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Spatiotemporal implications of flooding on relocation risk in rural and urban coastal municipalities

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ABSTRACT

The research on coastal hazards predicts substantial adverse impacts of chronic and episodic flooding on populated coastal areas. Despite the growing evidence about anticipated flood risks, many coastal communities are still not adapting. The observed disconnect between science on physical impacts and adaptation decision-making in part reflects stakeholders' inability to envision the implications of these impacts on socioeconomic systems and the built environment in their jurisdictions. This inertia is particularly apparent in the discourse on flood-driven displacement and relocation. There is a lack of knowledge about direct and indirect flood impacts on community attributes and services that contribute to relocation decision-making. This study holistically evaluates the flood exposure on municipal features vital for socioeconomic stability, livelihoods, and quality of life across spatiotemporal scales. As such, it uses a more nuanced approach to relocation risk assessment than those solely focused on direct inundation impacts. It measures flood exposure of land use, land cover, and sociocultural and economic dimensions that are important drivers of relocation in selected rural and urban areas. The approach uses a 50-year floodplain to delineate populated coastal locations exposed to 2% Annual Exceedance Probability (AEP) storm surge projections adjusted for 2030, 2060, and 2090 sea level rise (SLR) scenarios. It then evaluates the potential impacts of this flood exposure on different types of land uses and critical socio-economic assets in rural (Dorchester and Talbot Counties, Maryland, USA) and urban (Cities of Hampton, Norfolk, Portsmouth, and Virginia Beach, Virginia, USA) settings. The results show that some urban land uses, such as open space, military and mixed-use, and rural residential and commercial areas, might experience significantly more flooding. There are also notable differences in the baseline flood exposure and the anticipated rate and acceleration in the future among selected communities with significant implications for relocation planning.

1. Introduction

Climate change is expected to increase global sea levels (IPCC, 2021) and the intensity and magnitude of coastal storms over the next decades (Knutson et al., 2010; Villarini and Vecchi, 2013; Taherkhani et al., 2020). Models project a 0.6 m sea level rise (SLR) in the U.S. between 2020 and 2100, possibly increasing over 1 m if future emissions are not reduced (NOAA, 2022). Moreover, moderate coastal storm flooding will occur ten times more frequently by 2050 than currently (NOAA, 2022). The compound coastal flooding from SLR, precipitation, and extreme weather events will have significant adverse impacts on coastal communities (Kirezci et al., 2020), including damage to infrastructure, natural features, livelihoods, and quality of life (Church et al., 2008; Frey et al., 2010; Irish et al., 2010; Knutson et al., 2010; Nicholls and Cazenave, 2010; Karl et al., 2009). It will also directly or indirectly affect social, environmental, and economic sectors in coastal urban areas (Alexander et al., 2012). The heightened flood risk in some areas reflects a combination of physical vulnerability (Titus, 2009; Kulp and Strauss, 2019) and the legacy of unsustainable land use and development in coastal areas, encouraging high population densities and urban expansion along the oceanfront (NCADAC, 2013). The manifestation of flood impacts is location-specific, with some coastal communities

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experiencing a major disaster (e.g., Hurricane Sandy disaster in New York and New Jersey and Hurricane Katrina in New Orleans) and others repeated exposure to chronic or nuisance flooding (e.g., Hampton and Norfolk).

Communities have three main options to respond to flooding: they can protect their assets and people using engineering solutions, accommodate flooding with flood-control measures, or relocate (Klein et al., 2001; Nicholls and Tol, 2006; Butler et al., 2021). Even though current and future coastal flood risks are already well-defined, many coastal communities are still not adequately preparing for their acceleration and change in extent (Barnett et al., 2014; Olazabal et al., 2019). The hesitation to prioritize adaptative efforts is even more evident when considering permanent relocation, even though this strategy sometimes represents the most viable long-term solution to advancing coastal flooding and erosion. Relocation is a permanent voluntary movement of the whole or part of a community due to gradual or sudden coastal stressors that differ from the typical climate and environmental variability (Bukvic, 2015). It is often considered the most challenging adaptive strategy due to its potential socioeconomic, cultural, and political costs for sending and receiving locations (Magnan et al., 2022). However, relocation can receive more public support when associated with extensive public engagement and participation in all steps of the relocation process (Shi et al., 2022) or conversion of the acquired properties into public open spaces (Buss, 2005).

Some coastal communities are already actively considering relocation in response to coastal erosion, land loss, and persistent flooding (Cronin and Guthrie, 2011; Patel, 2006; Campbell et al., 2005; Dannenberg et al., 2019), such as Newtok and Kivalina villages Alaska (Alaska Climate Change Sub-Cabinet, 2010; Bronen, 2015) and Isle de Jean Charles in Louisiana (Simms et al., 2021). The recent coastal flood events and disasters advanced the scholarly discussion on the effectiveness of relocation for flood risk reduction (Groen and Polivka, 2010; Landry et al., 2007; Elliott & Pais, 2006). However, the research on proactive relocation is prevalently lacking, even though an anticipatory approach would prevent property damages, save resources and lives, and allow for thoughtful consideration of sociocultural, political, and economic context to preserve the place-based attributes and values (Lopez-Carr and Marter-Kenyon, 2015). The 3rd National Climate Assessment Report noted that relocation might become a more pressing adaptation option for many coastal locations as half of the socially vulnerable areas face displacement under 0.3 1.2 m of SLR (Moser et al., 2014). This risk of forced displacement reflects the inability of communities to afford structural protections, difficulty in justifying the public expense for expensive interventions, and the lack of political support for a more orderly relocation process (Moser et al., 2014).

Currently, the key policy and financial mechanism to facilitate relocation in the U.S. is through voluntary buyouts or acquisition programs supported by federal agencies (e.g., FEMA/Hazard Mitigation Grant Program and HUD/Community Development Block Grants programs) and state and local initiatives (e.g., Blue Acres Program and Harris County Flood Control District Voluntary Buyout program) (Freudenberg et al., 2016). Local governments assist homeowners dealing with repetitive flood damages by helping them apply for FEMA s Hazard Mitigation Grant Program and providing 25% of matching funds for property acquisition compensation (FEMA, 2017). The current buyout programs are primarily based on cost-benefit analysis and rarely account for qualitative socio-cultural and other contextual community considerations, such as quality of life, social networks, and community cohesion (Greer and Brokopp-Binder, 2016; Godschalk et al., 2009). The households qualify for the buyouts based on their location in the floodplain and the duration and extent of prior flood damages. Such criteria do not account for other flood impacts on the community vital for quality of life and public safety, such as limited accessibility, loss of livelihood, and social disarticulation. Recent studies observed that willingness to relocate reflects a broader set of considerations, with land use decisions, zoning changes, and development affecting the push and pull factors of mobility decision-making (King et al., 2016). For example, Cummings et al. (2012) noted that relocation could catalyze infrastructure improvements and new development, increase property values, revive the retail sector, and lead to a more sustainable economic future with adequate planning and financial inputs. It can also improve the physical, environmental, and socioeconomic resilience of communities challenged by flooding while allowing them to maintain their essential economic functions, social capital, and cultural identity with minimal federal investment (Godschalk et al., 2009).

