Impacts of welfare loss on flood risk assessments

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By:

Milan Rijsenbrij

Student Number – 2692992

Supervisor – Eric Koomen

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Abstract

Because of climate change the frequency of floodings in the future is set to increase. Therefore, it is crucial that our understanding on the impacts of floods is heightened to analyse the regions in need of protection. However, current flood risk assessments only utilize asset damages, causing unfair judgement towards poorer portions of the population. To resolve this bias, Jarl Kind and the World Bank implemented social welfare functions to improve current flood risk assessments. This paper will analyse the impacts of these social welfare functions on the assessed losses for a flood occurrence in Charleston, USA. Furthermore, household options for financial aids to reduce welfare losses are explored, attempting to improve the social welfare functions and assess the effect of those improvements on flood damage losses. Introducing the social welfare functions caused the total losses to decrease and transfer higher values from richer to poorer neighbourhoods. Relocating the regions most at risk of flooding from downtown Charleston to the outskirts. The household options to decrease welfare loss through finances were identified as: insurance and savings, crowdfunding and charity, remittance and social monthly aid and budgeting. After applying these improvements to the World Bank social welfare function a slight percentage decrease in welfare losses was observed for three of the improvements, only the insurance and savings improvement drastically decreased the welfare loss experienced. The shown impact on flood risk assessments by both the social welfare functions and improvements is significant. Greatly altering the results to identify losses based on welfare, countering the unfair bias present in expected annual damage assessments. However, attempts on identifying more improvements and integrating them into the social welfare functions are feasible. While furthering the research on the applicability of the social welfare functions is necessary for realistic application of the strategies.

Content

1 Introduction

1.1 Flood risk assessment

The frequency of flooding was the highest of all-natural disasters that occurred from 1998 to 2017, while also affecting the most people, with over 2 billion worldwide. (Mizutori & Guha-Sapir, 2017). Consequently, governments like the Netherlands and institutions such as the European Union legislate the requirement of up-to-date flood risk assessments to analyse and map critical flood areas (Rijksoverheid, 2009; European Union, n.d.). Providing an insight on expected future damages due to floodings in their regions and improving the decision-making capability of mitigation or adaptation strategies. Aiming to reduce the humanitarian and financial effects of future flood hazards.

1.1.2 Hazard, exposure and vulnerability in risk assessments

To perform a flood risk assessment four steps are required (Penning-Rowsell et al., 2005; Markandya et al., 2014): the assessment of (1) hazard, (2) exposure, (3) vulnerability and (4) risk. The hazard of flooding is measured based on the following characteristics: water depth, velocity of flow, debris floating and the area flooded for different return periods. The next step is to analyse what is exposed to the flooding, which is often carried out with the help of land-use maps that display buildings (residential, commercial and public), infrastructure, nature reserves, industries, agricultural zones and other objects prone to flood damage. Thirdly, the vulnerability assessment measures the probability of any exposure actually leading to damages. Differentiating between structure type, rigidity and material and their respective susceptibility to water damage. Finally, a risk assessment is created by overlaying the hazard, exposure and vulnerability maps onto each other. These four steps form the fundamental basics for every flood risk assessment, as shown in Fig. 1.

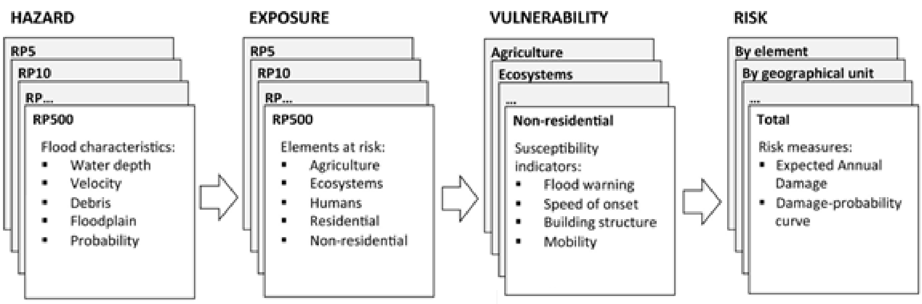


Figure 1 - Step diagram for flood risk assessment. See ref. (Erdlenbruch et al., 2008).

1.1.3 Expected Annual Damage function (EAD)

A great and widely used tool for risk assessment is the expected annual damage function, or in abbreviated form EAD (Oubennaceur et al., 2019; Tariq, 2013). EAD’s consist of the area under a damage-probability curve. This curve is plotted by allocating the damages caused by a flooding in respect to the probability of such a flood occurring (Foudi et al., 2015). The probability of occurrence for a flood is scientifically named the return period (Robson, A. J. and Reed, D. W., 1999). Flooding of a greater magnitude entails a longer return period and vice versa. Therefore, floods with longer return periods (lower probability), generate deeper and stronger flows of water. Subsequently the damage factor increases with larger inundation-depths for residential buildings, thus a non-linear trend in total flood damages is observed in Fig. 2 (Vanneuville et al., 2006). The area under the damage-probability curve represents the total damages expected to happen each year.

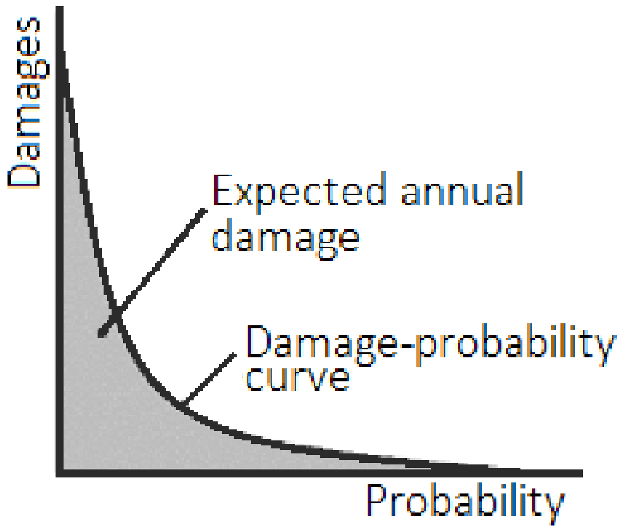


Figure 2 – EAD curve (Foudi et al., 2015).

1.2 Social welfare function

However, something EAD's do not take into account is the welfare differences between rich and poor people. It estimates the flood damages purely on total object value lost for infrastructure, industries, public, commercial and residential buildings. Consequently, a poor person losing all of its assets is valued to the same extent as a rich person losing some of its assets. Even though relatively, the poor person lost financially more to the flooding. This is due to the high monetary worth in the loss of 1$ dollar to a poor person compared to the loss of 1$ for a rich person (Walsh & Hallegatte, 2019). This distribution is illustrated in the downward concave trend of the curve displayed in Fig. 3, where each incremental increase of money devalues its utility for a single person (Vlaev et al., 2008).

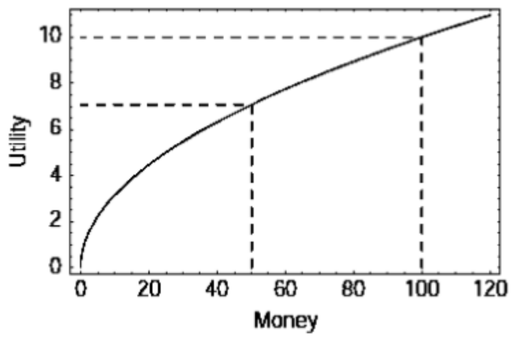


Figure 3 – The utility function of money (Vlaev et al., 2008)

1.2.1 Jarl Kind and World Bank method

To compensate for the unfair distribution caused by the dismissal of the relative value of assets, an annual expected damage function should include a difference in welfare variable. Eliminating a bias on high-value property and correcting to relative losses for future flood risk assessments. Two methods which adjust for welfare differences have been developed by Jarl Kind (Kind et al., 2017) and the World Bank (Walsh & Hallegatte, 2019). Both using income disparity between population groups as the criteria for relative wealth based on the utility function. However, the utility method assumes that all income is also consumption, meaning that every person spends everything they earn. Thus, when a flood causes damages to the assets of a person and repairs need to be financed, a cut in their income/consumption can be calculated. Then the difference between their normal income and the one affected by the flood repairs indicates their welfare loss. However, the techniques for calculating the effect of flood repairs on income/consumption levels for both methods are different.

