Communicating Sea Level Rise Risk with a Coastal Vulnerability Index

Global climate change stressors downscale to specific local vulnerabilities, thus requiring unique local adaptation strategies. In southeast Florida, sea level rise (SLR) is of specific concern, both as a present and as an impending threat. Coastal populations are vulnerable due to erosion, inundation and increased storm surge. Interior populations are also susceptible to rising water tables and flooding amplified by SLR (i.e. groundwater inundation).

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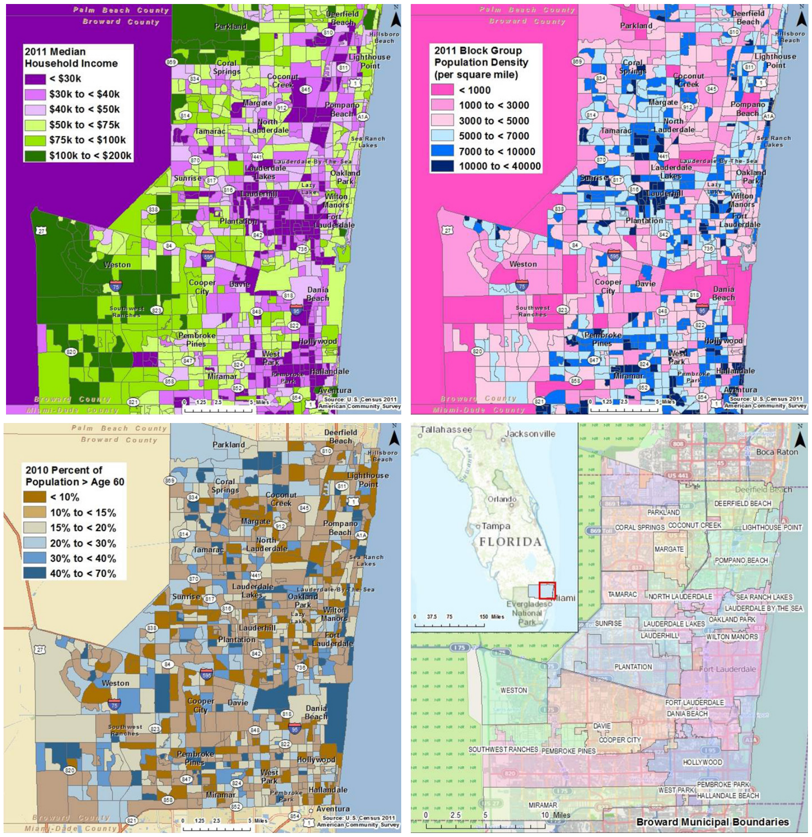
This study is designed to measure actual risk of SLR in terms of physical risk (likelihood) and social risk (community impact). It examines socioeconomic patterns at low elevations in Broward County, Florida to distinguish vulnerable communities that lack the ability to respond to SLR. Using GIS, highly accurate Light Detection and Ranging (LIDAR) elevation data was overlaid with block census data to pinpoint clusters with low-lying vulnerable populations. A coastal vulnerability index (CVI) was generated based on likelihood of inundation as well as socioeconomic impacts. This technique is based on the objective and traditional method used to quantify risk: to multiply probability by consequence.

STUDY AREA

Before human settlement, Southeast Florida was dominated by low-lying wetlands. Initially, settlers were confined to living on the elevated Atlantic Coastal Ridge. In the early to mid-1900's, extensive dredging and draining began to allow agricultural and urban development to expand into previously uninhabitable areas.[1] Land elevations in Broward County range from below mean sea level (mainly wetlands) to 29 feet above mean sea level (Figure 1). The northern portion of Broward has the highest elevations, which descend moving south and southeast. Keqi Zhang estimated that between 1.5 and 3 m (4.9 to 9.8 ft) of SLR, 79% of Broward County's land area is vulnerable to potential inundation.[2]

