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Building Flood Resilience Among Older Adults Living in Miami-Dade County, Florida

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Abstract

Objective: This paper explores compounding challenges for older coastal populations due to accelerated sea level rise at the nexus of physical hazard exposure and place-based socioeconomic and health considerations.
Methods: This study applies geospatial analysis to assess the spatial distribution of older adults (age 65+) and their socioeconomic characteristics in Miami-Dade County in Florida. Next, it uses logistic regression to evaluate the socioeconomic determinants of block groups with 20% or more of residents age 65 and older at 3 feet of sea level rise compared to the other block groups in Miami-Dade.
Results: The results show that this study area has an older population clustered in flood-prone locations along the shoreline. The block groups with more than 20% of older adults and sea level rise risk have higher homeownership and vacancy rates, a higher percentage of homes constructed before 1980, and more older individuals who live alone.
Conclusion: This study identifies place-based compounding factors undermining the ability of older residents to adequately cope with accelerated sea level rise flooding in coastal urban locations. Namely, owning an older home in a declining neighborhood and living alone can trap older individuals in place and increase their flood risk.

Many US coastal areas are experiencing more severe tropical storms and hurricanes,[1–4] sea level rise (SLR),[5–7] and land subsidence,[8] leading to socioeconomic disruption, especially in densely populated, urban coastal areas.[9] At the same time, they are subject to continued population growth,[10] with around 24 662 000 people residing in census blocks along the oceanfront or within the Federal Emergency Management Agency's (FEMA) 1% annual chance of coastal flooding corridor.[11] The increase in population has been especially discernible in Florida's coastal counties, often considered as a "retirement magnet" or preferred living destination for older adults,[12] despite their high flood risk.[13] During 1970-2010, the coastal shoreline counties experienced an 89% increase in the older populations (age 65 and over) and a 97% increase in coastal watershed counties, with some of the highest increases in South Carolina (443%), Hawaii (340%), and Florida (208%).[14]

Florida is the oldest US state based on its demographic composition and the second oldest based on the total number of older adults, with some locations like Sumter County having over 43% of residents age 65 and over.[15] Regardless of the reasons behind the choice to settle in coastal areas, the older populations are expected to increase, with a growing proportion of baby boomers entering this age group in the coming decades. The baby boomers, or post-World War II generation, started joining the 65+ demographic cohort in 2011, which will peak by 2029, pushing the total US population of older adults to over 20%.[16] The present-day older populations live longer than any previous generations and prefer to live longer independently or "age in place" to preserve a quality of life.[17,18] These trends will place more older adults at risk of flooding and weather extremes due to their lifestyle choices, proximity to hazards, and heightened physical and psychosocial vulnerability.[19–21] The susceptibility of older adults to hazard and disaster impacts has been recognized for decades, including their limited ability to receive disaster warnings, hesitation to evacuate, and difficulty with recovery.[22] Older adults are more likely to experience adverse physical health outcomes[23] and higher mortality and morbidity from natural disasters.[24,25] For example, about 71% of the Hurricane Katrina disaster victims were older than 60, with as many as 68 individuals found deceased in nursing homes and some abandoned by their caretakers.[26]

Even though the older age category is regularly listed as one of the critical determinants of social vulnerability,[24] only limited research explores the extent and role of aging and related health and socioeconomic considerations on the cumulative vulnerability of aging in place.[27] Even though the nexus between older age and health has been extensively explored in the context of preparedness, evacuations, response, and recovery, and specific disaster,[25,27–36] the majority of these studies focus on response and recovery with less attention given to preparedness, especially on a personal and household level.[37] Most disaster research on aging

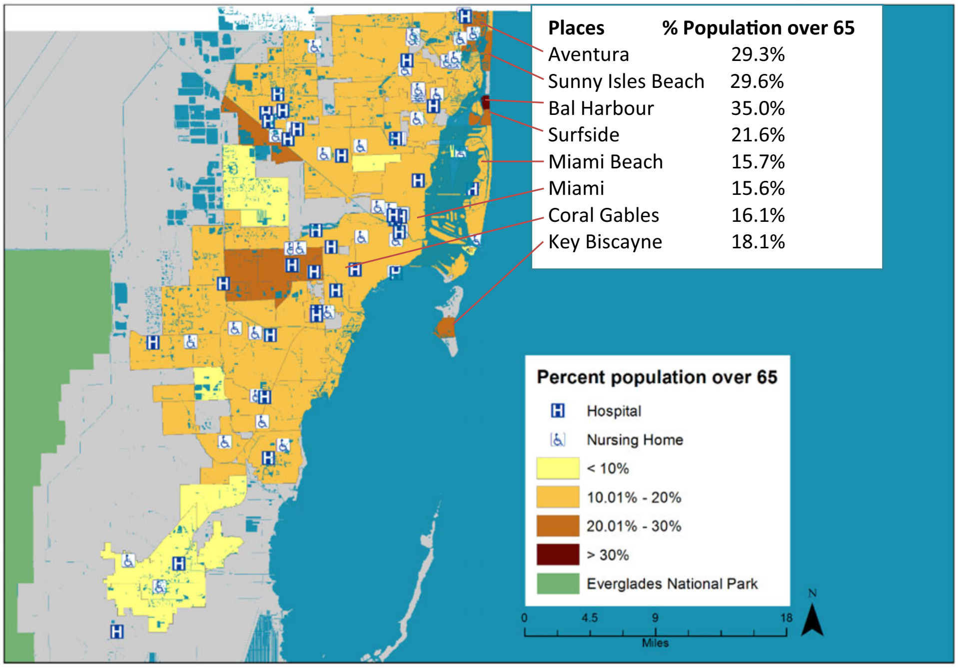

Figure 1. Distribution of older populations (65+) in Miami-Dade County's communities.