The Jarl Kind method employs risk-premiums based on a social vulnerability factor, which in turn is based on respective income. In practice used by insurance companies as the risk premium comprises the pure risk of an asset by natural hazards into pricing (Leung, 2022). Therefore, the welfare loss is included as an adjusted expected annual damage function and treated it as a yearly amortize for housing (Van Hattum et al., 2021).

The World Bank method utilizes a recovery rate for households depending on their respective incomes. Low incomes have a lower recovery rate and therefore take longer to recover from a disaster (Verschuur et al., 2020). This increases their total consumption loss in comparison to richer people. The cumulative consumption loss over the recovery time is the welfare loss experienced.

1.3 Adjustments on the social welfare functions

The social welfare methods developed by the World Bank and Jarl Kind have been subjected to adjustments in multiple papers. Predominantly, in the subject of microeconomics (Kind et al., 2019; Hallegatte et al., 2016) and macroeconomics (Hallegatte & Przyluski, 2010; Markhvida et al., 2020), as they correlate well with the economic structure of these methods. In the subject of microeconomics, the effects on welfare through the socioeconomic possibilities a household or community possesses to adapt or mitigate a flood are explored. Whereas, the papers examining the effect on welfare through macroeconomics address adaptation strategies to avoid the changes in national gross domestic product, market security and labour/housing sector after a flood. Other attempts in improving the accuracy of the models through social variability such as education level, healthcare availability, access to good infrastructure and food security (Bangalore, 2015), required large region-specific databases and thus were very labour intensive. Therefore, this paper will look into the economic strategies employed to further improve the social welfare functions. Specifically, at the microeconomics since the macroeconomics do not provide solutions on household level, thus not providing differentiation on the scale of the assessment done in this rapport.

1.3.1 Improvements upon the current method

To improve upon the current methods, the variables with influence on the socioeconomic decisions of households need to be identified. Kind et al. (2019) only utilized household savings to decrease welfare loss. Whereas, Hallegate et al. (2016) explored the use of decreases in construction costs, asset vulnerability, vulnerability bias and exposure, while also potential increases in disaster-support, income diversification, savings and income shares. Covering a broad perspective on the effect of financial differences for welfare loss. However, this paper aims to understand the impacts of financial options available to offset the losses. Therefore, the suggestions of influenceable variables in this aspect from Walsh and Hallegatte (2019) will be explored, these are: insurances, savings, remittances, public support and budgeting.

1.4 Research questions

The research objectives of this paper are to analyse the changes that arrive by introducing the social welfare functions into traditional flood risk assessments. Utilizing both the Jarl Kind and World Bank methods for the comparison. While questioning the scientific underpinning of the recovery rate used in the World Bank method and suggesting upon improvements. Then analysing the effects on the outcome of the World Bank method results caused by the changes. These objectives are addressed in the following research questions:

1.4.1 Main research question

- How does the application of welfare loss functions affect the expected annual damage estimations for floodings?

1.4.2 Sub-research questions

1. What is the difference between losses expressed in a traditional annual expected damage approach and the losses expressed in an accounted-for welfare loss approach (Kind and the World Bank) for the Charleston case?

2. What are the main financial external factors that can influence the recovery rate to further enhance the world bank method the World Bank?

3. How much the application of improved recovery functions affects the welfare loss corrected annual damage estimations and socioeconomic resilience or the World Bank method?

2 Methodology

2.1 Research area

In order to perform a social welfare adjusted flood risk assessment for this case study, a suitable location is required. The location had to meet these three requirements: (1) Have frequent flooding to ensure enough availability for data gathering and be socially relevant to perform a flood risk assessment. (2) Be in a first world nation because the social welfare adjusted flood risk assessment had been performed mainly in third or second world countries before. Thus, not providing any information on its performance and relevancy in first world countries. (3) Contain a premade expected annual damage assessment to allow performing a social welfare adjusted flood risk assessment. By applying these conditions, the suitable location found was Charleston, South Carolina, USA.

2.2 Data acquisition and processing

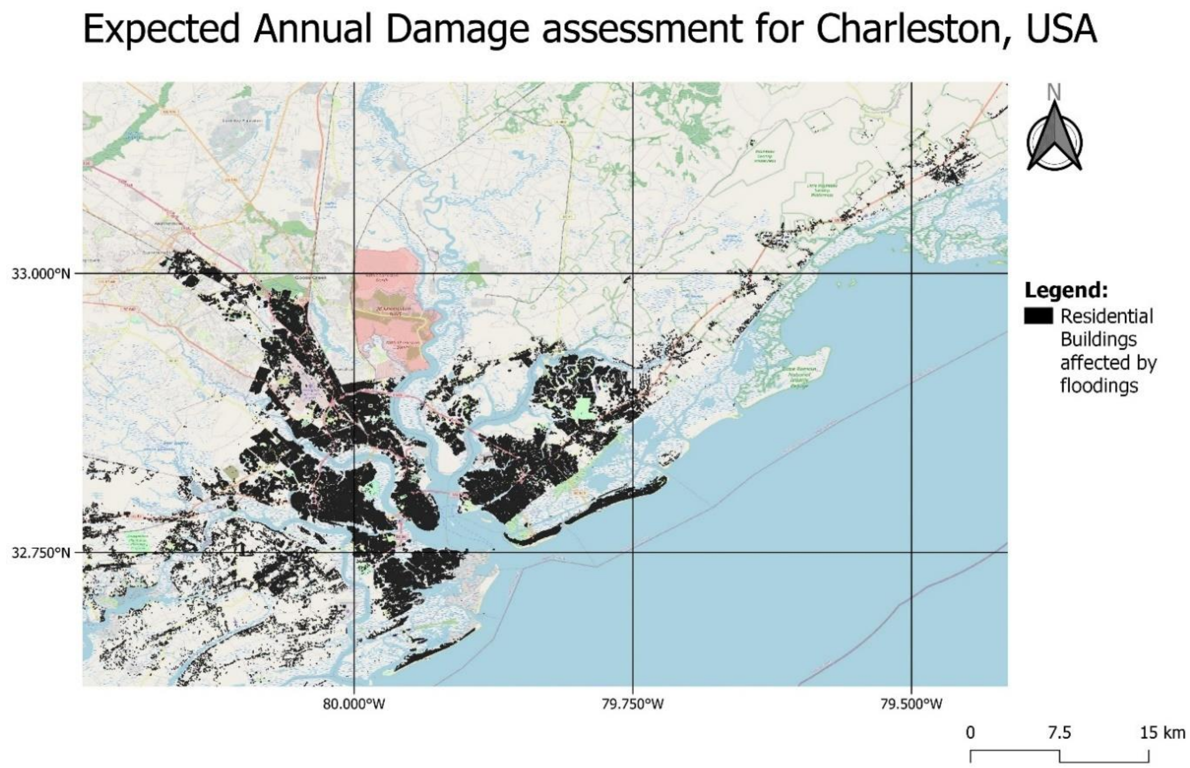


Figure 4.

To acquire the expected annual damage simulations for Charleston, the institute for applied research in the field of water Deltares, located in Delft was approached. Providing a dataset from the Delft-FIAT Flood Impact Assessment Tool containing the total structure and object damage for every building in Charleston and each return period (1 in 1,2,5,10,25,50,100 years). However, damages for all public, industrial and commercial buildings were removed as analysis using the social welfare functions only applies to civilian consumption loss. The dataset also included coordinates for every residential building, this file could therefore be read as a shapefile in QGIS, as seen in figure 4.

However, to calculate the social welfare adjusted flood risk assessment the gross domestic product per capita is required. This data was acquired through the Census Bureau and their American Community Survey (ACS), taken in the year 2021 (Census Reporter, n.d.). The GDP-per capita is on census tract level, an area size based on neighbourhoods of around 1000-8000 citizens. Thus, to consolidate both datasets the buildings containing the EAD information are overlapped with a map of the tract regions, shown in figure 5. Generating a map and database that contain the structure and object damage of a flood for all residential buildings per tract area.