According to the 2010 census, Broward County has a population of 1.75 million. While it is the second most populous county in the state, the growth rate has been declining and is lower than the state average. The population growth rate was reduced by a third from the 1990-2000 period to the 2000-2000 period. The median household income (MHI) is \$52k, but clusters of block groups have a MHI below \$30 and 13% of the population lives



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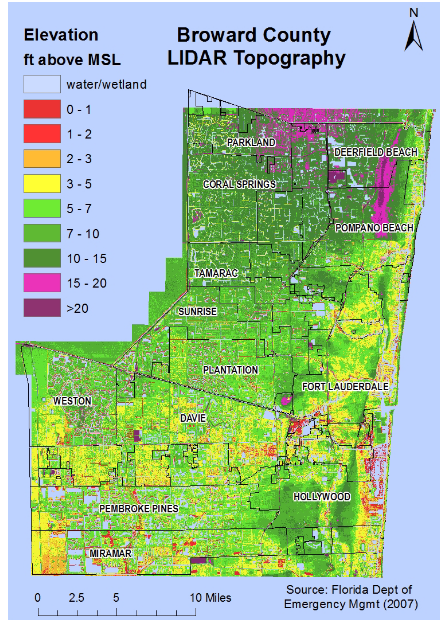

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below the poverty level. The median age is 40, but there are scattered block groups with over half of the population over 60 (Figure 2). The population is 44% White (non-Hispanic), 27% Black (non-Hispanic), and 25% Hispanic.[3]

SLR RISKS AND THEIR ASSOCIATED MISCONCEPTIONS

SLR focus groups conducted in Miami-Dade and Broward Counties acknowledged the vulnerability, but did not feel that action was required. The participants expressed more concern about increased taxes and insurance rates than the threat of SLR.[4] Focus groups from inland zip codes also voiced feelings of safety due to the misconception of SLR impacts being limited to the coast. The mechanism by which SLR can exacerbate inland flooding is a water table rise that reduces the soil's storage capacity. These complex linkages are not necessarily understood in South Florida, even by experts. One study examines the relationship of rising seas with rising coastal water tables in Honolulu to find that the land loss doubles when inland groundwater pooling is accounted for.[5]

SLR is permanent, yet it is also predictable. It is difficult to grasp the longer timescale associated with SLR when temporary flooding is short-term and erratic. SLR increases the foundation upon which the high tide and storm surge build, leading to temporary events of water reaching further inland. Eventually, SLR causes permanent land loss in low-lying coastal areas. For areas like the Netherlands, armoring the shoreline is sufficient for protection, but South Florida has a different situation. Water can seep underground through the porous and permeable limestone substrate of the coastal Biscayne Aquifer. It will be increasingly difficult to maintain a balance between protecting the water supply in the dry season and preventing

Figure 1: Broward County Relief

Figure 2: Broward County Select Demographics

floods in the wet season. Despite all of these challenges, there is adequate time to pioneer cutting edge approaches for planning and technology to address both chronic and acute SLR impacts.

SLR RISK PERCEPTION: RAISING AWARENESS WHILE PREVENTING RESIGNATION

Outreach strategies are critical for increasing SLR awareness and promoting action in Broward County residents. However, risk communication is a sensitive issue and must consider psychological aspects of risk perception. To illustrate potential inundation, many maps color land with elevations below a projected SLR in shades of blue similar to the ocean. Without proper explanation and encouragement, homeowners may feel alarmed and upset that their property is visually underwater. While it is crucial to promote concern, it is just as important to direct these concerns towards finding solutions. Perhaps potentially inundated areas should be symbolized differently than the ocean to distinguish areas most at risk without the finality of implying they will be definitively submerged.

In another example, a recent study has given U.S. coastal cities a "year of commitment" beyond which their submersion below sea level has been "locked in" due to global emissions scenarios and their correlating SLR projections.[6] For many cities in Southeast Florida, this point of no return will happen by 2030 if changes haven't been made to drastically reduce emissions. While the lock-in years are within the lifetimes of most residents, the actual years for complete inundation could be millennia. The information can be confusing and misleading to one without background understanding.