approaches this issue through the lens of sociodemographic changes, functional health decline, and institutional policies for assistance needs.[32] Even though there is significant variation in vulnerability among older adults in health, level of function, and social status,[31] many have decreased mobility, chronic medical conditions, dependencies on medications and treatments, fewer social interactions, and limited financial means.[38] The disaster vulnerability of older individuals is also compounded by their overall physical frailty, cognitive, sensory, and physical decline,[26] and the possibility of living alone with limited resources and fewer opportunities for social interactions.[31] They are often unprepared to shelter in place and unwilling to evacuate due to their physical frailties and limited resources.[39]

This study explores the spatial implications of SLR flooding on older populations living in Miami-Dade County, Florida—an epicenter of high exposure to coastal hazards and disasters and older demographic. It further evaluates the relationship between older urban populations and socioeconomic considerations that may increase their vulnerability to flooding. The research approach uses geospatial mapping and statistical analysis to identify some of the key attributes that may undermine the coping capacity of older populations to chronic and episodic flooding. Identifying considerations that can lead to aggregate impacts can inform the development of more effective, innovative, and targeted programs and services, enabling this demographic group to continue living safely in coastal locations.

Methods

Case Study Location

Our research is conducted in Miami-Dade County in the southeastern part of Florida (Figure 1), which represents one of the most vulnerable locations to sea level rise and storm surge flooding, with the anticipated impacts on more than 45% of the county's assets.[40] Miami-Dade County is also prone to accelerated beach erosion and saltwater intrusion through the highly porous limestone that may cause the salinization of freshwater underground reservoirs.[41] According to 2019 US Census estimates,[42] Miami-Dade County has a population of 2 716 940, with 20.2% persons younger than 18 and 16.2% older than 65 years of age and primarily white race (78.8%) with Hispanic origin (67.7%). Six percent of persons under 65 have a disability, 19.4% of residents over 65 do not have health insurance, and 16% live in poverty.[42] Based on the American Community Survey's 1-year population estimates, the county's population has increased by 13.6% since 2007. During the same period, those aged 65 years and over increased by 23.0%.[43] Though Miami-Dade County is characterized by diverse populations, many neighborhoods reflect residential clustering by race and ethnicity and between younger and older households.[44] To accommodate the anticipated increase in older populations, the county initiated some planning and programmatic efforts to improve the land use and community design features such as walkability, access to affordable public transportation, spaces for social interaction, and amenities for this demographic group.[45] Based on the cross-sectional household survey, Zevallos et al.[46] found that three different Miami-Dade County areas (north Miami-Dade, Little Haiti, and South Miami) have predominantly older, female, uninsured, and poor minority populations where older residents often had limited health access, high prevalence of chronic diseases, and poor health behaviors.

Geospatial and Statistical Analysis

We first performed the geospatial analysis to determine the distribution of older populations and supportive facilities (eg, hospitals and nursing homes), socioeconomic characteristics, and SLR exposure in the study area. Next, we used statistical analysis (logistic regression or logit model) to explore the relationship between the spatial hotpots of older populations and socioeconomic attributes relevant to disaster vulnerability on a census block group level. We used the SLR data[47] showing relative flood depth 0-6 feet above Mean Higher High Water (MHHW) to demonstrate the scale of potential chronic flooding. This data set is derived by subtracting National Oceanic and Atmospheric Administration's Vertical Datum (VDatum) MHHW levels from the Digital Elevation Model (DEM). The data provide a course representation of SLR inundation and do not account for coastal erosion, land subsidence, or the future built environment.[47] Next, the socioeconomic data from American Community Survey (ACS) (2012–2016) was mapped using US Census Bureau shapefiles to map the distribution of older populations, facilities, and populations with disabilities on a census place, census tracts, and block group levels. The distribution of 6 different disabilities among the older individuals (65+) was also mapped on the census tract level, using the 2016 Census Tract data, including vision disability, hearing disability, cognitive disability, self-care difficulty, and ambulatory and independent care difficulty. The socioeconomic data were joined to the corresponding shapefiles in GIS and overlaid with nursing homes/assisted living facilities locations downloaded from Homeland Infrastructure Foundation Level Data[48] and hospital locations from the Miami-Dade GIS data collection.

In this study, we relied on the current estimates of the older population, considering the uncertainties in long-term residing preferences and place-based circumstances that may result in the decadal oscillations and reversal of expected demographic trends. For example, even though Manuel et al.[49] used future projections of older populations to estimate their exposure to SLR, the authors also emphasized the challenges of accurately predicting increases and decreases in older populations on a granular spatial scale. Considerations such as community decline, increase in crime, advanced health care needs, demand for new/better amenities and services, sudden changes in the availability of affordable or rental housing, and closure of assisted living facilities can significantly alter the future demographic projections.[49] We ran a logit model using STATA statistics software to evaluate other compounding factors deemed important determinants of social vulnerability for this population group. The following socioeconomic variables (2016 5-year ACS) on a block group level were considered in the analysis: income (log of median household income), percent of owner-occupied units built before 1980, disability (percentage), migration (changed location 1 year ago); living alone (householder 65+ in percentage), tenure (percent homeowner); vehicle ownership (no vehicle among population age 65+ in percentage), and vacancy (percentage). The block groups with over 20% of the population over 65 and impacted by 3 feet of SLR were considered areas of combined physical and demographic vulnerability.