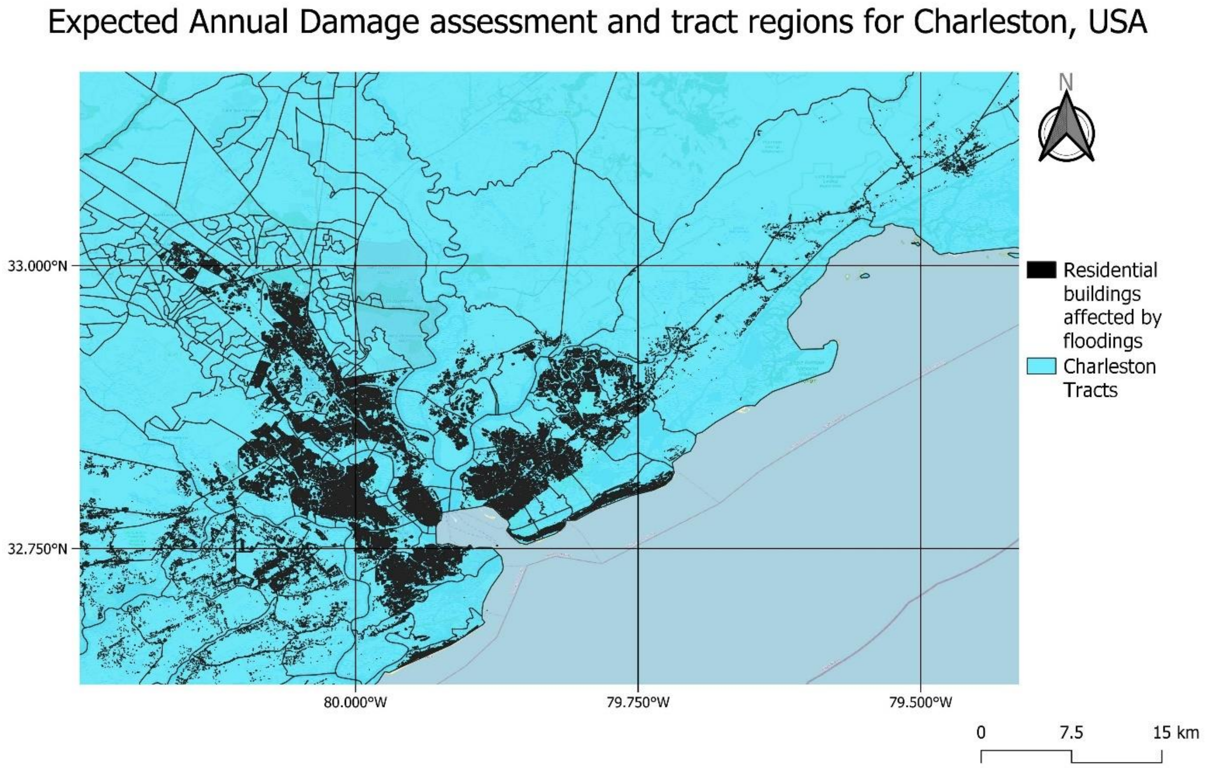


Figure 5.

2.3 Social Welfare calculations

2.3.1 Jarl Kind Method

The Jarl Kind method utilizes the utility consumption function (1) to calculate the welfare loss for every person. In which (γ) is the elasticity of marginal utility of consumption (C). The difference in expected consumption and expected utility based on a probability of a flood occurrence each year is called the risk-premium, illustrated in figure 6.

$$U(C) = \frac{C1-\gamma}{1-\gamma} \qquad (1)$$

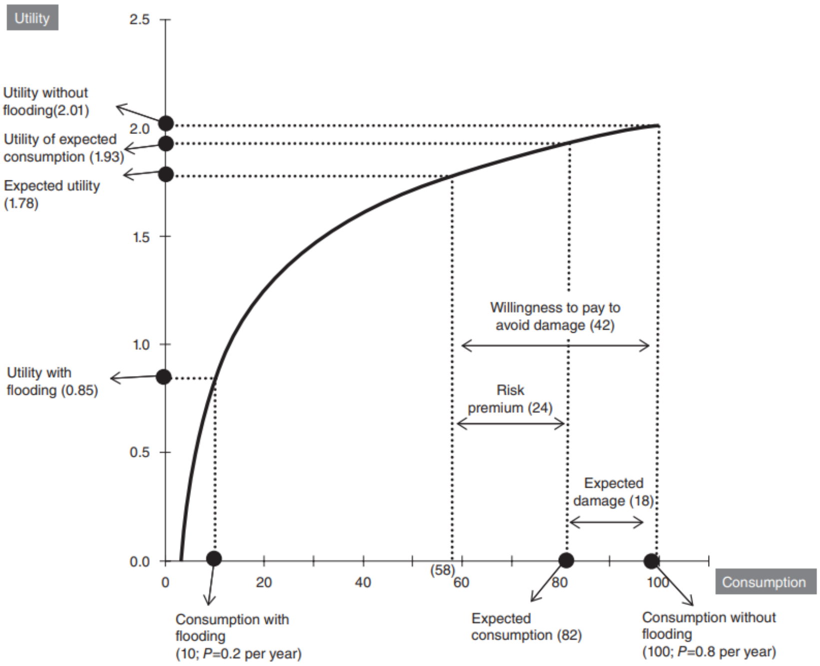


Figure 6 - Expected damage, risk premium and willingness-to-pay for eliminating flood losses (Kind et al., 2016)

To calculate the risk-premium for a certain probability of flood event the equation (2) is:

$$R_{WTP/ED} = \frac{1-(1+P\left\{(1-z)^{1-\gamma}-1\right\})^{1/(1-\gamma)}}{P*z} \qquad (2)$$

In which the (P) is the probability of a flood, (γ) elasticity and (z) is the social vulnerability which is the total flood damage divided by the total income. However, because this is only for one probability event. Thus, to include all the return periods, an integration of the risk-premiums is made.

The Certainty Equivalent Annual Damage (CEAD) can then be calculated by multiplying the EAD and the risk premium. This corrects for the relative income faults in the traditional expected annual damage function.

However, concerns over the equity in the flood risk assessment need to be addressed. Thus, the solution is to calculate equity weights based on income (3). The Equity Weighted Annual Expected Damage (EWAED) incorporates the equity weights by multiplying them with the EAD.

$$Equity\ Weights = \left(\frac{Income\ per\ cap}{Average\ income\ per\ cap}\right)^{-elasticity\ (\gamma)} \quad (3)$$

The third and last step is to calculate the Equity Weighted Certainty Equivalent Annual Damage (EWCEAD), which is done by multiplying the CEAD and equity weighting. This framework compensates for all the concerns about social vulnerability and equity weighting. It also resembles the welfare loss in this method.

2.3.2 World Bank Method

The world bank method uses a cumulative of consumption loss (C_l) to calculate the welfare loss caused by a flooding (4). Where asset damage (A_d) is the total building value lost to the flooding. Secondly, (AP_k) is the average product of capital for the USA. Thirdly, the recovery rate (R) value represents the natural logarithm divided by time till recovery in years. Lastly, the time (t) passed in months after the disaster divided by the 12 months in a year.

$$C_l(t) = A_d * (AP_k + R) * e^{(-t*R)} \quad (4)$$

However, this equation uses the average capital loss per capita. Thus, the EAD has to be divided by the population of the tract area to correlate correctly with the capital loss first. Furthermore, the (R) is dependent how much income per capita is earned. Those with more income can use a bigger sum of it to repair the damages because they can cut back on luxury goods. Whereas, those with less money are bound by the consumption of basic goods needed to survive, so spending more on repairs is not feasible. Therefore, the richer part of the population will recover in a shorter period then the poorer side.

Wellbeing loss at any single timestep is calculated using the following equation:

$$WL\ (t) = \frac{\left(e^{\frac{(-t*p)}{(1-\gamma)}}\right) - \left({I_{PP}}^{(1-\gamma)} - (I_{pp} - C_l)^{(1-\gamma)}\right)}{W_{prime}} \quad (5)$$

In which (t) is time in months divided by 12 months, (p) is discount, (γ) is the elasticity of marginal consumption utility, (I_{pp}) is Income per capita in US$ and (C_l) is the average capital loss for that timestep. W_{prime} is the average productivity of capital in the USA (AP_k) adjusted for income elasticity (6).

$$W_{prime} = AP_k{}^{(1-\gamma)} \qquad (6)$$

The welfare loss per timestep is then summated to get the total welfare loss for the allotted recovery period. This recovery period is based on the income per capita and the (R) value. For example, as household is rich and can recover in 3 years: the summated welfare loss stops at 12*3 = 36 months into the recovery period.