While these examples of messages are likely to instill a sense of danger and urgency, they are also open to being interpreted with negative forms of concern such as worry, fear, and resignation. A change in behavior is more likely when risk communication empowers residents to be prepared and to be in control.[7] Positive outreach can motivate residents to plan for the future and feel safe.

SLR RISK COMMUNICATION: INDEX MAPS VERSUS INUNDATION MAPS

Information about risk can be displayed and explained in a way that engages residents to change their behaviors towards feeling safe and prepared. One way to do this is to present data in the form of indexes that map relative vulnerability to various SLR impacts, such as storm surge and flooding. A coastal vulnerability index (CVI) is a measure of relative risk, displayed spatially to pinpoint areas in which resources should be directed toward increasing resilience of the natural and built environments to coastal hazards such as storm surge and flooding. CVIs take into account both the probability of an event occurring and the impact of that event.

CVIs have less exposure to quantitative uncertainty than inundation maps (static bathtub models that assign units of elevation to indicate inundation vulnerability). Inundation maps do not account for natural and anthropogenic processes, such as erosion, accretion, beach nourishment and seawalls. While some studies distinguish inland and coastal vulnerabilities[2,5,8], most methods only use 8-way connectivity to the shoreline that does not account for increased inland flooding as a result of SLR lifting the water table in coastal aquifers. By showing relative risk, CVIs are less open to error associated with assigning units of elevation. An inundation map says, "Your home is vulnerable to potential inundation at this increment of SLR," while a CVI's message can be presented as, "Your home is in an area that is at the high end of the risk spectrum when compared to other areas in your county/region." By accounting for social vulnerability, CVIs add a new dimension that can assist planners and decision-makers to rank various geographic units according to a selection of risk components. One drawback to a CVI is that the accuracy of the data is lost when the elevation cells are averaged to larger spatial areas.

WHY SOCIAL AND NOT FINANCIAL VULNERABILITY?

Traditional vulnerability analyses assess SLR projections and land elevations to estimate the economic impact of various SLR scenarios. Many of these studies focus on cost benefit analyses that are based on financial exposure.[9-13] Yet, there is a key distinction between financial vulnerability and community resilience. In general, the owner of a highly valued property is more likely to have the monetary means to relocate in the case of a disaster, and is therefore more resilient. SLR vulnerability analyses must consider consequences in terms of impacts on the community if they are to maintain the scope of environmental justice and equality. However, the argument can be made that high valued properties support a significant portion of the tax base that supports the community. It is thus important to maintain a balance and consider both approaches. Keqi Zhang and the Southeast Florida Climate Change Compact each have done studies to quantify property values at various increments of sea level rise.[2,14]

METHODS

The traditional equation used to quantify risk is: "Risk = probability * consequence". [15] The following methods lead to an initial attempt to create a coastal vulnerability index (CVI) based on physical vulnerability and social vulnerability. Probability, or likelihood, will be represented by physical risk, and consequence will be represented by social risk. Physical indicators include elevation and storm surge zone averaged to the block group level. The social spectrum incorporates a separate social risk index that uses median income, population density, and age to classify social vulnerability as high, medium and low. For the CVI, a spatial intersection of the physical vulnerability and social vulnerability was used to create a five category index indicating physical SLR risk likelihood and impending consequence (Figure 3).

SOCIAL VULNERABILITY INDEX

A main drawback of creating indexes comes with issues related to averaging and weighting of indicators. It is difficult to objectively justify why one variable carries more weight than another, particularly when they include race and ethnicity. Hence, most studies use a large number of variables and give them all equal weight. Using this method, issues arise in the results pertaining to the vulnerability of large rural areas being overstated. For example, a vast census tract with only 50 people might be ranked as the most vulnerable. On a map, the size of the tract makes it stand out. While the sparse population has fewer opportunities, there is little economic impact of increased protection. When adaptation resources are limited by extent of the area, an effective strategy would be to protect the most people within the smallest space, while also making sure that these are the people who need help the

LIKELIHOOD				
	< 5.8 ft	M	MH	H
	5.8 ft-8 ft	ML	M	MH
	> 8 ft	L	ML	M
		0-.33	.34-.66	.67-1
CONSEQUENCE				

3

Figure 3: CVI Matrix

most. When population density is mixed in evenly with 30 other variables, the criticality of the issue is obscured. For this reason, indicators were limited to the most fundamental ones.