Results

The study first characterized the spatial distribution of older populations within Miami-Dade County. The county scale often represents an optimal analytical unit, defineing important administrative and institutional factors such as education, service delivery, local ordinances, and planning decisions.[50] The granular scale of analysis that accurately captures the relationship between local influences and population health with "macro-level considerations" may indicate broader social and health trends beyond the individual or household level.[50] Even though location-specific influences has been widely accepted as an important determinant of health outcomes, there is still an ongoing debate on which scale is the most appropriate to examine the relationship between spatially explicit socioeconomic and environmental variables and health outcomes.[51] Some scholars suggest that the neighborhoods represent the optimal unit of analysis,[52] whereas others argue that the neighborhood level is too abstract with discrepancies in how neighborhood boundaries are defined.[53] Therefore, in this paper, we use the county scale as an outer boundary and a census block group as a more granular unit of analysis that could better identify urban pockets of vulnerability for programmatic interventions.

In Miami-Dade County, there are 72 administrative units (incorporated municipalities, cities, towns, villages, and unincorporated census-designated places). Eight communities have an older population (age 65 and over) exceeding 20% of the total residents (see Figure 1). Bal Harbour, a village on the northern tip barrier island, has the highest percentage of the older population (35%). Ten communities in the county have an older population ranging from 20 to 30%, with the highest numbers in Sunny Isles Beach community located on the barrier island (29.6%) and Aventura on the oceanfront with 29.3% of older residents. The other cities and townships with the highest percentage of this older population are also located in the same general area of the county, either on the barrier island or facing the ocean: Surfside with 21.6% of the older population, Key Biscayne with 18.1%, Coral Gables with 16.1%, Miami with 15.6%, and Miami Beach with 15.7%. The same communities are at high risk of a low-grade "sunny day" or nuisance SLR-driven flooding.

We selected 20 communities with the highest population of older residents (65+) to evaluate four critical socioeconomic attributes that could augment their flood vulnerability. For example, such factors include financial hardship[54] from the increasing costs of medical care and health services, insufficient retirement savings,[15] and the lack of transportation and age-appropriate communication technology.[29] Homeownership of older homes that may not be structurally sound to withstand extensive or repetitive flood damages poses a risk of place-based entrapment. Table 1 shows that places with a higher percentage of the older population also have a higher rate of older residents living alone, in poverty, and in older homes they own.

In the age group 65 and older, the highest percentage living alone is in Bal Harbour (54.40%), followed by Aventura (36.80%) and Sunny Isles Beach (33%). Places with the highest populations of older residents living in poverty are Medley (33.21%), University Park CDP (17.97%), and Coral Terrace CDP (17.05%), all located away from the shoreline. Homeownership is highest in Bal Harbour (71.80%) and Surfside (55.88%), located on the barrier island, and Medley (53.54%), located farther inland. The lowest homeownership (under 50%) is in places not near the coast. Four communities that have more than 80% of homes built before 1980 are located away from the shore, namely Westwood Lakes (96.20%), West Miami (93.24%), Coral Terrace (88.04%), and Westchester (87.12%). Those with newer housing stock built after 1980 include Aventura (64.96%, on the Bay) and Medley (43.85%, inland).

Considering Florida was the second state in the United States with a percentage of the population age 65 and over with one or more disabilities at 7.4% or 1.2 million of older residents in 2008–2012,[55] this paper also evaluated the prevalence of this compounding factor on the flood risk in the case study location. Among older residents with a disability, many are single women with low educational attainment and low income approaching the federal poverty threshold.[55] Residing in assisted living facilities or nursing homes is not necessarily a safer option for this age group. Hurricane Katrina highlighted some of these risks, such as abandonment by

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Table 1. Places with the highest population of older residents in Miami-Dade County and their socioeconomic characteristics[61,62]

Place	Percent 65+	Percent 65+ living alone	Percent 65+ living in poverty	Percent 65+ home-owners	Percent living in home built before 1980
Bal Harbour village	35.04	54.40	16.34	71.80	69.46
Aventura city	29.58	36.80	13.75	51.08	35.04
Medley town	29.51	24.50	33.21	53.54	56.15
Sunny Isles Beach city	25.81	33.00	14.80	50.33	61.51
Surfside town	25.32	23.70	7.14	55.88	64.26
West Miami city	22.32	15.70	15.42	37.54	93.24
Westchester CDP*	21.73	13.10	13.75	44.53	87.12
Coral Terrace CDP	21.35	15.50	17.05	39.06	88.04
Westwood Lakes CDP	20.65	11.80	8.27	36.78	96.20
University Park CDP	20.34	16.10	17.97	46.22	65.39

*Census-designated place.

Table 2. Difficulties among Miami-Dade 65+ residents in percentages for all Census Tracts[61]

Type	Definition	Mean	SD	Max.
Hearing difficulty	Deaf or having serious difficulty hearing	9.36	6.17	51.26
Vision difficulty	Blind or having serious difficulty seeing, even when wearing glasses	7.23	6.06	63.98
Cognitive difficulty	Having difficulty remembering, concentrating, or making decisions because of a physical, mental, or emotional problem	12.40	6.90	36.24
Ambulatory difficulty	Having serious difficulty walking or climbing stairs	23.50	9.36	65.12
Self-care difficulty	Having difficulty bathing or dressing	10.49	6.65	63.95
Independent living difficulty	Having difficulty doing errands alone, such as visiting a doctor's office or shopping, because of a physical, mental, or emotional problem	17.04	7.71	63.95
One type of disability	Civilian noninstitutionalized population 65 years and over with 1 type of disability	13.27	6.42	37.90
Two or more types of disability	Civilian noninstitutionalized population 65 years and over with 2 or more types of disability	20.13	8.84	63.98

caregivers and ineffective assistance during and after a disaster event.[56]. The risks also extend to transportation, where, for example, 24 Hurricane Rita evacuees from a nursing home perished in a bus fire exacerbated by the explosions of oxygen tanks.[57]