To inform relocation discourse, local stakeholders need to understand the comprehensive risks and indirect impacts of flooding on different dimensions of the human system, such as quality of life, psychosocial health, personal safety, and economic aspirations. Such knowledge can inform adjustments of fiscal resources to create new community programs, employment and microfinance opportunities, microfinance services, training and education options, health care access, and land use adjustments (Hill et al., 2006). The main barriers to advancing the current discourse on coastal relocation include its scale, scope, and fragmented approach, all affecting the transferability of lessons learned to different contexts. It is also unclear how the relocation process will unfold due to varying household and community-level tipping points driving mobility decision-making. The narrow framing of relocation discourse as a part of broader mobility preferences and migration trends might prevent a more holistic discussion on all community aspects influencing people s decision to move. Barnett et al. (2014) proposed that localities should focus on possible adaptation pathways instead of disjoint strategies that would provide sufficient time to build community consensus on the next steps, paving the road to a public and politically acceptable adaptation framework such as managed relocation.

One approach to advance relocation research focusing on more integrated place-based considerations is to account for other community dimensions but household flood impacts. Many studies measuring spatial implications of coastal flooding on the human systems tend to identify high-impact areas under different flood scenarios and quantify assets and populations at risk that would be directly affected by flooding or displacement. A recent review of 33 papers looking at SLR exposure and migration found that they measure one of the following: people affected by different SLR scenarios, those living in areas experiencing recurrent flood events, and populations residing in Low Elevation Coastal Zone (LECZ) (McMichael et al., 2020). The authors noted that such analytical approaches often undermine the complex relationship between SLR and mobility (McMichael et al., 2020), commonly shaped by various behavioral, socioeconomic, political, and institutional factors affecting human mobility (Hauer et al., 2020). Further, Fischer (2018) found that climate change was a negligible driver of adaptive behaviors compared to concerns with economic decline, loss of job opportunities, restrictive environmental management regulations and land use policies, demographic changes, and natural hazards. These observations suggest that flood impacts on Land Use and Land Cover (LULC), community assets, and local economic engines might play an important role in moderating the mobility outcomes of future flood exposures.

Local governments will likely experience the most profound impacts of coastal flooding on their fiscal resilience. Their institutional decision-making structures tend to isolate individual problems based on the administrative and funding domains (e.g., housing, transportation, public works, and social services), often disregarding their interconnectedness and dependencies vital for community resilience. This siloed approach can also result in a limited understanding of correlations between the government s ability to address community problems and outmigration. The primary objective of this study is to assess the possible consequences of coastal flooding on local jurisdictions in selected rural and urban settings over different spatiotemporal scales that might lead to displacement and relocation. Our approach aims to evaluate the potential flood impacts of LULC, socioeconomic conditions, and cultural identity, all of which play a vital role in relocation decision-making. For

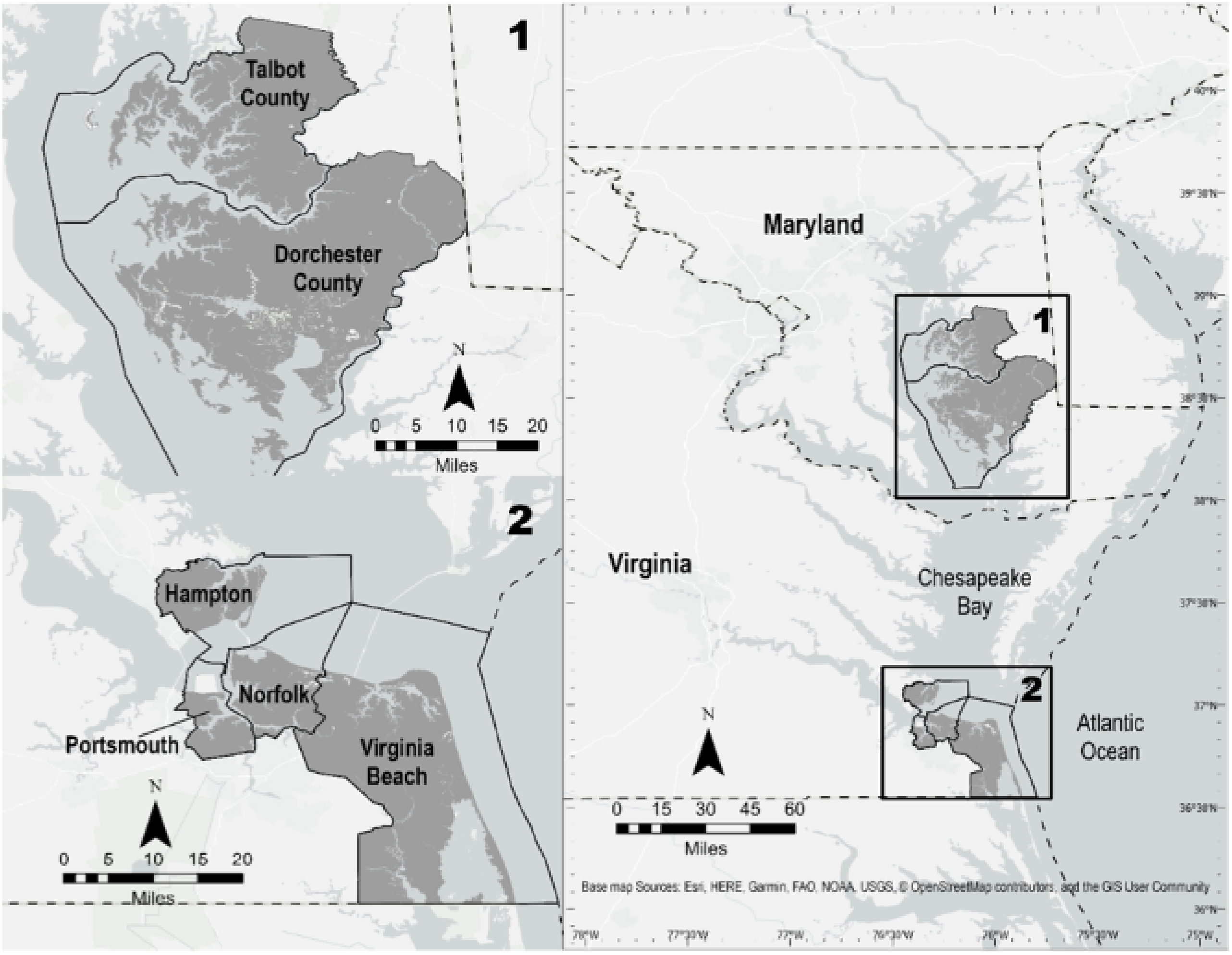


Fig. 1. Map of the study area: The Counties on the Eastern Shore, Maryland (top left), cities in Hampton Roads, Virginia (bottom left), and their geographic relation to each other (right).

example, LULC affects migration by indicating desirable (e.g., open public spaces and green areas) and undesirable (e.g., industrial areas and derelict commercial areas) community features that shape place attachment and quality of life important in relocation decision-making. Moreover, comparing flood exposure in rural and urban locations is vital to address the broader scope of rural-to-urban and urban-to-rural migration often enabled by LULC decisions, leading to more effective management of regional growth and development (Park et al., 2022). One example of proactive spatially-explicit community realignment is the officially adopted City of Norfolk's Vision 2100, designed to guide future investment and development in this municipality based on its flood risk (City of Norfolk, 2016). This forward-looking document was integrated into a new zoning ordinance aiming to improve flood resilience and facilitate the transition to areas with higher elevations using Coastal Resilience Overlays (CROs).

Lastly, it is important to acknowledge that rural and urban residents will respond differently to increased flood risk based on their coping capacity, assistance needs, and priorities. Despite the increasing socioeconomic and environmental integration between these two settings mostly related to ecosystem services utilization, some differences persist (Gebre and Gebremedhin, 2019). For example, urban areas continually grow and have more ethically and racially diverse populations than rural areas (Parker et al., 2018). In addition to the growing political divide between these two settings, rural residents are more committed to their places than urban populations but more economically insecure (Parker et al., 2018). Even though the blending of rural and urban settings results in new types of land use and economic activities, the urban areas have more leverage to develop infrastructure for continued service delivery in response to climate stressors than the increasingly politically and economically marginalized rural areas (Morton et al., 2014). A number of scholarly papers recognized the differing capacities of these two settings to engage in risk reduction and climate change planning.