2.3.3 Percentile changes and socioeconomic resilience

To analyse what the impact of the social welfare methods is on a flood risk assessment, a look should be taken at the percentual changes for every tract. To do this I took the welfare loss results from each of the social welfare methods and calculated the percentile changes by using (7):

$$\Delta\% = \left(\frac{Welfare\ loss}{Asset\ loss} - 1\right) * 100 \qquad (7)$$

Then import all the percentile changes onto a map with all tracts to display regional differences in hue.

Another aspect to compare both social welfare functions is how well the population of the tract is able to cope with a flood. This is called the socioeconomic resilience: this term was coined by Hubacek et al. (2016) to show the difference between actual asset and welfare losses and is calculated in the following way (8):

$$Socioeconomic\ resilience = \frac{Asset\ losses}{Welfare\ losses} \qquad (8)$$

If the socioeconomic resilience is under 1, the welfare losses are bigger than the asset losses. When the socioeconomic resilience is 1, they are the same and when its bigger then one the welfare losses are smaller than the asset losses.

2.4 Recovery rate

The World Bank method explores the impact of flooding on consumption loss through a recovery rate. Thus, the welfare loss results are partially dependent on the rate and time until recovery is complete. However, in the current method, only a couple of influence factors have been included to calculate the recovery rate. Indicating that the scientific underpinning for a realistic recovery rate might be lacking.

The consumption loss (C_l) in the World Bank method is made up of 4 influential factors (Verschuur et al., 2020), as displayed in the equation (4).

$$C_l(t) = A_d * (AP_k + R) * e^{(-t*R)} \tag{4}$$

However, three out of the four variables are constants (AP_k and t, while A_d is constant for each building), only varying in value between different events and countries (Markandya et al., 2014). Therefore, on the scale in which most of the flood risk assessments are carried out, change in these factors will not influence the results. Whereas, differences in recovery between different neighbourhoods is common, due to varying socioeconomic and social status they possess (Zein, M., 2010). Thus, improvement on the realism of the recovery rate through analysing variables of influence on a smaller scale is possible. Especially the inclusion of influenceable socioeconomic variables: savings, insurances, remittance, public support and budgeting which had been analysed by Walsh and Hallegatte (2019.

2.4.1 Identifying and integrating the improvements

In this case study, savings and insurance serve the same purpose because both these forms of financial support are a designated sum of money (Delavallade et al., 2015). The size of which is dependent on incremental payments made before the flooding. For this reason, they are combined into savings and insurance. Furthermore, remittance is the non-commercial transfer of money from a family member abroad earning higher wages. However, since the USA experiences some of the highest earning wages, transfers from other countries will be of minimal help and thus not occur. On the other hand, the USA encompasses many states of significant sizes, therefore a flooding is very unlikely to befall the entire country. Thus, aid for income loss can come from family members in other regions. Furthermore, financial aid from other states also remains possible. Therefore, the category is renamed to remittance and monthly aid. Lastly, public support will be considered as charity or relieve aid. A financial aid in the form of a sum of money at a later stage in the recovery period. The reason is because gathering and distributing funds is a time-consuming process. To better reflect the financial procedure for this improvement, it is renamed to crowdfunding and charity.

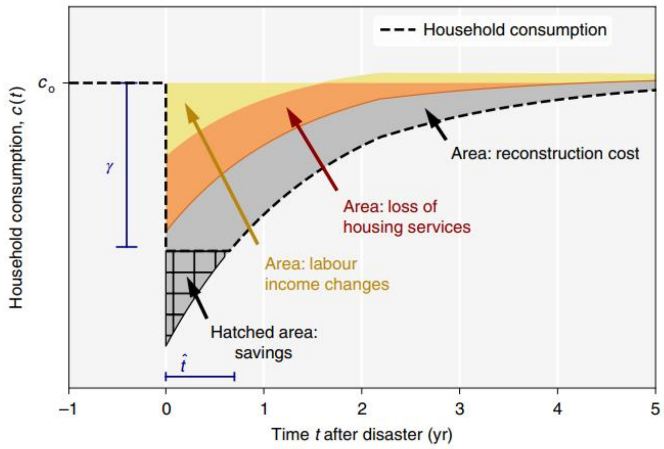


Figure 7 - Consumption curve before, during and after a flood (Markhvida et al., 2020)

Identifying the impact of these new recovery variables will be done through graph economics. Employing the same techniques used to explain the influence of savings for mitigation of consumption loss by Markhvida et al. (2020) shown in Fig. 7. Which separates the loss of consumption into (1) reconstruction costs for the house (2) loss of housing services (Utilities such as water, electricity and heating requiring stay or usage elsewhere) and (3) labour income changes (loss in workspace or work hours). Noticeable is the use of consumption offset (the hatched area) caused by savings instead of decreasing the loss in the consumption curve. The reason is that repairing buildings and infrastructure is never instantaneous. Thus, even if repair expenses are paid upfront the loss in consumption remains spread out over the full repair duration. Utilizing this logic, the unrepresented socioeconomic variables of: savings and insurance, remittances and monthly aid, crowdfunding and charity and budgeting are applied to consumption loss curve displayed in figure 7.

3 Results

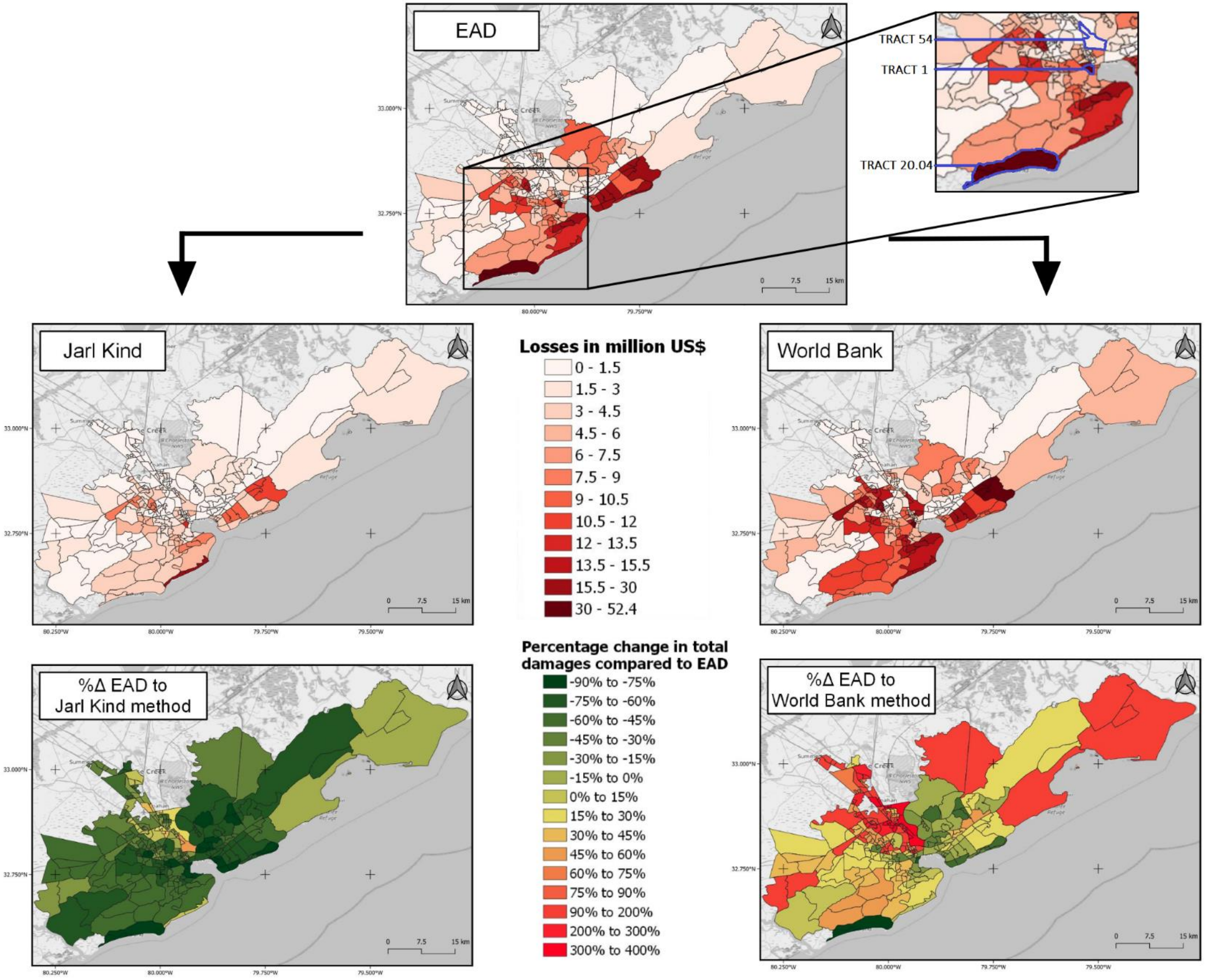


Figure 8 – Total welfare losses of the EAD, Jarl Kind and World Bank method, including the percentage change from EAD to the Jarl Kind and World Bank methods.