The limited accessibility due to flooding would render many older residents homebound[37] and increase their physical and social isolation, adversely affecting their health and well-being.[58] On the other hand, the disaster-induced displacement and dislocation from the familiar setting could also lead to the onset or worsening of chronic health conditions stemming from the limited access to pharmacies and health/medical facilities.[59] Considering the overall growth of Florida's oldest adult population (age 85 and over), such flood-driven disruptions will have more complex implications for living arrangements and transitioning to extended care and assisted living facilities.[15] The oldest adults have the lowest level of disaster preparedness. Over one-third of this age group report a lack of emergency provisions of food, water, and medicine or a plan for the intermittent or prolonged loss of power.[29] Disabilities significantly affect the ability of older individuals to engage in disaster preparedness, response, and recovery and contribute to their heightened social and place-based vulnerability. Maltais[60] found that older individuals with physical or cognitive difficulties are less likely to receive adequate assistance during natural disasters and, therefore, are more likely to have adverse health outcomes than older populations without disabilities. Table 2 shows definitions and prevalence of six disabilities among the older populations in Miami-Dade County.[61] The most prevalent difficulties are ambulatory difficulty, with a 23.5% average prevalence in Miami-Dade County's census tracts, and independent living difficulty, with 17.04%. The mean percent of the older population with cognitive difficulty is also higher at 12.40%, indicating potential challenges with interpreting risk information and warnings and participating in preparedness and response activities. The percentage of older individuals with two or more disabilities is 20%, posing an additional challenge in managing different healthcare services and dependency on the functional and cohesive service network.

Figure 2 shows the spatial distribution of the older population with two or more types of disabilities on a Census Tract level in Miami-Dade County. Areas with clusters of more than 20% of the population aged 65 and over are primarily located in Miami, Miami Beach, Homestead, and North Miami. Some of these communities, namely neighborhoods in North Miami, Miami Beach, and South Miami, are located directly on the coast and have higher exposure to coastal flooding. Identifying such pockets of age-related disabilities will be necessary for emergency response planning and in-home assistance when older individuals cannot leave their premises due to recurrent or nuisance flooding. To better understand the role of other compounding factors that may further increase the vulnerability of older residents to flooding, we selected nine indicators identified in the literature as important determinants of vulnerability.[63,64] The description of the variables with their respective means and standard deviations is available in Table 3.

The logistic regression was applied on a census block group level. The logit model explains 22.8% of the variance in the dependent variable representing the block groups with 3-ft SLR exposure and 20% or more of the older populations (65+). The specific block

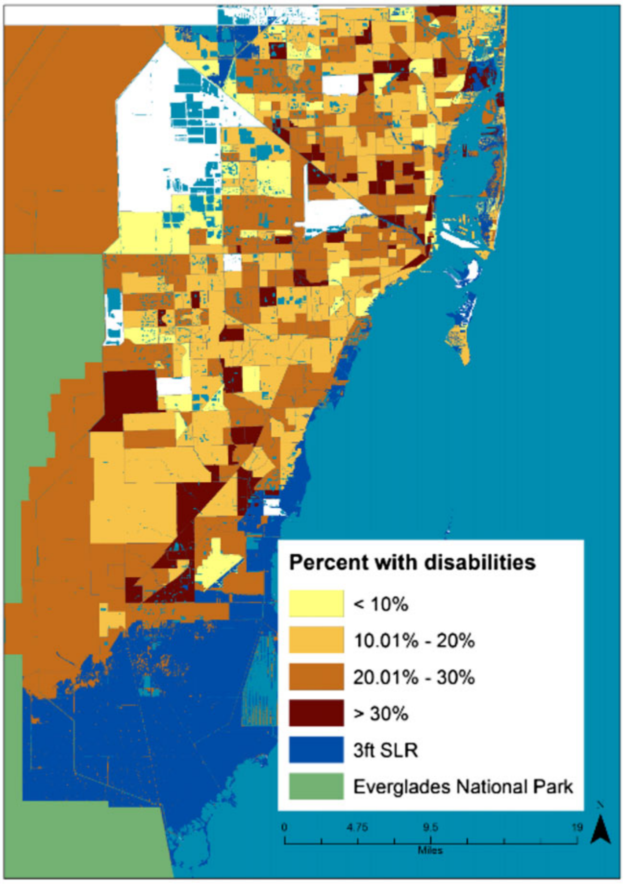

Figure 2. Older population with 2 or more disabilities in Miami-Dade County.