For example, Su et al. (2022) conducted a comparative study of rural and urban areas to assess their climate change resilience and suggested that urban locations depend more on socioeconomic structures while rural areas on local knowledge and economic self-sufficiency for resilience. Zhou et al. (2022) also used the rural and urban typology to study vulnerability to climate change in South Africa and concluded that adaptation policy solutions should be tailored to reflect different root causes of vulnerability in these two settings. Another study looked at the social dimensions of riverine and coastal flood risk along rural-urban gradients in the US and concluded that flooding risk is higher in rural census tracks with more vulnerable populations and sensitive land- and water-based industries (Rhubart and Sun, 2021). In addition to climate stressors and flooding, rural versus urban dichotomy has been used to assess the feasibility of adaptation strategies in the water sector in Jakarta and Rotterdam, indicating that institutional impediments are more significant barriers to flood management implementation than the technological challenges, especially in urban settings (Singh et al., 2020). Another study exploring climate change migration in Mexico found that international migration was only observed in rural parts due

Table 1
The key socioeconomic indicators for selected municipalities.

Municipality	Population Density per sq. mile	Median household Income	White alone %	Bachelor's degree or higher %	Persons in Poverty %	Persons 65 Years and over %
RURAL						
Talbot County	140.7	$67,204	83.3	40.6	9.2	29.7
Dorchester County	60.3	$52,145	66.7	21.2	15.4	22.1
URBAN						
Hampton	2673.2	$54,550	41.4	26.9	15.8	14.5
Norfolk	4486.4	$49,146	47.0	28.8	19.7	10.6
Portsmouth	2838.8	$50,224	39.8	21.9	17.2	14.2
Virginia Beach	1758.9	$74,186	66.3	36	7.6	13.2

Source: U.S. Census Bureau (2021)

to climate change impacts on agriculture and employment in this sector (Nawrotzki et al., 2015).

This paper brings together the elements of coastal vulnerability risk assessment that could undermine place-based socioeconomic and cultural assets and, as such, contribute to the relocation push factors in addition to direct flood impacts. It responds to the need for research beyond simplistic casual observations and instead captures the complexity of political and socioeconomic underlying conditions that often contribute to displacement and migration (Warner et al., 2010). Thus, our analysis accounts for flood impacts leading to loss of livelihoods, personal safety, and identity from damages to cultural assets, critical facilities, and workplaces. Hauer et al. (2020) note that the individual in situ adaptation measures are insufficient if schools, health facilities, workplaces, and other residential and non-residential assets are not equally protected. Conventional research methods assessing flood impacts on the human coastal systems in the context of migration are mostly limited to future projections of permanent SLR overlaid with current or future population estimates. Even though coastal vulnerability assessments increasingly account for social dimensions of flood exposure (e.g., number of buildings or percent of older populations at risk), they do not explicitly focus on attributes relevant to relocation. They also do not recognize the variation between rural and urban settings that may result in different types and extents of displacement and its long-term outcomes. Even though some scholars emphasize the blurring of rural and urban settings (Balta and Atik, 2022) and challenge the dichotomous classification of these two settings as we know it (Cyriac and Firoz, 2022), in our study, the selected rural locations are located on a peninsula and geographically more isolated from urban areas preserving many traditional rural features and typical challenges.

2. Methods

2.1. Case study location

This study is focused on the rural Dorchester and Talbot Counties in Maryland and the urban Cities of Hampton, Norfolk, Portsmouth, and Virginia Beach in Virginia, the US. These locations were selected based on their flood risk and the varied extent of social vulnerabilities within their administrative boundaries (Fig. 1). An area is classified as urban if it incorporates at least 2500 people, with a minimum of 1500 residing outside the institutional housing (U.S. Census Bureau, 2022). The U.S. Census Bureau's urban classification also accounts for population density and other land-use characteristics. Rural areas are all those that are not urban and are less dense, with a smaller population, less built environment, and greater distances between amenities (Ratcliffe et al., 2016). In Virginia, the selected cities represent independent administrative units with similar autonomous governance structures as counties and their tax base, services, and resident populations (Turnbull and Tasto, 2008). According to the U.S. Census Bureau (2016), the Counties are self-governing primary legal subunits of the states. In this study, the independent cities in Virginia can be considered urban equivalents of the rural counties in Maryland. However, they differ in size, population density, and level of development. The four cities were selected among 17 municipalities in the Hampton Roads metropolitan area due to their high physical vulnerability to coastal flooding. Namely, this coastal area has the highest relative sea level rise on the East Coast of 4.7 mm/year

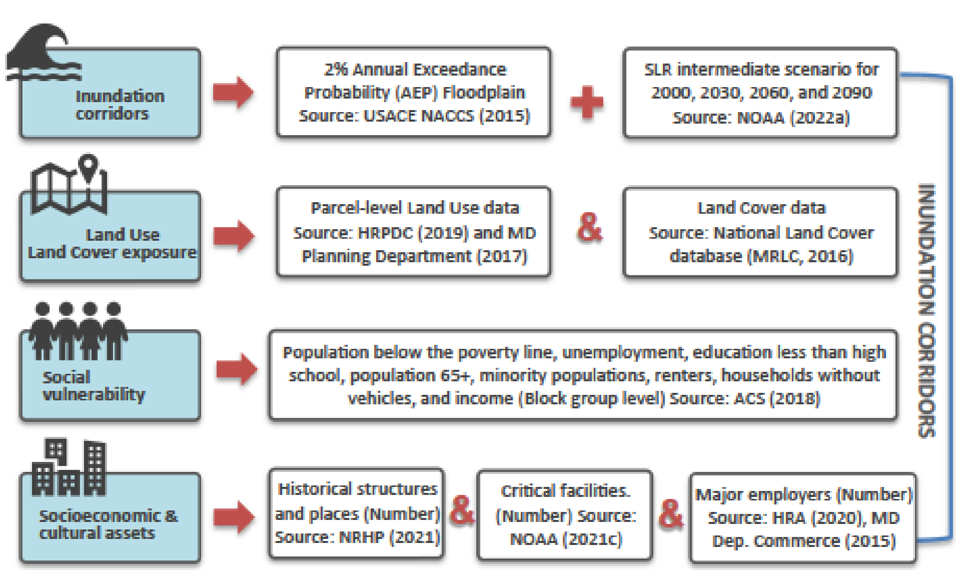


Fig. 2. Research approach and methodological steps.

(Sweet and Park, 2014), with significant projected impacts on the residential properties, critical facilities, economic assets, hazardous waste sites, and infrastructure (Strauss et al., 2014). These higher SLR estimates primarily stem from the land subsidence at a rate of 2.8 mm/year, sediment compaction, and glacial isostatic rebound (Eggleston and Pope, 2013).

