAs) of disaster prevention or remediation programs. It could be estimated on the ground of the risk premium (R), calculated by multiplying the expected damage by the risk premium multiplier (R) defined above. The resulting measure, explained by (Hattum et al., 2020) the equity weight (EW) and willingness to Pay (WTP) increases more than proportionally with the fraction of household income lost. This provides empirical evidence which ensures that 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 BCA is a useful improvement over AAL.

Here Figure 03 represents the conceptual framework for the calculation of SWFR. We summarized all the necessary equations in this framework and also included the linkage between each calculation.

Equity Weighted (EW) value can be obtained from the income dataset, where Y is the baseline income data, d is the discount rate and t is the time period.

$$\text{EW} = \left(\frac{\text{Y}}{\text{Y}_{\text{avg}}}\right) \times \sum_{\text{t}=0}^{\text{T}} \frac{\text{EAWBL}}{(1+\text{d})^{\text{t}}} \text{ …….(4)}$$

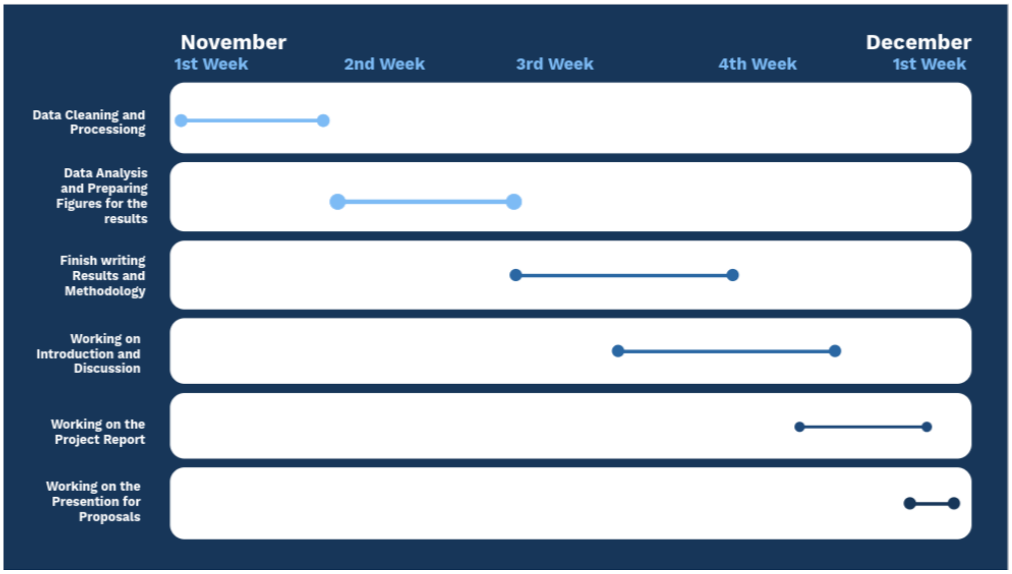
Then Social Welfare Flood Risk (SWFR) can be obtained from,

$$\text{SWFR} = \sum_{i=1}^{N} EAD + \sum_{i=1}^{N} EASWL + \sum_{i=1}^{N} VoSL \text{…………(5)}$$

By introducing this equity weight in the calculation of AALs, we can obtain an alternative measure, named by (Kind et al., 2017) Equity Weight Social Welfare Loss (EASWL). EASWLs are obtained as the product of AAL and the equity weight, and they represent the weight assigned to a dollar loss by the affected individual. We will take different variables for the each scenario and run a monte carlo simulation in python.

Scenarios		
Marginal Utility	1.2	1.4
Freeboard	1 foot	2 feet
Flood Depth	Coastal	Fluvial

1. Timeline



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