Rygel et al. created a novel storm surge social vulnerability index that avoids problems that arise when weighting and ranking variables.[16] The results showed that when all of the indicators were aggregated and assessed with a principal component analysis, three main components were the overarching links; poverty, immigration, and old age/disability. To keep the spatial analysis at the block group level, the two indicators available in the census data are median household income and age. Income is a main factor that influences the ability to absorb losses and have access to opportunities and resources. Age was set to percent of population over 60 because a higher proportion of elderly people in the area leads to an increased likelihood that the residents have limitations due to health and mobility.

Each block group was assigned a value between 0 and 1 based on its rank in comparison to other block groups in the county. The ranking value is the ratio of each census block's value to the county's block group maximum value. For median household income, the value was subtracted from 1 because high income decreases vulnerability. The values for composite social risk index were evenly distributed into categories of low, medium, or high in terms of consequence of impact for each risk.

PHYSICAL INDEX AND AGGREGATION OF CVI

The LIDAR digital elevation model used is from the Florida Department of Emergency Management and has 10-ft horizontal resolution and a fundamental vertical accuracy of 0.6 ft at 95% confidence level. The storm surge zones were taken from the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model from the National Hurricane Center. The physical vulnerability was assigned by taking the average land elevation per block group and the storm surge zone and classifying them into equal increments of low, medium, and high.

Once each block group has been classified into evenly distributed categories of low, medium, and high for both physical (likelihood) and social (consequence) risk, it is possible to aggregate the two into an index (Figure 3). The likelihood can be represented by adjusted elevation, and the consequence is the composite social risk index that related each block group based on the 3 variables. As medium (M) risk block groups will be average, the low (L), medium-low (ML), medium-high (MH) and high (H) can be classified relative to the average.

RESULTS

For the social vulnerability index, there are clusters of high risk areas that correlate more to population density and income than age (Figure 4). This is likely due to the clustering of high density and low income along the central north-south corridor of the county. These social risk indicators also have more relationship to the composite CVI than age as quantified in table 1.

The results of the initial physical and social vulnerability indexes suggest that risk to SLR to residents is not limited to the coastal populations. Based on social risk, the majority of vulnerable people live landward (west) of gravity driven flood control structures. The CVI results are also not