Neighboring rural Talbot and Dorchester Counties are located on the Eastern Shore in Maryland and differ in size, political, institutional, and socioeconomic characteristics, cultural and historical context, and fiscal health (Table 1). Talbot County is smaller and more populous, with higher residential density, a whiter and older population, and higher revenues than Dorchester County. Even though Hampton Roads jurisdictions are geographically, physically, and socioeconomically interconnected and interdependent (e.g., shared infrastructure, work-home commute, services, and investments), they differ in several socioeconomic indicators and institutional capacity to deal with coastal flooding (Bukvic and Harrald, 2019). The differences between urban and rural locations are especially evident in the population density and percentage of persons over 65. For example, the population density in Norfolk is 4486.4 persons per square mile versus 60.3 in Dorchester. The portion of the population over 65 is lower than 15% in all four Hampton Roads locations, while these values exceed 20% in Talbot and Dorchester Counties. Between rural areas, Talbot County has a lower percentage of persons living in poverty and a higher median income than Dorchester County. Among selected cities, Virginia Beach has the lowest rate of people in poverty at 7.6% and the highest median household income compared to the other three municipalities. Overall, Talbot County has the highest white population, with 83.3%, and the most educated residents, with 40.6% having completed Bachelor s degree or higher.

2.2. Geospatial analysis

Our research approach consists of several steps holistically assessing community-level features affecting mobility decisions and patterns (Fig. 2). The first step was to characterize flood risk using SLR-adjusted storm surge flood projections over multiple spatiotemporal scales. After identifying the inundation corridor, we assessed the current and future flood exposure of LULC, social vulnerability, and socioeconomic and cultural assets in study locations.

2.2.1. Inundation corridors

First, we determined the storm surge flood risk at different SLR scenarios. Based on those estimates, we delineated the inundation corridors within our study locations (Mitchell et al., 2023). We considered the 2% annual exceedance probability (AEP) flood hazard to represent a moderately frequent flood hazard. In the absence of any change in the risk (e.g., in the absence of SLR and mitigation measures), a person whose home falls into the 2% AEP floodplain is taking on a 1 in 2 chance of flooding over 30 years (typical mortgage life in the United States). To characterize the current and future 2% AEP flood hazard, we leveraged the U.S. Army Corps of Engineers (2015) North Atlantic Coast Comprehensive Study s statistical coastal flood hazard data (NACCS; Cialone et al., 2015; Nadal-Caraballo et al., 2015). The NACCS flood statistics are based on state-of-the-art statistical methods (Resio and Irish, 2015) and high-fidelity surge simulations for hurricanes and extratropical storms (ADCIRC; e.g., Dietrich et al., 2011). Astronomical tides were accounted for within the modeling and statistical framework. The surge simulations used a base mean sea level derived from the 1983 2001 tidal epoch, approximately corresponding to the mean sea level in 1992 (Cialone et al., 2015). We used the statistical mean NACCS 2% AEP results with uncertainty on the order of 0.5 m (68% confidence interval) (Nadal-Caraballo et al., 2015). The NACCS hazard characterization methodology is consistent with the methods used by the United States Federal Emergency Management Agency for establishing Flood Insurance Rate Maps.

NACCS 2% AEP flood elevations are reported at 2632 unique geographic stations in the Chesapeake Bay region (635 and 948 stations, respectively, at our rural Maryland and urban Virginia sites). The NACCS-reported 2% AEP flood elevations differ little across the rural Maryland site, with 90% of the stations within 0.22 m of the median value of 1.64 m, NAVD88 (1992 mean sea level). The NACCS-reported 2% AEP flood elevations are much higher at the urban Virginia site, with a median value of 2.39 m, NAVD88 (1992 mean sea level). In addition, flood elevations are much more variable, with 90% of the stations between 1.29 and 2.88 m, NAVD88 (1992 mean sea level). This more extreme hazard and wide variation in flood elevation at the Virginia site is attributed to hydrodynamic complexities arising from proximity to the open ocean and the exit of several rivers into the Bay, as well as the extensive infrastructure in this urban area.

Because of the nonlinear relationship between SLR and coastal flooding (e.g., Smith et al., 2010; Mousavi et al., 2011; Bilskie et al., 2014; Taylor et al., 2015; Liu et al., 2019), the NACCS study quantified SLR versus flood elevation nonlinearity based on dynamically simulating surge atop a 1-m SLR (Cialone et al., 2015; Nadal-Caraballo et al., 2015). The NACCS study shows this nonlinearity is relatively uniform across the rural Maryland site with normalized nonlinearity (defined as dynamically simulated new flood elevation less the current flood elevation and SLR amount, divided by the SLR amount; Bilskie et al., 2014) at 90% of stations between 8 and 2%, with a median of 4%. Negative normalized nonlinearity at the Maryland site means that SLR dampens the meteorological surge response. Thus, while resulting in an overall increase in flood elevation with SLR, flood elevation differences at the Maryland site are generally more minor than the amount of SLR, by about 4% on average. At the urban Virginia site, the NACCS study shows that the surge-SLR nonlinearity varies widely across the area, with normalized nonlinearity at 90% of the stations ranging from 12 to 5%, with a median of 3%. Positive nonlinearity is prevalent in the southern Virginia Beach area, leading to new flood elevations that exceed current flood elevations by more than the SLR amount. On average, Norfolk and Hampton exhibit moderate to weak negative nonlinearity, with new flood elevations differing from existing ones by less than the SLR amount.

We leveraged the NACCS study s characterization of surge-SLR nonlinearity for the 1-m SLR case to project 2% AEP hurricane flood elevations for the base year of 2000 and the future years 2030, 2060 and 2090 using the National Oceanic and Atmospheric Administration s (NOAA) Intermediate projections (Sweet et al., 2017). The NACCS-reported 2% AEP flood elevations are adjusted by multiplying the normalized nonlinearity by the sea level change from 1992 to the target year, then adding this quantity to the sum of the NACCS-reported 2% AEP flood elevation and sea level change (Appendix, F1). This approach represents interpolation of the NACCS data for sea level change between 0.00 and 1.00 m (2000, 2030, and 2060) but extrapolation beyond the NACCS data for sea level change greater than 1.00 m (2090). Primary sources of uncertainty in our future 2% AEP projections arise from this interpolation and extrapolation, but to a larger extent from the NOAA 2017 sea level change projections, from the assumption of no change in coastal morphology or anthropogenic activity between the sea level change scenarios simulated in the NACCS study, and from uncertainty in the statistical extremes. The point grid USACE data was converted into a raster format using inverse distance weighting in ESRI s ArcGIS Pro after the data was projected to match the digital elevation model (DEM) references to the NAV88 vertical datum (NOAA, 2022). The values of this raster represent the water surface elevations. Once the DEM was subtracted from this raster, all remaining positive values represented areas where flooding would occur under the given scenario. These rasters were reclassified by converting any value over 0.2 m to one and the rest to zero. The minimum depth value of 0.2 m was selected as a threshold of depth where property damage can be expected (Dinh et al., 2012; Balica et al., 2013). A polygon version of the final raster was also made to support the analysis between the inundation corridor and other polygon layers.