Table 3. Variables indicating social vulnerability of older populations (65+) in Miami-Dade County

Variable	Obs.	Mean	SD	Min.	Max.
Percent age 65 and over	1576	16.39	9.72	0.00	100.00
Percent living in home built before 1980	1573	61.40	32.90	0.00	100.01
Median income (log)	1503	10.76	0.60	7.82	12.43
Percent of owner-occupied housing unit	1573	55.47	28.38	0.00	100.00
Percent of vacant units	1575	12.82	14.34	0.00	100.00
Percent with 1-person households	1573	26.10	17.16	0.00	100.00
Percent without vehicles	1594	1.72	2.97	0.00	23.58
Percent moved from a different metropolitan area in the last 1 year	1594	1.57	3.63	0.00	81.25
Percent with disability	1594	7.39	6.68	0.00	63.16

Table 4. Exposure of block groups with 20% or more of older populations (65+) to different SLR scenarios (1–6 ft of projected inundation)

SLR	High risk	Not at risk
1 ft	113 (7.09%)	1481 (92.91%)
2 ft	141 (8.85%)	1453 (91.15%)
3 ft	**165 (10.35%)**	**1429 (89.65%)**
4 ft	190 (11.92%)	1404 (88.08%)
5 ft	218 (13.68%)	1376 (86.32%)
6 ft	306 (19.20%)	1288 (80.80%)

groups of interest for this analysis were selected from the SLR exposure risk assessment in Table 4. The 3 ft of SLR would affect 165 block groups or 10.35% of all block groups in Miami-Dade County.

The block groups were selected as a unit of analysis as they represent the lowest geographic scale for which the data for variables of interest were available. In a logistic model (Table 5), the dependent variable was binary, distinguishing between the block groups with 20% or more older residents at 3 ft risk of SLR and all other block groups in Miami-Dade County. Nine social vulnerability variables served as independent variables. The fitted model shows that the block groups representing hotspots of SLR exposure and the presence of older populations (65+) are associated with a higher number of properties constructed before 1980, a higher percentage of owner-occupied units, a higher number of vacant properties, and a higher percent of 1-person households.

Discussion

Understanding emerging challenges, primarily from coupling social and physical vulnerabilities such as aging and coastal hazards, will be vital to developing effective disaster preparedness plans. As observed with Katrina and Rita hurricane disasters, proactive engagement of older residents in disaster preparedness with the support of other local stakeholders and organizations can lead to improved outcomes.[56] To be effective, disaster planning responses must be aligned with the place-based circumstances and contextual needs of older populations. As such, specific knowledge of what drives physical and social vulnerabilities will play an important role in determining which priority actions would provide more immediate and better protection for this vulnerable demographic group. The current literature mainly focuses on major disaster events and less on the chronic slow-onset climate change impacts that will substantially affect this vulnerable population.[65] Older, structurally compromised homes (eg, built before the 1980s) tend to experience more damage and accrue higher costs of flood- and wind-proofing and repairs than the newer and renovated homes subjected to present building codes.[66] Older residents may not have the resources for home elevation and other disaster risk reduction retrofits, especially if they cost more for older, structurally unsound homes. They may also be unable to cover the upfront cost and invest resources in home upgrades due to other financial priorities such as increasing costs of medical care and savings for transition to the assisted living facility. At the same time, many older residents are homeowners with equity tied into their homes that may lose their value due to flooding and related community decline. Many older individuals will likely become trapped in their locations due to the inability to recover their investment, sell the home, strong place attachment, and fear of being dislocated from a familiar environment.

A higher percentage of vacant properties in a community may affect the neighborhood stability, perceived safety, and physical and mental health of residents,[67] undermining the overall resilience of older populations. Further, living alone can lead to psychosocial isolation and lack of immediate support, reducing confidence, sense of security, and ability to cope with flood events among older adults. Understanding these compounding factors

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Table 5. Logistic regression between block groups at risk of 3 ft SLR with 20% or more of older populations (65+) and social vulnerability indicators (number of observations 1503, Wald Chi2(8) 162.18, R2 0.2277)

Bi_65above20 SLR3 → high-risk areas*	Odds ratio	SE	z	*P* > z	95% Confidence interval	
Percent living in home built before 1980	1.0066	0.0034	1.96	**0.050**	0.9999	1.0133
Median income	0.6753	0.1548	1.71	0.087	0.4309	1.0585
Percent of owner-occupied housing	1.0320	0.0054	5.92	**0.000**	1.0213	1.0428
Percent vacant	1.0514	0.0074	7.13	**0.000**	1.0370	1.0660
Percent with 1-person households	1.0496	0.0078	6.51	**0.000**	1.0344	1.0651
Percent with no vehicle, 65+	1.0377	0.0293	1.31	0.190	0.9817	1.0969
Percent moved from a different metropolitan area in the last 1 year	0.9804	0.0327	0.59	0.554	0.9183	1.0467
Percent disability	0.9970	0.0183	0.16	0.873	0.9617	1.0336
Cons	0.0724	0.1792	1.06	0.289	0.0005	9.2536

*High-risk areas are defined as BGs at risk of 3 ft SLR with a 20% population age 65+.

can drive household- and place-specific innovation in developing novel financial and policy mechanisms to support older coastal populations (eg, community-based micro-loans and neighborhood support networks). In a spatially explicit study that examines the impacts of SLR on older populations in coastal communities, Manuel et al.[49] found that even though flooding will not directly affect health service facilities supporting older populations, it will impact assets they rely on to sustain their physical and emotional well-being. Duggan et al.[68] further noted that older people expect unobstructed access to amenities and services, perceiving them as a fundamental right and within legitimate expectations.

Our results contribute to evidence suggesting that many older individuals living in disaster-prone areas live alone in circumstances that exacerbate their physical and social vulnerability. Whether the compounding factors are isolation, disability, or housing conditions, technology can help older coastal residents understand their risk, cope with flood exposure, and keep connected with resources and social support networks during flood episodes. The role of assistive technology before, during, and after a disaster among older individuals received limited research and policy attention,[69] even though some tools can efficiently manage their disaster risk. Older populations have been increasingly adopting smartphones, social media, and computers/tablets to communicate and obtain information since 2012.[70] Thus, increasing computer and smartphone literacy and broadband Internet access may help minimize adverse impacts on older residents due to direct and indirect flood impacts. Emergency management interventions should focus on developing multipronged communication strategies for older coastal populations that should not only focus on immediate disaster assistance but also on building their confidence in personal preparedness through shared experiences and community support.