3.1 Social welfare calculations

Figure 8 illustrates the risk assessment in Charleston for the EAD, Jarl Kind and World Bank methods. Displaying the total losses in a million US$ for every tract region, with red areas suffering heavier losses. To understand the impact of the social welfare functions, an understanding of the expected annual damages in the case study region has to be established. Making use of interest regions, tract 1, 21.04 and 54 and their respective economic and social statistics (Census Reporter, n.d.).

The total damages for the expected annual damage calculation range from 0 to 52,4 million US$. Of note is the dark red region of tract 21.04 in the south-west of the map, sustaining a total of 42,7 million US$. A causality of close proximity to the ocean and high median value of owner-occupied housing units of around $1,442,000. A similar trend can be observed for tract 1 in downtown Charleston, suffering 52,4 million US$ in damages. However, the median value of owner-occupied housing units at $1,046,100 is lower. This discrepancy is due to a higher density of housing and greater number of waterbodies surrounding the region. Poorer regions on the outskirts of Charleston sustain significantly less damage, such as tract 54 which losses around 3 million US$. The low damages are in correlation with low median value of owner-occupied housing of $219,500 experienced in the region. Further trends are the high damages along the coastline and into the Charleston Bay while land inwards the damages lessen drastically.

The Jarl Kind method produced a much lower damage total, ranging from 0 to 16 million US$. Indicating that the welfare functions had a significant impact on the results. Furthermore, the tract area with the highest damages has relocated closer towards the entrance off the bay. This tract region consists of an estuary with swampy underground and a few liveable peninsulas, which have been fully developed with fancy beach houses for mostly retired people. Therefore, the average income is only $56,736 which heavily affects the social welfare function. Tract 1's total damages significantly decreased with 76% to a total of 12,4 million US$, due to a high income of $90,578 per person. Tract 21.04 had a comparable decrease of 90%, bringing the total welfare losses to only 4,25 million US$. Comparing this to the increase of 54% to a total of 4,42 million US$ in losses experienced in tract region 54, the importance for future protection between tract 21.04 and 54 has flipped. This invert of losses is nicely illustrated in the percentage change map for the Jarl kind method. Furthermore, it can be observed that almost all tracts decrease their total losses, except the tracts with very low income. Signifying the importance of income level for this method.

The World Bank method also significantly altered the expected annual damage results. The overall welfare loss has decreased in range from 0 – 32.9 million US$. Another noticeable difference between the EAD is the shift in losses from the coastal regions to the regions further land inwards. This effect is very visible in the percentage change map for the World Bank. Aswell as in the total losses change for tract 21.04 decreased by 77% to a total of 9,9 million US$ compared to the further inland tract 1 which only decreased by 37% to a total of 32,9 million US$. Furthermore, income played a big role in the change for overall losses. As seen in the massive increase of 399% for tract 54, now reaching a total welfare loss of 14,4 million US$. This heavy discrepancy in losses is due to the low recovery rate experienced by lower income regions who require much more time to get back to their normal consumption rate, compared to their richer counterparts. Therefore, lower income regions who are barely affected by the flood in the expected annual damage calculations now also experience much higher losses. Thus, influence of income on the calculated losses for the World Bank method is significant, not only for high but also low incomes.

In comparison the Jarl Kind method decreases the losses in almost every tract region in great contrast to the World Bank method which increases the losses. Furthermore, the World Bank method has a much more dramatic increase of up to 300% in comparison to the Jarl Kind method that only increases with up to 40%. This difference can be explained by the singular risk premium calculation in the Jarl Kind method compared to the continuous consumption loss calculation in the World Bank method.

3.2 new recovery function

After a flood occurrence, the normal consumption takes a dive caused by the necessity to pay for damage repairs, for use of exterior housing services and loss of income (Markandya et al., 2014). Over time the consumption climbs back to its old level because of decreasing expenses on reconstruction, services and return of income. Thus, the consumption curve comes about as plotted in Figure 9.

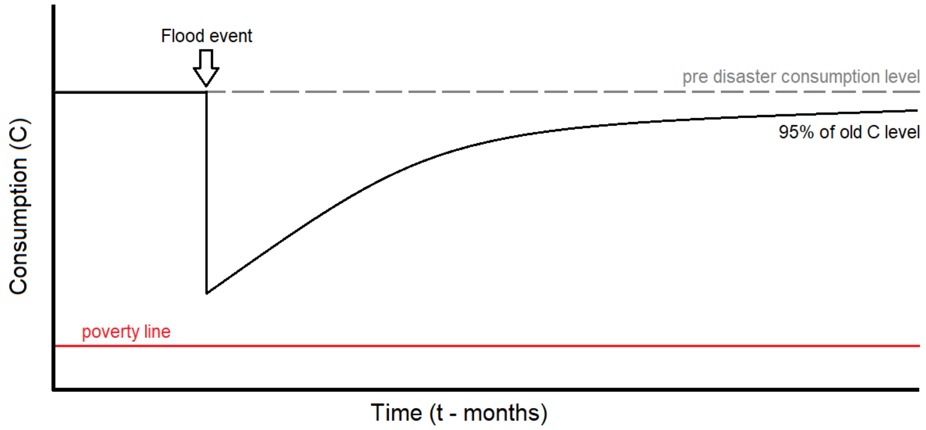


Figure 9 – Consumption loss curve after a flood disaster.

3.2.1 Savings and insurance

Savings and insurance can offset the consumption loss experienced right after a flood disaster. The rate in which it can offset the loss is dependent on how much money was saved or is given by the insurance company. However, once it runs out the consumption loss will follow the original curve (Fig. 10.).

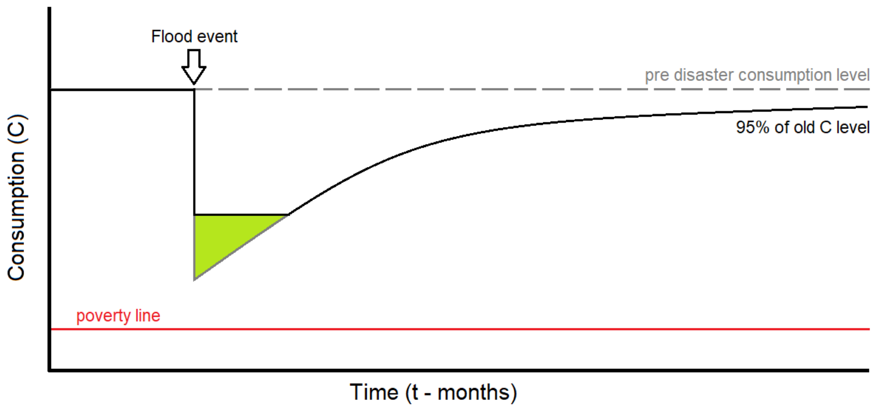


Figure 10 – Saving and insurance adjusted consumption loss curve after a flood event.