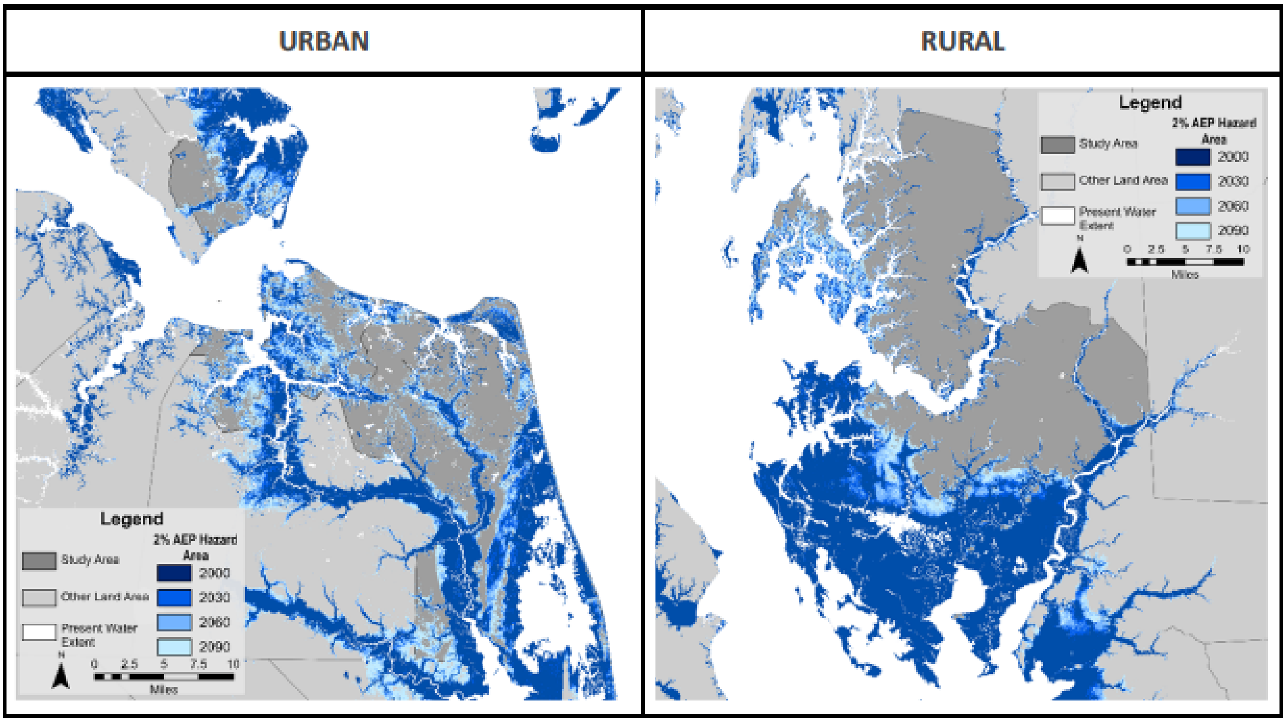


Fig. 3. Flood exposure for 2000, 2030, 2060, 2090 SLR scenarios.

2.2.2. *Parcel level analysis*

We used static, current parcel-level LULC data within the inundation corridor to identify which types are most at risk of flooding in the future. Parcel-level land use data for Hampton Roads comes from the Hampton Roads Planning District Commission (HRPDC) (2019). The HRPDC standardized these data across municipalities to accommodate for differences in zoning categorization. For Talbot and Dorchester Counties, parcel-level data comes from the MdProperty View database maintained by the Maryland Department of Planning (2017). The data had to be delineated to accurately analyze flood-prone areas since the property lines extended into the water and did not reflect the actual shoreline. The coastline was delineated by uniting the TIGER county outlines with a layer of open water from the National Hydrography Dataset (USGS, 2022) and deleting the water areas from the new layer. Open water, defined by the NOAA GIS workflow (NOAA, 2021b), includes bays/inlets, lakes/ponds, reservoirs, seas/oceans, and estuaries over 10 acres. However, we used 5 acres as the minimum criteria for a finer delineation. We used this edited layer to clip the layers to exclude water areas. These delineated county/city outlines were used to determine the inundation area in each location.

To assess the flood impacts on land use, the land use data on a parcel level were resampled to a 30-meter resolution to match the resolution of the inundation corridors. The percent of each land use category inundated for each scenario was then calculated. The land use categories for the rural parcels differed from those for the urban parcels. Commercial, industrial, exempt commercial, and commercial condominiums were the selected categories for these parcels. The exempt commercial category includes tax-exempt uses, such as churches and public properties. Land cover within the inundation corridors was evaluated using the National Land Cover Database (NLCD) (MRLC, 2016). The NLCD layer was masked using the inundation corridors. The pixels count for each land cover type was multiplied by the area of each pixel to determine which land cover types are inundated for each flood scenario. Historic places (buildings, sites, and structures) from the National Register of Historic Places database (NRHP, 2021), critical facilities (e.g., law enforcement facilities, fire stations and EMS facilities, hospitals, and other medical facilities, and schools) (NOAA, 2021c), and major employers (1000 + employees in urban and 100 + in rural places; Hampton Roads Alliance, 2020; Maryland Department of Commerce, 2015) within the inundation corridors were identified by selecting relevant parcels that were located entirely within the inundation corridor for each scenario.

2.2.3. *Social vulnerability assessment*

We used the Census data from the 2018 American Community Survey 5-year estimates (ACS, 2018) to construct a simple social vulnerability index at the block group level. We then applied zonal statistics to find an inundated area within each block group and then divided it by the total area to find the ratio of the inundated zone. This index was used to identify at-risk populations with difficulty recovering from each flood event and investing in flood risk-reduction measures. We selected the ten most commonly used variables in social vulnerability assessments (Cutter et al., 2003; Yoon, 2012): Population below the poverty line (Census Table ID B23024); unemployment (Census Table ID B23025); education less than high school (Census Table ID B29002); population 65 + (Census Table ID B01001); minority population (Census Table ID B02001); English non-speaking households (Census Table ID C16002); disabled population (Census Table ID B23024); households occupied by renters (Census Table ID B25044); households without vehicles (Census Table ID B25044); and income (Census Table ID B19013).

These variables were standardized using a min-max rescaling, x (scaled)=x-min(x)/max(x)-min(x) (Yoon, 2012), and then combined using linear aggregation (Bathi and Das, 2016; Nicolodi and Peterman, 2010) to assign a vulnerability score to each block group. A vulnerability score with higher values indicates higher social vulnerability. Since higher income values indicate less vulnerability, we used the inverse of the standardized income values in the aggregation. Block groups were then categorized into five risk levels using the natural breaks method (Moreira et al., 2021). The average of all neighboring block groups accounted for missing income values. Overall, only three block groups in Hampton Roads that were not adjacent to open water were missing data for all selected variables. One of these block groups contains the Norfolk International Airport, likely without any permanent residents within its bounds.

	Municipality	% Change
URBAN	Norfolk	44%
	Portsmouth	40%
	Hampton	27%
	Virginia Beach	22%
RURAL	Dorchester	10%
	Talbot	14%

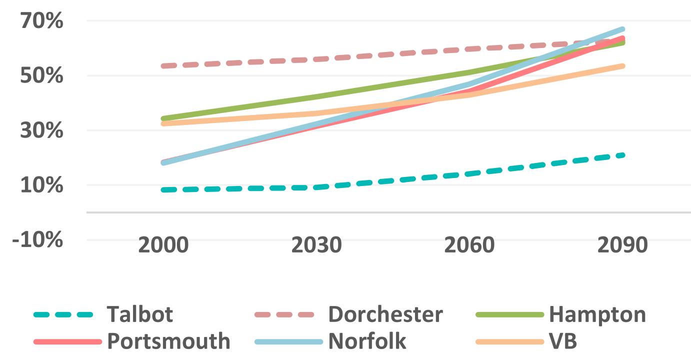


Fig. 4. Total percentage of change in flood-prone area 2000 2090 (table on the left) and the percent of the total area inundated over time in each location (graph on the right, rural counties shown in dashes).

Table 2
The land use exposure to coastal flooding in percent per total land area within the administrative boundaries of selected rural and urban municipalities.