In addition to household-level impacts, older adults will likely be affected by broader community changes due to flooding. Vacant properties, flooded roadways, closed businesses, service interruption, and similar issues may affect their sense of place, real or perceived personal safety, and physical and mental welfare. Local officials, emergency managers, community-based organizations, and the private sector should coordinate efforts and identify innovative ways for short- and long-term assistance of older coastal populations. For example, such actions could include flexible service delivery and telehealth options, technical support for low-cost home flood-proofing upgrades (eg, flood vents installation, application of flood-resistant coatings and sealants, and flood-resistant landscaping), and support network building. The focus of this paper on chronic SLR flooding emphasizes the need for more integrated emergency management approaches that assimilate disaster risk reduction efforts with coastal adaptation strategies to provide holistic protection against compounded coastal risks.

One limitation of this study is using current socioeconomic data as a demographic risk indicator and future SLR projections as a physical risk indicator. As discussed in the Methods section, the proportion of older adults and other socioeconomic variables may change, impacting a community's future vulnerability and flood risk. Future research could model changes in socioeconomic variables based on historical trends and test the efficiency of different policy interventions across multiple demographic scenarios. Further, machine learning could model the historical trends pertinent to this population and predict the outcomes of various programmatic actions. This study also does not account for the episodic storm surge flooding that would exacerbate our estimates and lead to acute and substantial damages and psychosocial impacts. Another potential issue is the scale of analysis used in this research. In disaster studies, there is still no consensus on the appropriate analytical scale, considering each has unique strengths and weaknesses that are often highly contextual to place-based circumstances and policy needs. While aggregating the census block group or census tract data provides a broader overview of social vulnerability and risk across older populations, this scale may fail to capture the household-level disparities. Additionally, aggregate data may not provide insights into individual coping and adaptive capacities, innate resilience, and specific support needs. For example, older adults living alone face different challenges than those living with families or in nursing homes. These nuances are better captured by individual or household-level data that are more difficult to obtain.

Conclusions

This study found that Miami-Dade County has several hotspots of aggregate elevated risk of coastal flooding, older populations, social vulnerability, and disability. Even though not all residential areas with a higher percentage of older individuals will be directly affected by SLR inundation, many access roads will experience chronic flooding due to SLR-augmented high tides and storm surges. The older populations are highly vulnerable to direct flood exposure in their homes and dangerous roadway conditions or impassable roads, which can affect their ability and confidence to cope with flooding. The flood impacts can also disrupt access to health and medical services, affect physical and mental health, and

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lead to isolation and deterioration of the well-being of older coastal residents. Our results indicate that localities need to take a multipronged-pronged approach to address the vulnerability of older populations to coastal flooding. One strategy should focus on physical safety in places of residence, another one address accessibility issues, and the last one should focus on the infrastructure and networks older people depend on for informal and formal assistance, social support and services, and information. Even though the older populations are often recognized as highly vulnerable to hazards and disasters due to their lower income, deteriorating health, higher health care needs and medical costs, and living conditions, these determinants vary between locations and contexts. Our study shows that within the hotspots of coupled physical and age-based vulnerability in Miami-Dade County, the older population is more likely to live independently in older homes and areas with more vacant housing. These factors can undermine their safety regardless of other household-level preparedness efforts.

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Borate: Methodology and formal analysis, mapping products, writing – review and editing.

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Competing interests. The authors have none to declare.