The quantity of saved money can be estimated by using a percentile of income. The federal reserve estimates the following percentiles of savings from each income class (table 1):

Income thousand US$	<20	20-39.9	40-59.9	60-79.9	80-89.9	90-100+
Savings as a % of income	8.4	11.26	16.39	28.68	51.84	229.3

Table 1 – Savings as a percent of income (The Fed - Table: Survey of Consumer Finances, 1989 - 2019, n.d.)

However, because the consumption loss is not primarily due to repairs (Markhvida et al., 2020), an assumption is made that only 50% of it can be offset by the savings.

3.2.2 Crowdfunding and charity

Crowdfunding and charity will offset the consumption loss similarly to the savings and insurance. However, because receiving the financial aid is delayed the offset will happen in a later timeframe. Giving poorer households that experience a slower recovery rate an advantage, as richer households have already paid off their damages. The financial aid does not increase the speed of the recovery rate (Fig. 11.).

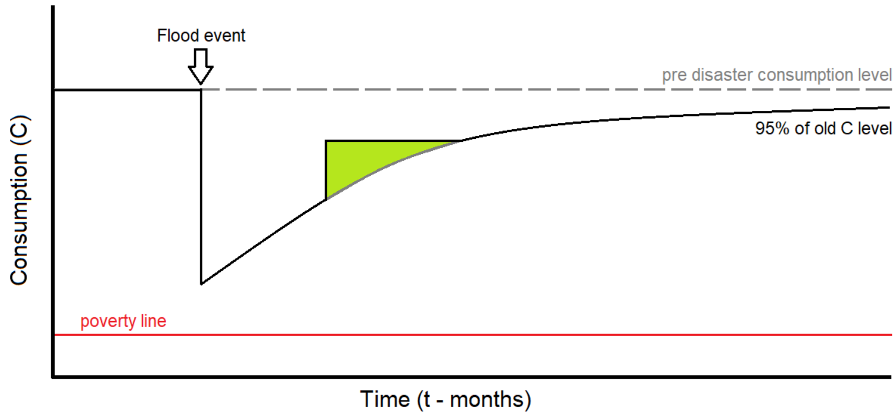


Figure 11 – Crowdfunding and charity aid adjusted consumption loss curve.

The quantity of financial aid is fully dependent on the amount donated by social support. However, for this case an assumption is made that 20% of the average gross domestic product per capita is donated to each person.

3.2.3 Remittance and social monthly aid

The remittance and social monthly aid will offset the consumption loss experienced with a percentage of the damages each month. This is because the supplementary monthly aid after the disaster will increase the base consumption and when repairs are made the financial aid will slowly decrease until the old consumption level is reached (Fig. 12.)

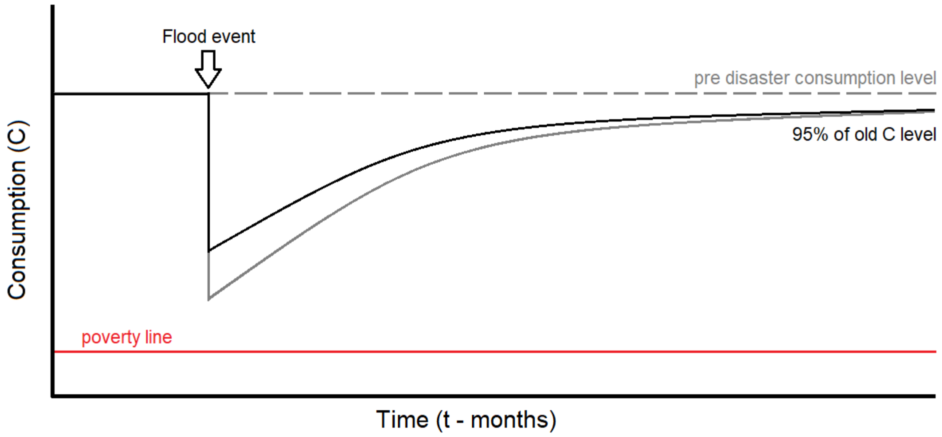


Figure 12 – Remittance and social monthly aid adjusted consumption loss curve.

To calculate the effects of this an assumption is made that every person receives the 10% of their consumption loss from the government, family or friend.

3.2.4 Budgeting

Budgeting is cutting off the consumption of luxury goods to invest in more rapid repairs. Therefore, the initial consumption loss after the event will be higher than normal, but the recovery rate will also increase (Fig. 13.). However, this is only a viable option if a resident is already consuming luxury good before the disaster and not only basic goods. Otherwise, the consumption level falls below the poverty line after budgeting causing the recovery rate to halt completely.

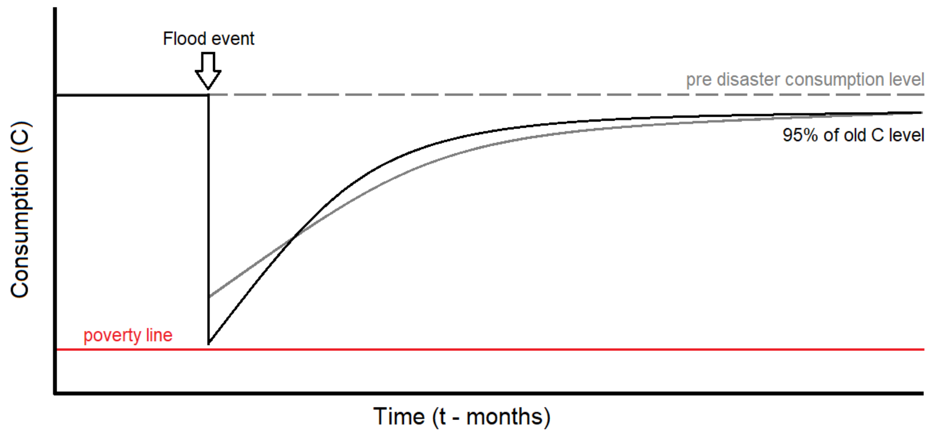


Figure 13 – Budgeting adjusted consumption loss curve.

To calculate the effects of budgeting the R value in the equation will be increased for anyone living above 35.000 US$ a year. Thus, decreasing the time taken to complete the repairs and increasing the consumption loss at the beginning.