	URBAN				RURAL			
LAND USES	2000	2030	2060	2090	2000	2030	2060	2090
Residential	18%	24%	33%	47%	41%	45%	50%	56%
Commercial	11%	14%	21%	34%	59%	61%	63%	65%
Industrial	19%	25%	36%	53%	11%	11%	12%	12%
Agriculture	36%	44%	54%	69%	25%	28%	33%	38%
Military	30%	38%	49%	61%	-	-	-	-
Mixed Use	28%	37%	49%	68%	10%	12%	18%	24%
Open Space	59%	64%	69%	76%	-	-	-	-
Vacant	32%	37%	45%	57%	-	-	-	-
Institutional	17%	22%	30%	41%	-	-	-	-
Exempt	-	-	-	-	76%	78%	80%	83%
Marsh	-	-	-	-	100%	100%	100%	100%

N.B. Residential includes residential condos; Commercial includes commercial condos and exempt commercial; Mixed use includes residential commercial and commercial residential
Source: Own elaboration

3. Results

3.1. Exposure to coastal flooding

Our projections (Appendix, Table A1) indicate that 2% AEP flood elevations in 2030 at both sites will increase by 15% and will approach or exceed the year-2000 adjusted NACCS 1% AEP flood elevations (1 in 4 chance in 30 years). By 2060, we project that the 2% AEP flood elevations will approach or exceed the 2000 0.5% AEP flood elevations (1 in 7 chance in 30 years), increasing 25 50% depending on location. By 2090, we project the 2% AEP flood elevations to be 40 90% higher than those in 2000, depending on location. Similar estimates have been produced by Mitchell et al., 2023, albeit on a more aggregate scale. The projected coastal flooding shows a significant inundation in both rural and urban areas in Maryland and Virginia, in areas facing the bay and ocean, and along the major and minor waterways (Fig. 3).

On a municipal scale (Fig. 4), even though the rural areas initially have the greater extent of inundated area (2000 baseline R 39% and U 28%, 2030 R 42% and U 34% of the total area), by 2060 and 2090, it is comparable to that of selected urban settings (2060 R 46% and U 43%, 2090 R 50% and U 56%). A more notable difference is evident from the absolute percent change in inundation, with rural counties having minimal change over time (2000 2090, Dorchester 10%, and Talbot County 14%). Urban cities experience more significant change, especially Portsmouth (40%) and Norfolk (44%), located within the Elizabeth River watershed. Virginia Beach (22%) and Hampton (27%) have a lower percentage of change over time.

Table 2 shows that the most affected land uses in urban areas according to the 2090 SLR scenario are open space (76%), agriculture (69%), mixed-use (61%), and military (61%), while the least affected are commercial areas (34%). The open space will experience the least percent change in exposure over the selected period. In contrast, residential land use will see 2.6 times increase, commercial three times increase, industrial 2.7, and mixed-use and institutional 2.4 times

Table 3
The land cover exposure to coastal flooding in percent per total land area within the administrative boundaries of selected rural and urban municipalities. The Table s categories were grouped from the original NLCD classes.

	URBAN			RURAL				
LAND COVER CATEGORY	2000	2030	2060	2090	2000	2030	2060	2090
Developed, Open Space	20%	25%	34%	46%	17%	21%	26%	33%
Developed, Low-High Intensity	15%	21%	32%	47%	20%	22%	25%	29%
Mixed Agriculture	15%	26%	37%	55%	12%	15%	21%	26%
Non-Wetland Vegetated	22%	28%	36%	50%	18%	21%	25%	31%
Mixed Wetlands	66%	71%	76%	83%	70%	72%	76%	79%

Source: Own elaboration

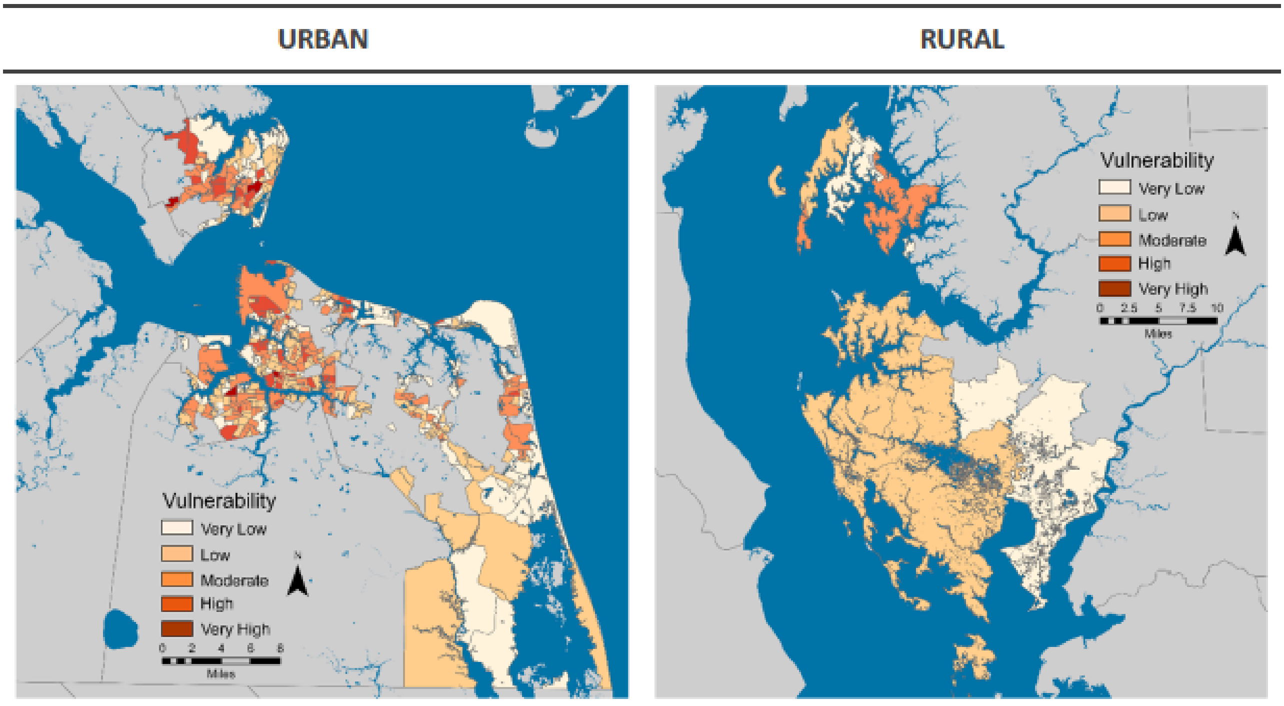


Fig. 5. Social vulnerability of block groups at least 50% within the inundation corridor in 2090.

Table 4
The average standardized indicator scores for each municipality (ACS, 2018; lower values indicate lower vulnerability, higher scores indicate higher vulnerability within the 2090 flood corridor).

Variable	URBAN	RURAL
Unemployed	0.1135	0.2699
No high school	0.1306	0.2013
Limited English	0.0470	0.0108
Income	0.7005	0.4931
Below poverty level	0.1118	0.0958
Disabled	0.2263	0.1818
Minority population	0.1116	0.0450
Renters	0.1455	0.1027
No Vehicle	0.1075	0.0441
Over 65	0.1183	0.1029
Total	0.1814	0.1547

Source: Own elaboration

increase in exposure. The exposure of currently vacant areas will almost double from 32% to 57% by 2090, indicating that potential redevelopment initiatives should consider this propagating risk when making future investments. Our results suggest that, even by 2060, a third of residential areas will be at risk of coastal flooding, followed by commercial, industrial, and institutional spaces. The exposure of military facilities will double by 2090 compared to other land uses and reflect already high baseline exposure (30–61%). The mixed-use and industrial land uses will experience a steeper increase in exposure between 2060 and 2090, clearly showing exposure acceleration past the mid-century.