References

1. **Trenberth K.** Uncertainty in hurricanes and global warming. *Science.* 2005;308(5729):1753-1754.
2. **Knutson TR, McBride JL, Chan J, *et al.*** Tropical cyclones and climate change. *Nat Geosci.* 2010;3(3):157-163.
3. **Elsner JB, Kossin JP, Jagger TH.** The increasing intensity of the strongest tropical cyclones. *Nature.* 2008;455(7209):92-95.
4. **Holland G, Bruyère CL.** Recent intense hurricane response to global climate change. *Clim Dyn.* 2014;42(3):617-627.
5. **Karl TR, Melillo JM, Peterson TC, Hassol SJ.** *Global climate change impacts in the United States.* Cambridge University Press; 2009.
6. **Church JA, Clark PU, Cazenave A, *et al.*** *Sea level change.* PM Cambridge University Press; 2013.
7. **Nicholls RJ, Cazenave A.** Sea-level rise and its impact on coastal zones. *Science.* 2010;328:1517-1520.
8. **Climate Change Science Program (CCSP)**. Coastal sensitivity to sea-level rise—a focus on the mid-Atlantic region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, D.C., U.S. Environmental Protection Agency; 2009.
9. **Melillo JM, Richmond TT, Yohe G.** Climate change impacts in the United States: the third national climate assessment. *Econ Environ Sci.* 2014;52:1-841.
10. **Crosset KM.** *Population trends along the coastal United States: 1980-2008.* National Oceanic and Atmospheric Administration, Government Printing Office; 2005.
11. **Crowell M, Coulton K, Johnson C, *et al.*** An estimate of the US population living in 100-year coastal flood hazard areas. *J Coast Res.* 2010;26(2):201-211.
12. **Johnson KM, Winkler R, Rogers LT.** *Age and lifecycle patterns driving US migration shifts.* Carsey School of Public Policy; 2013.
13. **Thieler ER, Hammar-Klose ES.** *National assessment of coastal vulnerability to sea-level rise: US Atlantic Coast.* USGS; 1999.
14. **Crossett K, Ache B, Pacheco P, Haber K.** *National coastal population report, population trends from 1970 to 2020. NOAA State of the Coast Report Series.* US Department of Commerce; 2013.
15. **Reynolds J, Gunderson J, Bamford M.** *Florida's aging population: critical issues for Florida's future 2015.* Pepper Institute on Aging and Public Policy; 2015.
16. **Colby S, Ortman JM.** *The baby boom cohort in the United States: 2012 to 2060.* US Department of Commerce, Economics and Statistics Administration, US Census Bureau; 2014.
17. **He W, Goodkind D, Kowal PR.** *An aging world: 2015.* U.S. Census Bureau, International Population Reports, P95/16-1, U.S. Government Publishing Office; 2016.
18. **Sheffield C, Smith CA, Becker M.** Evaluation of an agency-based occupational therapy intervention to facilitate aging in place. *Gerontologist.* 2013;53(6):907-918.
19. **Gamble JL, Hurley BJ, Schultz PA, *et al.*** Climate change and older Americans: state of the science. *Environ Health Perspect.* 2013;121(1):15-22.
20. **Lamb SE, McCabe C, Becker C, *et al.*** The optimal sequence and selection of screening test items to predict fall risk in older disabled women: the Women's Health and Aging Study. *J Gerontol A Biol Sci Med Sci.* 2008;63(10):1082-1088.
21. **Perry RW, Lindell MK.** Aged citizens in the warning phase of disasters: re-examining the evidence. *Int J Aging Hum Dev.* 1997;44(4):257-267.
22. **Friedsam HJ.** Older persons as disaster casualties. *J Health Hum Behav.* 1960;1(4):269-273.
23. **Cherniack EP.** The impact of natural disasters on the elderly. *Am J Disaster Med.* 2008;3(3):133-139.
24. **Cutter SL, Boruff BJ, Lynn Shirley W.** Social vulnerability to environmental hazards. *Soc Sci Q.* 2003;1-15.
25. **Powell S, Plouffe L, Gorr P.** When ageing and disasters collide: lessons from 16 international case studies. *Radiat Prot Dosimetry.* 2009;134 (3-4):202-206.
26. **Gibson MJ, Hayunga M.** *We can do better: lessons learned for protecting older persons in disasters.* Washington, DC: The AARP Public Policy Institute. Published 2006. Accessed May 2019. http://assets.aarp.org/rgcenter/il/better.pdf
27. **Cornell VJ, Cusack L, Arbon P.** Older people and disaster preparedness: a literature review. *Austral J Emerg Manag.* 2012;27(3):49-53.
28. **Aldrich N, Benson WF.** Disaster preparedness and the chronic disease needs of vulnerable older adults. *Prev Chronic Dis.* 2008;5:1-7.
29. **Al-Rousan TM, Rubenstein LM, Wallace RB.** Preparedness for natural disasters among older US adults: a nationwide survey. *Am J Public Health.* 2014;104(3):506-511.
30. **McGuire LC, Ford ES, Okoro CA.** Natural disasters and older US adults with disabilities: implications for evacuation. *Disasters.* 2007;31(1):49-56.
31. **Ngo EB.** When disasters and age collide: reviewing vulnerability of the elderly. *Nat Hazards Rev.* 2001;2(2):80-89.
32. **Tuohy R, Stephens C, Johnston D.** Qualitative research can improve understandings about disaster preparedness for independent older adults in the community. *Disaster Prev Manag.* 2014;23(3):296-308.
33. **Yoo M, Lee M, Tullmann D.** Perceptions of disaster preparedness among older people in South Korea. *Int J Older People Nurs.* 2016;11(1):18-23.
34. **Henderson TL, Roberto KA, Kamo Y.** Older adults' responses to Hurricane Katrina: daily hassles and coping strategies. *J Appl Gerontol.* 2010;29(1):48-69.
35. **Otani J.** *Older people in natural disasters: the Great Hanshin Earthquake of 1995.* Trans Pacific Press; 2010.
36. **Sirey JA, Berman J, Halkett A, *et al.*** Storm impact and depression among older adults living in Hurricane Sandy–affected areas. *Disaster Med Public Health Prep.* 2017;11(1):97-109.
37. **Kang K.** Disaster preparedness among vulnerable older adults with chronic diseases: results from a cross-sectional study in Incheon, Korea. *Nurs Health Sci.* 2014;16(1):46-51.
38. **Special Committee on Aging**. Preparing early, acting quickly: meeting the needs of older Americans during a disaster. Hearing before the Special Committee on Aging, United States Senate, One Hundred Ninth Congress, No. 109–15, Washington, DC; 2005.