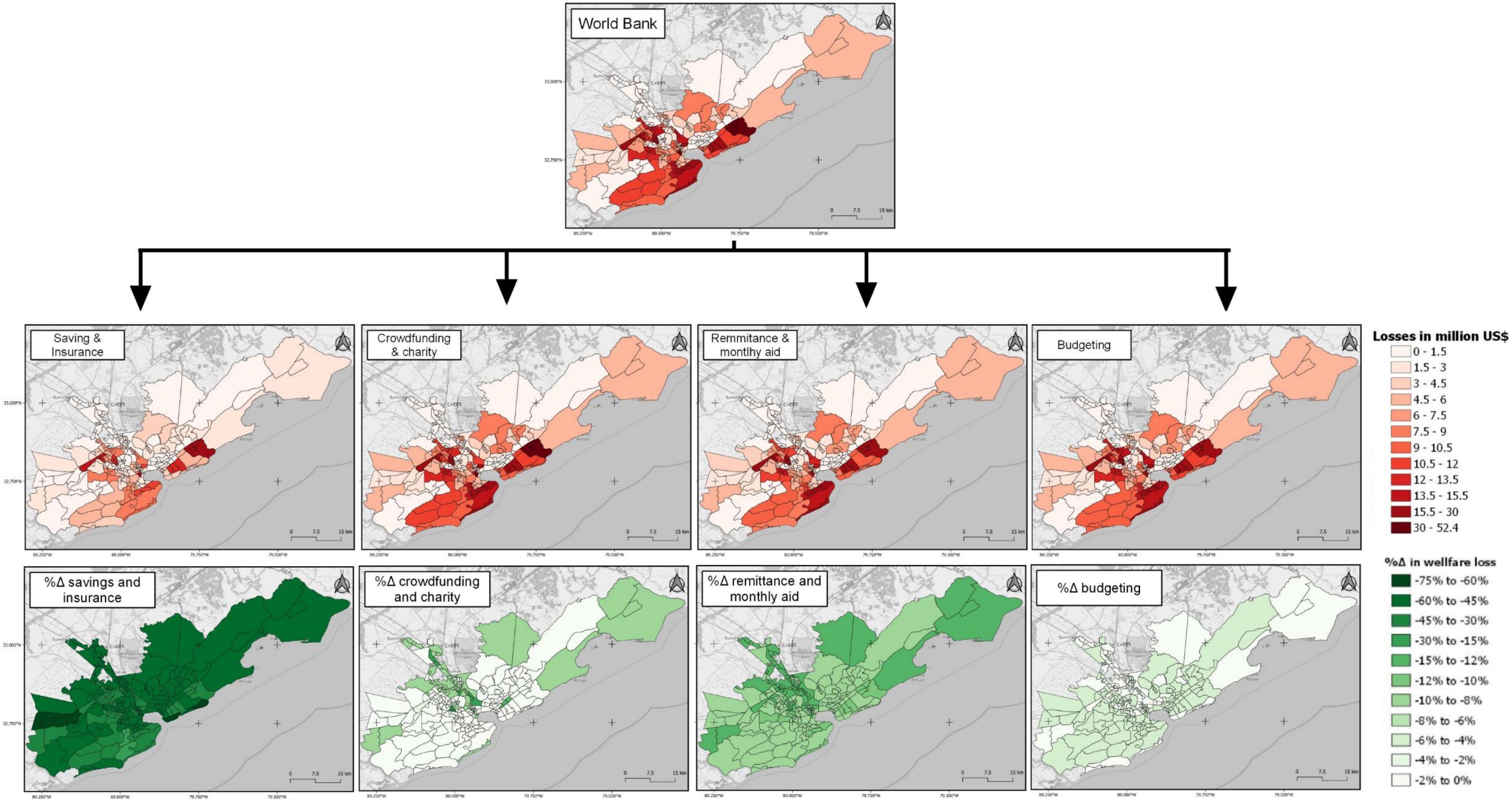


Figure 14 – Total welfare losses after recovery rate improvements (Saving & Insurance, Crowdfunding & Charity, Remittance & Monthly aid and Budgeting) for the World Bank method and the percentage change from the World Bank method.

3.3 Results of new recovery functions

The new recovery functions are all adjustments to the World Bank method. Thus, comparisons are relative to the calculated welfare loss in the World Bank method. For the comparison the welfare losses for each tract were: tract 1 sustained 32,9 million US$ in losses, tract 21.04 lost 9,9 million US$ and tract 54 lost a total of 14,3 million US$. Shown in figure 14.

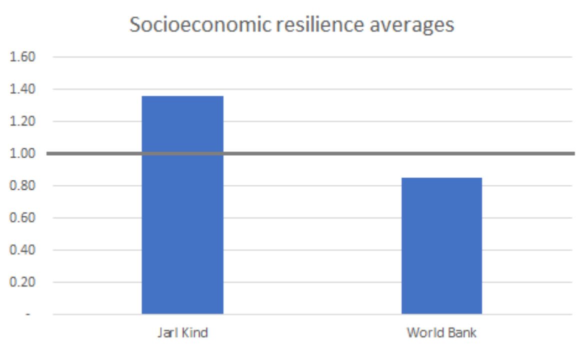
The total welfare loss after the implementation of savings and insurance use is drastically lower, a decrease from a maximum of 32 to 19 million US$. However, it should be noted that the decrease in total damages is nearly identical amongst the tract regions. This homogeny might be the effect of the assumption that only 50% of the consumption loss is repairs, consequently the savings can only offset a fraction of the applicable consumption loss. This offset is clearly visible in tract regions with higher incomes such as tract 1 and 21.04 which decreased by 50% and 56% respectively. Whereas, tract 54 only managed to reduce 38% of the consumption loss. However, this would apply that almost everyone had the necessary savings to accommodate that 50%. Not an unlikely scenario as the United States is a wealthy country.

After the crowdfunding implementations the welfare loss totals for most tract regions experienced a very slight decrease. However, by studying the percentage change compared to the normal welfare loss map, the regions that did experience remarkable decreases are predominantly poorer. In tract 54, which only experiences an income of $16,742 a year, the welfare losses decreased by 21%. In comparison crowdfunding and charity for the richer tract 1 only decreased the welfare losses by 6%, while tract 21.04 experienced no change in welfare loss at all. Thus, deducing that charities and crowdfunding actions are significant relieve aids to the poorer fraction of the population.

The implementation of remittance and social monthly aid slightly impacted the total welfare losses. The maximum losses only decreased from 32 to 29 million US$. However, the distribution in welfare change is more evenly spread compared to the other implementations. As seen by the percentage change for tract 1, 21.04 and 54 which are 9%, 8% and 12% respectively. This is due to the remittance and/or monthly aid being based on a percentage of the repair costs. Therefore, the only difference in percentage change come from the time until full recovery is achieved. Thus, benefitting poorer regions which take longer to recover.

The implementation of budgeting causes a divide in the percentage change of welfare loss. This divide is characterized by the ability to participate in budgeting, this is dependent on the consumption pattern before the flood event. Tracts 1, 21.04 and 54 all experience no change because they belong to the higher and lower income groups. For the lower income groups participation is impossible due to the consumption dropping below the poverty line. On the other hand, the higher income group already operates on the optimum recovery rate. This is due to recovery rate increasing above 1 and overvaluing the asset damage, thus paying more than its worth to fix the damages. Therefore, the change in welfare loss by budgeting can only be experienced by the middle-income class, as they are not at risk of falling into poverty or overvaluing their assets.

3.4 Socioeconomic resilience



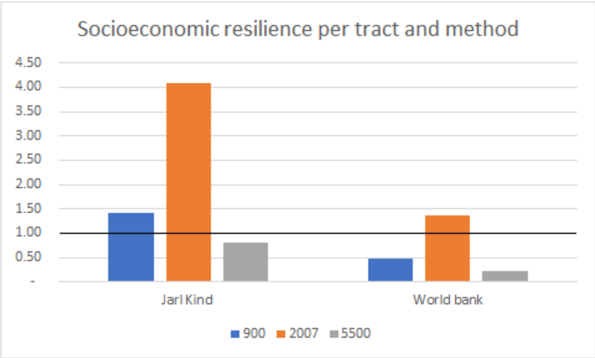


Figure 15.

Figure 16.

Looking at the socioeconomic resilience averages in figure 15, with an 1,38 the Jarl Kind method suggests that the population of Charleston, USA is very capable of dealing with the flood as the overall welfare losses are smaller than the asset losses. Whereas, the World Bank method displays an average of 0,86, indicating that the population is barely unable to cope with the flooding, suffering greater welfare losses then asset losses.

However, by comparing the socioeconomic resilience on tract level, a huge discrepancy between the rich and poor regions can be observed. Indicating that socioeconomic resilience is heavily influenced by income levels. Furthermore, the Jarl Kind method evaluates the socioeconomic resilience of tracts higher than the World Bank method, as seen in figure 16. Often lowering the socioeconomic resilience of individual tracts to below the line, or 1. Thus, suggesting that they suffer higher welfare losses than actual asset losses.

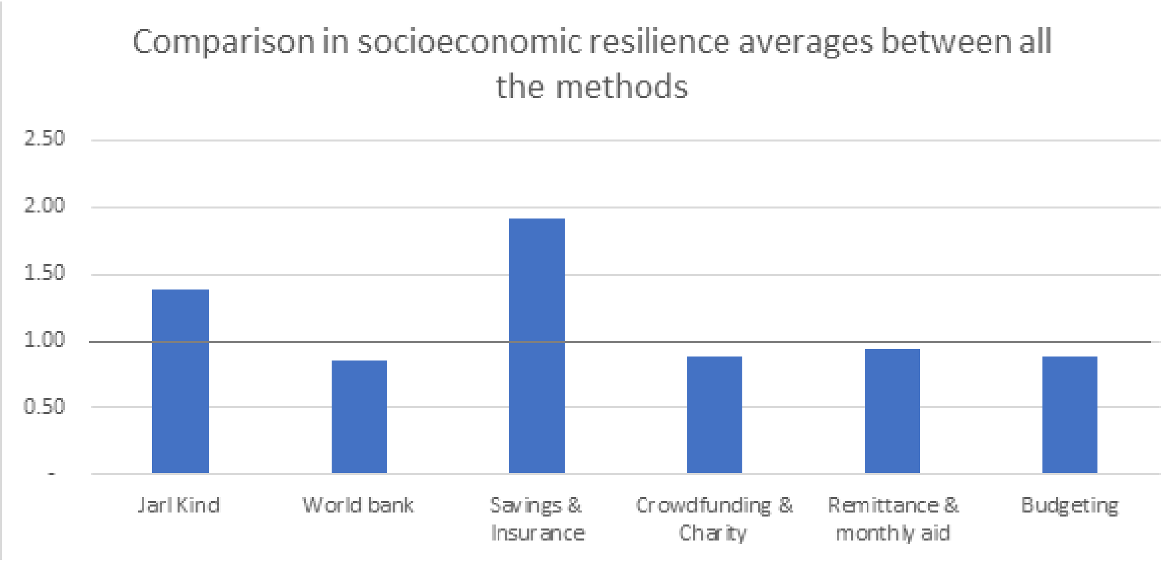


Figure 17.