In rural areas, the most exposed land uses are marshes (100%), exempt areas (83%, e.g., golf courses, churches, and areas under conservation easements), and commercial locations (65%). The exposure of the residential areas to future coastal flooding is also substantial, starting with a 41% exposure baseline and exceeding 56% by 2090. This high risk to residential properties reflects the legacy of clustered development along the shoreline to support a water-based economy and preference for coastal living. As for the land cover, wetlands will be most affected in rural and urban areas (79% and 83%, respectively) (Table 3).

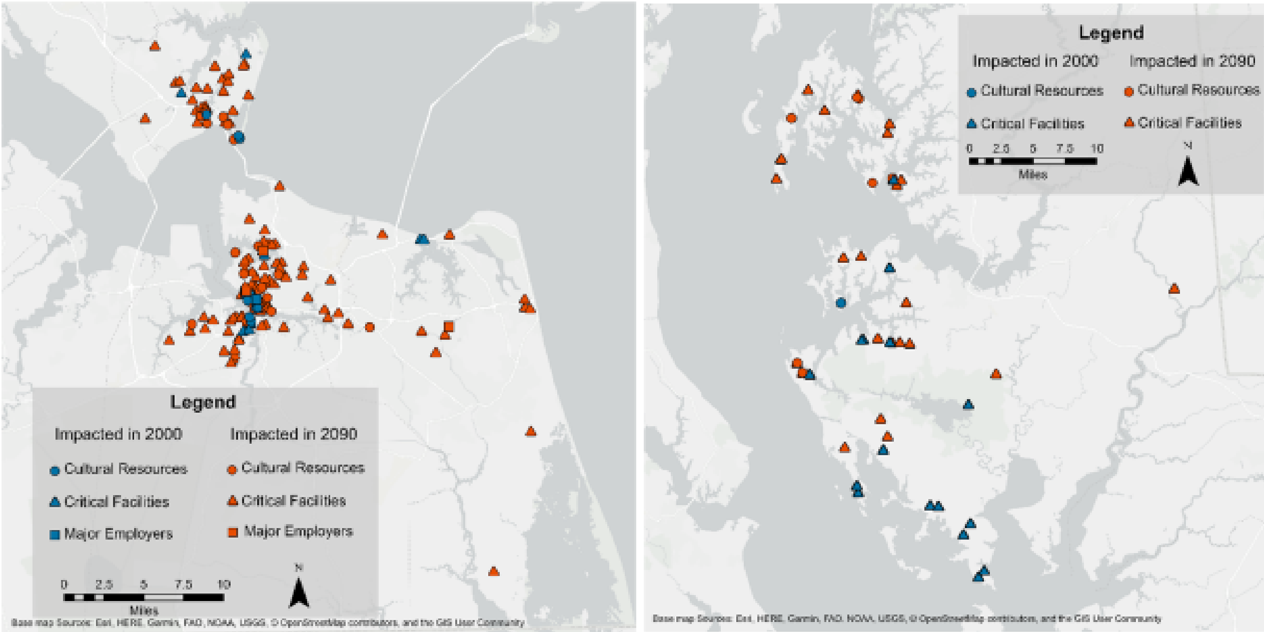
3.2. Social vulnerability within the flood corridor

Fig. 5 shows social vulnerability estimates of block groups with at least 50% of land area within the inundation corridor in 2090. The urban municipalities are more vulnerable than the rural counties mainly due to lower income, populations with a disability, renters, and residents who did not complete secondary education (Table 4). The social vulnerability of two rural counties varies and is driven by their unique socioeconomic circumstances. Talbot County is overall more socially vulnerable, with Tilghman Island and an area around Bellevue community having a moderate vulnerability. In the urban area, Virginia Beach, with its tourism-oriented oceanfront and rural locations inland, is the least vulnerable among urban municipalities. The other three cities have similar social vulnerability with smaller pockets of heightened vulnerability, likely reflecting their historic socioeconomic context. Among the individual indicators, rural areas have notably higher unemployment rate and a population with incomplete high school. In contrast, urban areas have more residents who speak limited English, live below the poverty line, have higher incomes, and are disabled. Three vulnerability indicators were notably higher in urban areas, namely the presence of minority populations, people who do not own a vehicle, and renters.

Considering many high and very high socially vulnerable urban block groups are not directly adjacent to the waterways or oceanfront, they may be perceived as safer and serve as prime relocation receiving areas, leading to higher transiency in near-water fringe and gentrification.

3.3. Other destabilizing community aspects

The relocation decision-making is driven by complex internal and external considerations related to job security, services, and sociocultural and historical amenities. Thus, we also evaluated the potential impacts of flooding on the commercial properties/major employers in the flood-prone corridor, critical facilities, and historic properties (Fig. 6). There are 74 historic buildings in urban areas, 11 in Hampton, 36 in Norfolk, 11 in Portsmouth, and 16 in Virginia Beach. Hampton has three churches, two government buildings, four historic houses, a



	URBAN					RURAL				
FACILITIES	Total #	2000	2030	2060	2090	Total #	2000	2030	2060	2090
Cultural Resources*	83	11	17	27	42	29	1	3	4	8
Major Employers	20	1	1	2	5	0	0	0	0	0
Critical Facilities	495	14	32	62	129	171	16	24	35	43

*Buildings and structures

Fig. 6. The key assets at risk of coastal flooding by 2090 in urban and rural areas: map (top) shows the location of assets, and the table displays their number (bottom).*Buildings and structures.

lighthouse, and a hotel. Norfolk mostly has churches, historic houses, educational and government buildings, a few industrial facilities, historic theaters, a mill, and a train station. Virginia Beach has mostly historic homes, a church, a hotel, and a museum. The National Historic Landmark structures in Hampton Roads include lighthouses in Virginia Beach; a drydock (naval shipyard) and fixed lightship in Portsmouth; three tunnels, Lunar Landing Facility, Hampton carousel in Hampton, and USS WISCONSIN (BB-64) battleship permanently docked in the water in Norfolk. There are 29 historic buildings in rural counties, primarily churches and historic homes, followed by a few hotels, commercial and agricultural buildings, a mill, and a museum. The cultural resources and structures in rural locations include historical structures and include skipjack/boats, a long canoe, and a bugeye (oyster boat).

In the Hampton Roads area, we considered only private businesses with over 1000 employees (Hampton Roads Alliance, 2020) verified as still active (e.g., Landmark Enterprises LLC in Norfolk was listed as permanently closed). Considering Maryland case study locations are rural and have fewer larger employers, we only accounted for verified businesses with over 100 employees (MD Department of Commerce, 2015). Companies were excluded from the assessment if they did not have an authenticated location using an online search or were permanently closed (e.g., Adventist Behavioral Health System Easter Shore, Qlarant, Wildlife international, Bloch & Guggenheimer, and Interstate Container). Urban major employers within the flood corridor include Landmark Interactive, the King's Children's Hospital, Sentara Norfolk General Hospital, and LM Sandler & Sons, with hospitals serving as both critical facilities and major employers.

4. Discussion

This paper has two main objectives. The first one is to demonstrate that many municipal features will be impacted by projected coastal flooding simultaneously with the residential areas, compounding the push factors of the decision to relocate. The second objective is to evaluate how this risk will propagate across different spatiotemporal scales in rural and urban municipalities. Such spatially-explicit knowledge about flood risk proliferation can inform the selection of adaptation pathways and priorities on local and regional levels. The assessment of current global adaptation efforts indicates failed policy implementation, spatially uneven planning efforts centered in urban locations, and a lack of inclusion of future climate projections (Olazabal et al., 2019). The addition of adaptation actions in official urban planning documents is also rare (Hurlimann et al., 2021). Even though anticipatory land use policies are highly needed to address emerging issues like SLR (Geisler & Currens, 2017), many local officials still make LULC and investment decisions based on present risk information. Municipalities that proactively pursue innovative land use adjustments often do so to demonstrate they can effectively resolve flood problems to their investors and economic partners. In Hampton Roads, such economic engine is military, while in other places, it is tourism, seaport, or oceanfront real estate.