39. **Dostal PJ.** Vulnerability of urban homebound older adults in disasters: a survey of evacuation preparedness. *Disaster Med Public Health Prep.* 2015;9(3):301-306.
40. **Sea Level Rise and Storm Surge Rapid Action Plan**. Office of Resilience. Miami Dade County Office of Resilience. Published 2018. Accessed November 2018. https://www.miamidade.gov/green/library/sea-level-rise-and-storm-surge-rapid-action-plan.pdf
41. **Tompkins F, Deconcini C.** Sea-level rise and its impact on Miami-Dade County. World Resources Institute. Published 2014. Accessed April 2021. https://www.wri.org/research/sea-level-rise-and-its-impact-miami-dade-county
42. **2019 Miami-Dade County Estimates**. U.S. Census Bureau. Published 2020. Accessed November 2020. https://www.census.gov/quickfacts/miamidadecountyflorida
43. **Miami-Dade County**. Miami-Dade County Profiles American Community Survey, 2016 American Community Survey 1-year Estimates Data. Updated September 2017. Department of Regulatory & Economic Resources Planning Research & Economic Analysis Section, Miami, FL; 2017.
44. **Elliott D, Srini T, Kooragayala S, Hedman C.** *Miami and the state of low- and middle-income housing*. Urban Land Institute, Washington DC; 2017.
45. **Age Friendly Initiative**. Action Plan for an Age-Friendly Miami-Dade. Published 2019. Accessed December 2020. https://agefriendlymiami.org/wp-content/uploads/2015/09/AFI-Action-Plan-Booklet.pdf
46. **Zevallos JC, Wilcox ML, Jean N, Acuña JM.** Profile of the older population living in Miami-Dade County, Florida: an observational study. *Medicine.* 2016;95(20):1-11.
47. **Frequent Questions: Digital Coast Sea Level Rise Viewer**. National Oceanic and Atmospheric Administration. Published February 2022. Accessed November 2020. https://coast.noaa.gov/data/digitalcoast/pdf/slr-faq.pdf
48. **Open Data, Homepage. Homeland Infrastructure Foundation-Level Data (HIFLD)**. Published 2017. Accessed March 2021. https://hifld-geoplatform.opendata.arcgis.com/
49. **Manuel P, Rapaport E, Keefe J, Krawchenko T.** Coastal climate change and aging communities in Atlantic Canada: a methodological overview of community asset and social vulnerability mapping. *Can Geogr.* 2015;59(4):433-446.
50. **Osypuk TL, Galea S.** What level macro? Choosing appropriate levels to assess how place influences population health. In: *Macrosocial Determinants of Population Health*. Springer; 2007:399-435.
51. **Root ED.** Moving neighborhoods and health research forward: using geographic methods to examine the role of spatial scale in neighborhood effects on health. *Ann Assoc Am Geogr.* 2012;102(5):986-995.
52. **Weiss RL, Maantay JA, Fahs M.** Promoting active urban aging: a measurement approach to neighborhood walkability for older adults. *Cities Environ.* 2010;3(1):12.
53. **Diez Roux AV.** Investigating neighborhood and area effects on health. *Am J Public Health.* 2001;91(11):1783-1789.
54. **Evans J.** Mapping the vulnerability of older persons to disasters. *Int J Older People Nurs.* 2010;5(1):63-70.
55. **He W, Larsen LJ.** *Older Americans with a disability, 2008-2012.* US Census Bureau, American Community Survey reports, ACS-29, Washington, DC; 2014.
56. **Cherry KE, Allen PD, Galea S.** Older adults and natural disasters. In: Dass-Brailsford P, ed. *Crisis and Disaster Counseling: Lessons Learned from Hurricane Katrina and Other Disasters*; 2009:115-130.
57. **Griffin L, Bajaj V.** Bus carrying elderly storm evacuees explodes near Dallas. The New York Times; September 23, 2005.
58. **Musich S, Wang SS, Hawkins K, Yeh CS.** Homebound older adults: prevalence, characteristics, health care utilization and quality of care. *Geriatr Nurs.* 2015;36(6):445-450.
59. **Ford ES, Mokdad AH, Link MW, *et al.*** Chronic disease in health emergencies: In the eye of the hurricane. *Prev Chronic Dis.* 2006;3(2):1-7.
60. **Maltais D.** Elderly people with disabilities and natural disasters: vulnerability of seniors and post trauma. *HSOA J Gerontol Geriatr Med.* 2019;5(4):1-7.
61. **How Disability Data Are Collected from the American Community Survey**. U.S. Census Bureau. Published 2018. Accessed March 2021. https://www.census.gov/topics/health/disability/guidance/data-collection-acs.html
62. **Services**. Health Council of South Florida (HCSF). Published 2106. Accessed March 2021. https://www.healthcouncil.org/services
63. **Andrew MK, Mitnitski AB, Rockwood K.** Social vulnerability, frailty and mortality in elderly people. *PLoS One.* 2008;3(5):e2232.
64. **Chau PH, Gusmano MK, Cheng JO, *et al.*** Social vulnerability index for the older people—Hong Kong and New York City as examples. *J Urban Health.* 2014;91(6):1048-1064.
65. **Bukvic A, Gohlke J, Borate A, Suggs J.** Aging in flood-prone coastal areas: discerning the health and well-being risk for older residents. *Int J Environ Res Public Health.* 2018;15(12):2900.
66. **Pinelli JP, Roueche D, Kijewski-Correa T, *et al.*** Overview of damage observed in regional construction during the passage of Hurricane Irma over the State of Florida. In: *Forensic Engineering 2018: Forging Forensic Frontiers*. American Society of Civil Engineers; 2018:1028-1038.
67. **Sampson N, Nassauer J, Schulz A, *et al.*** Landscape care of urban vacant properties and implications for health and safety: lessons from photovoice. *Health Place.* 2017;46:219-228.
68. **Duggan S, Deeny P, Spelman R, Vitale CT.** Perceptions of older people on disaster response and preparedness. *Int J Older People Nurs.* 2010;5(1):71-76.
69. **McSweeney-Feld M.** Assistive technology and older adults in disasters: implications for emergency management. *Disaster Med Public Health Prep.* 2017;11(1):135-139.
70. **Faverio M.** Share of those 65 and older who are tech users has grown in the past decade. Pew Research Center. Published 2022. Accessed May 19, 2023. https://www.pewresearch.org/short-reads/2022/01/13/share-of-those-65-and-older-who-are-tech-users-has-grown-in-the-past-decade

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