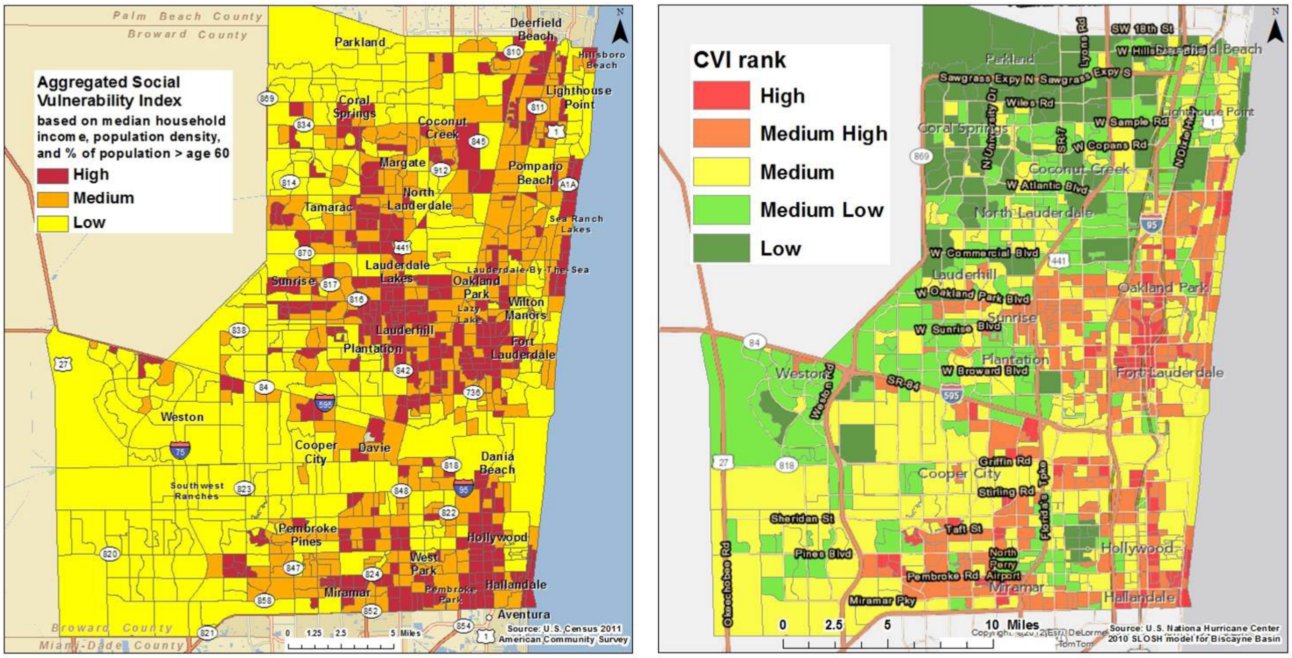

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Figure 4: Social Vulnerability Index and CVI

limited to coastal communities, with risk increasing from northeast to southwest. When the cluster with the high CVI ranking located in northwest Fort Lauderdale was assessed in terms of race, it was found to be predominantly African American. This area, the Sistrunk corridor, has been a focus for community redevelopment due to the disparity and lack of opportunity that have been observed (www.fortlauderdale.gov/ cra/plans/sistrunk.htm).

DISCUSSION

The decisions that planners make today to deal with current challenges in coastal development and protection will impact the future as SLR continue to exacerbate coastal hazards such as storm surge, erosion, and flooding. Policy-makers, stakeholders, and planners tend to have a "wait-and-see" attitude, but it might be too late to implement the best management practices by the time that the magnitude of increase in projections is more certain.[2]

Another method for promoting SLR adaptation action is to quantitatively show how the benefits of adaptation policies and actions can far outweigh the costs via saving from risk reduction. Once the general public understands this, there will be more support for adaptation tools. The most effective tools are:

1. land-use regulations that limit development in high risk areas
2. limits on insurance subsidies for coastal properties so that rates reflect true risk
3. redesign and retrofitting of structures to increase their resilience to inundation and storm surge
4. updates for drainage, flood control, and water supply infrastructure
5. increased coastal protection through buffers such as living shorelines

Many of these tools lead to co-benefits such as improved public health and conservation of natural areas. A CVI as well as an inundation map can be utilized in the first two tools to guide policy and inform planning decisions. Limited funds present challenges in implementing the final three tools, but this CVI can aid in prioritizing areas that have the most need, both physically and socioeconomically.

There is great potential for innovative geoengineering options that can reduce carbon dioxide in the atmosphere (contributor to thermal expansion of ocean waters, and the melting of land-based ice, two major causes of SLR) or increase heat reflectivity. There are also increasingly efficient possibilities for adaptation in terms of protection, redesign, and relocation. Robust SLR adaptation options will require significant economic costs; costs that one may not be willing to pay in the case of resignation or underestimated perception of risk. A key strategy to knock down these barriers is to empower the public to embrace and demand adaptation actions. Much of the investigation and planning for adaptation has been done, but implementation and tangible developments are limited.[17] The information-action gap must be bridged by effective communication and imagery.

FUTURE RESEARCH

In terms of climate change impacts, effective communication is lagging behind scientific knowledge.[18] This study is a preliminary step for the doctoral dissertation of the author, with an end objective of comparing actual risk to perceived risk in Broward County, FL. The CVI for actual SLR risk can be compared to future questionnaire survey results of perceived risk to determine if actual risk and perceived are aligned or if they represent discrepancies. Results may pinpoint areas to focus on for outreach.

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