After the implementation of the recovery rate improvements the socioeconomic resilience compared to the World Bank method increased, as shown in figure 17. Especially, for the savings and insurance improvement which now has an average socioeconomic resilience score of 1,92. Therefore, suggesting that the population of Charleston is more capable of dealing with the flooding compared to the Jarl Kind method. However, the crowdfunding and charity improvement did not affect the socioeconomic resilience to such extend. Only slightly increasing the total socioeconomic resilience of the population overall. But a significant change in socioeconomic resilience for poorer tract regions was observed. Budgeting provided similar results, however the increase in socioeconomic resilience was present for tracts with medium incomes. Lastly, the remittance and monthly aid improvement increased the socioeconomic resilience nearly enough to cope with the flood damages without losing more welfare than the damages in assets. Owing to the fact that all the tract regions had help recovering a percentage of their total asset losses. Thus, of all the improvements the savings and insurance largest impact on the socioeconomic resilience. This difference was partially caused by the availability of large sums of savings to cover the flood damages.

4 Discussion

4.1 How does it compare to similar studies?

The results gathered in this study are specific to the Charleston area for assumed floodings of return periods of one in every 1,2,5,10,25,50 and 100 years. However, by comparing it to other case studies an attempt can be made to understanding trends in welfare losses change caused by the World Bank and Jarl Kind methods.

The social welfare losses in the Ho Chi Minh Case study by Kind et al. (2019) for the no financial support scenario, shows a huge amount of people falling below the poverty line for a flood of 1 in 100 return period. Therefore, losing all the possibilities of maintaining their old ways of living. In comparison, when Charleston is hit by a 1 in 100 flood only one tract region suffered enough damage to fall below the poverty line. Emphasizing the difference in sustained welfare damages between first and second world countries, something the choice of a first world region such as Charleston, USA hoped to identify. However, the presence of catastrophic regions even in first world countries displays the necessity of these methods to identify and protect them.

The improvements for the World Bank method in this paper show that such measures do indeed have impact on the welfare losses. Similarly, a research paper by Hallegatte et al. (2016) shows decreases in the welfare loss because of policy changes. However, the range in changes between the improvements in this paper and theirs differ drastically. For example, savings only decreased the welfare losses by 0,3% whereas, in this case study it decreased by around 50%. This difference could be explained by location, the case in Hallegatte et al. (2016) paper took data from Mumbai, India in 2005. At that time India was still classified as a third world nation, whereas the case for Charleston is in a first world nation were saving wealth is much more accomplishable. Interestingly, cutting the duration of reconstruction decreased their welfare losses by 3,6%. Similarly, budgeting also decreases the construction time which also led to around a 5% decrease in welfare losses for the Charleston case. Thus, implying that no matter the economic status of the region, welfare loss can be reduced. Lastly, the post disaster relief (monthly aid) showed a similar decrease of around 9% in both case studies. Assuming that the relief amount is relative to the asset damages, the decrease in welfare loss replicable for multiple scenarios. Therefore, these improvements are useful to realize more realistic welfare loss calculations, independent of the location and only income.

4.2 Societal impact

The social welfare functions used by the World Bank and Jarl Kind greatly influence flood risk assessment results. Differentiating the asset losses from the welfare losses provides new insight on where protection against flooding is necessary. However, it can be argued that such results are misleading for where actual damages take place. Primarily, because this method only focuses on residential buildings and objects. Therefore, suggesting that these are the only buildings that might impact the populations welfare losses. However, infrastructure, commercial and industrial buildings are also allegeable to affect the welfare losses of a person. For example, the road is destroyed thus their route to work is gone or extended, costing them more to arrive there. Moreover, this scenario assumes that their workplace was not destroyed, seizing the availability to even work at all. Therefore, the realism and utility for societal impact of the social welfare functions in their current state is to be questioned.

4.3 Research suggestions

Since the social welfare functions do not include commercial, industrial and infrastructural components, the population of an area might experience more welfare losses than calculated. Therefore, further research to include these components in the welfare functions can increase the realism of the findings and consequently improve future decision-making drastically. Furthermore, the financial aid improvements discussed in this paper influenced the welfare losses per person drastically. Thus, to incorporate them in the social welfare function more research is required to estimate the availability for population groups to utilize these strategies. This includes understanding to what extent they are able to use these strategies, depending on region and circumstance. While also identifying relations between each of the improvements and analysing the use of multiple financial aids simultaneously. Lastly, researching to identify and incorporate more welfare loss reduction strategies can greatly improve the social welfare functions. However, to combine them will be a very labour, economical and computational intensive.

5 Conclusion

As the frequency of flooding is set to increase because of the climate changing, proper analysis for mitigation and adaption to flooding becomes much more crucial. Thus, continuously validating and assessing the current flood risk assessments techniques is of utmost importance. Such an assessment was done by Jarl Kind and the World Bank on the use of the expected annual damage method to analyse losses in a region. They concluded that social variables should be implemented to improve the results of the method. Consequently, providing a new method which utilizes income and consumption losses triggered by flood events. However, to continuously validate and asses flood risk assessments to improve our understanding and decision making based on the results. One should also analyse the effects of these new methods and strive for improvement. Therefore, how does the application of welfare loss functions affect the expected annual damage estimations for floodings?

By utilizing the FIAT-Delft flood risk assessment tool and simulating a flood for the region of Charleston, USA. Results from a topical expected annual damage function could be used to analyse the effects of the welfare functions. The Jarl Kind method significantly reduced the losses experienced compared to the EAD. Whereas, the welfare loss for the World Bank method generally increased from the EAD. However, both methods shifted the large losses from high income to low-income areas accordingly. Appropriately illustrating that high value asset losses can be compensated by high income and vice versa.

The World Bank method utilizes a recovery period to simulate welfare losses in the form of consumption losses after a flood over time. However, the approach to calculate the consumption losses lacks scientific underpinning for multiple approaches. Thus, using the theory of a consumption loss curve, multiple new approaches with influence over the recovery rate have been devised. Based on the possibilities to limit the damages through financial actions for households, the new approaches are: (1) using saved or insured money, (2) receiving charity or crowdfund aid, (3) obtaining remittance from family, friends or aid from the government and (4) cutting of the consumption of luxury goods; budgeting.

These new approaches were applied to the World Bank method to obtain new results. Using saved or insured money to offset your damages in the first few years drastically decreased the welfare losses experienced for all regions. This is partly due to the high number of residents possessing sufficient savings to do so. Approximately, receiving charity or crowdfund aid did not decrease the welfare losses considerably. However, it did affect the poorer fraction of the population a great deal more than the richer population because of the time delay and recover time. Obtaining remittance or financial aid from the government, friends or family slightly decreases welfare losses compared to the normal World Bank method results. Nevertheless, it does provide the most equal spread of decrease in losses of all approached. On the other hand, budgeting created a stark divide in welfare loss change between high/medium income and low-income regions.

Including a social welfare function greatly influences the outcomes of flood risk assessments. Jarl Kind and the World Bank demonstrated this change perfectly using just income as a variable. Bestowing a finer understanding of the regions that are actually the most affected by a flooding and allowing future decision-making to improve. However, more social vulnerability variables are assessable. Such as the four mentioned and explored in this paper, which had considerable effects on the outcome of the social welfare functions. Thus, research in the future should focus on identifying and assessing new variables to improve the accuracy and reality of our flood risk assessments.

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