Our spatial analysis projects a significant increase in flood exposure across multiple land uses and land covers, and a threat to critical facilities, places of employment, and cultural resources in study locations. Results show that the impacts will significantly differ in scale and scope between the studied rural and urban counties, which might hold for rural and urban areas at large. This differing risk partially reflects the biophysical vulnerability of each location based on their geomorphology, bathymetry, topography, elevation, rate of shoreline change, slope, SLR, tidal range, and wave height. It also mirrors development patterns along the coast in these two settings. In rural areas, properties are more dispersed, with some clustering in smaller communities reflecting a preference for living near water and access to water-based economic and recreational opportunities. Even though large swaths of rural areas are at risk of flooding, fewer households may be forcibly displaced from their location. However, other rural socioeconomic and cultural changes may facilitate the long-distance migration of rural families with a more profound impact on the social cohesion and way of life across the region. Our results also show that future flood risk will propagate at different rates. For example, rural Dorchester County has elevated initial flood risk compared to Talbot County but a modest change in risk over time. Urban Portsmouth and Norfolk have lower baseline flood risk but significant percent change, especially in the second half of the century. Such sudden acceleration may exceed the community s adaptive capacity if no actions are taken beforehand, leading to more extensive displacement. Hampton and Virginia Beach have a more gradual risk increase, allowing for incremental adaptation and identification of innovative strategies to learn to live with more water.

The findings show that urban land uses with the highest flood risk by 2090 are open space (76%), agriculture (69%), mixed-use (68%), and military (61%). The flood risk for almost all land uses will more than double over 90 years. A third of residential areas will already be at risk of coastal flooding by 2060, followed by commercial, industrial, and institutional land uses, likely leading to cascading impacts with implications for population mobility (e.g., loss of employment, reassignment to another location, and fiscal decline leading to the deterioration of services and maintenance of public spaces and infrastructure). While the residential, commercial, and industrial exposure will expand spatially, so will the risk to open and vacant spaces, limiting options for redevelopment to support local relocation. The flood risk to military spaces in urban areas will double by 2090, with significant implications on military readiness and operations and the economic stability of this region. The Department of Defense employs around 150,000 active duty and civilian personnel in the Hampton Roads area and supports the local industry with an additional 40,000 employees (Hampton Roads Chamber, 2022). It also indirectly provides the demand for services and amenities for military families, veterans, and the workforce in the related private sector. The most affected land uses in rural areas are coastal marshes and exempt, residential, and commercial spaces. Considering that 65% of commercial land use and 38% of agricultural land will be at risk of coastal flooding by 2090, the compound flood impacts on the main rural economic sectors might exacerbate the rural relocation from the coast.

Both rural and urban areas will experience a significant loss of wetlands, 79% and 83%, respectively. Loss or impaired wetland functions due to accelerated submergence would adversely impact many crucial roles of this ecosystem, such as wildlife habitat, biodiversity, carbon sequestration, recreation and tourism, storm protection, and water quality, with a notable reduction of its economic benefits (Mitsch et al., 2015; Sun and Carson, 2020). There is still no consensus on how wetlands will respond to SLR. This uncertainty is primarily associated with the coastal management decisions necessary to implement large-scale efforts for securing adequate upward and landward accommodation space for wetland migration (Schuerch et al., 2018). However, acquiring accommodation space may not ensure complete wetlands survival. The extent of wetlands migration to a new area also depends on the sediment supply from the riverine inputs, which are irrevocably declining due to anthropogenic activity and climate change (Tornqvist et al., 2021). Moreover, coastal wetlands may cope with flood intensification over a short period but may abruptly collapse in response to other location-specific geomorphological and climate conditions (Tornqvist et al., 2021). Even though the projected wetland loss in our rural and urban locations is similar, it will result in significantly different outcomes in the long term. Rural areas in Dorchester and Talbot Counties have more complex hydrology, a dispersed network of waterways, and more undisturbed and managed open space that can replenish sediment to new locations for marsh migration. On the other hand, urban areas in Hampton Roads are already experiencing a coastal squeeze that will inevitably worsen with SLR unless the municipalities intentionally vacate and manage spaces for marsh migration and restoration. This latter intervention in urban areas would call for partial property acquisition and rezoning and take time, resources, and public support.

In our case study locations, urban areas are more socially vulnerable mainly due to lower income, populations with a disability, renters, and residents who did not complete secondary education. Urban areas also have a notably higher proportion of minority populations and people who do not own a vehicle. On the other hand, rural areas have notably higher unemployment rates and a population with lower educational attainment. The coastal flooding will exacerbate preexisting social vulnerabilities and either lead to the forced displacement of vulnerable people or their entrapment in deteriorating places. Many place-based factors that shape social vulnerability and sense of place stem from personal, historical, cultural, economic, and legal contexts critical for moving or pursuing voluntary immobility (Yee et al., 2022). Adaptation efforts must support households unwilling to relocate due to their strong place attachment and concerns that relocation will exacerbate their vulnerabilities (Farbotko et al., 2020). Some of the displacement may stem from the development pressures and housing demand to accommodate local relocation to safer locations. For example, gentrification in New Orleans post-Hurricane Katrina was strongly associated with higher elevation (Aune et al., 2020). Similarly, real-estate buyers in Miami-Dade County prefer properties on higher elevations expected to appreciate over time, leading to regional gentrification (Keenan et al., 2018). Moreover, coastal housing market analysis based on flood-driven household behavior demonstrated that market sorting could alter demographics in high-risk areas, fostering the entrapment of socially vulnerable populations and gentrification elsewhere (De Koning and Filatova, 2020). Land use and rezoning decisions will be critical in developing equitable adaptation pathways that will not displace vulnerable populations and foster market-driven gentrification but explore innovative solutions such as inclusionary zoning combined with fair Transfer of Development Rights (TDR) (Bonjour, 2020).

The potential loss of major employers in urban locations is negligible and nonexistent in rural areas. The number of cultural resources at flood risk is lower in rural than urban areas. However, in rural areas, the culture is not necessarily valued via centralized physical attributes but rather by way of life and social capital. Even though the number of critical facilities with high flood exposure is lower in rural areas, any damage or loss of their services would have a detrimental impact on the local population and contribute to the decision to move elsewhere. There is an emerging interest in understanding the spatiotemporal implications of coastal flooding on communities and using this information to advance adaptation and resilience planning. This is even more pertinent to SLR planning, which needs to include thoughtful management of uncertainty by considering multiple SLR scenarios in adaptive risk management to guide the alignment between selected strategies and SLR impacts (Butler et al., 2016). For example, Bilskie et al. (2014) studied the relationship among the storm surge accounting for the past (1960), present (2005), and future (2050) SLR, topography, and LULC change along the Mississippi and Alabama coast. Authors demonstrated that urbanization and nearshore geomorphological changes could increase the frequency and level of flooding, allowing storm surges to propagate further inland (Bilskie et al., 2014).

The awareness of which specific areas and LULC will be affected by future flooding will foster conversations on mutually synergistic aspects of affected systems and provide more actionable information for local officials. Even in rural areas, where land uses vastly differ from the urban places, realignment with advancing coastal changes can divert some of the anticipated flood impacts and allow for successful adaptation utilizing a combination of incentives, technical and risk information, and policy mechanisms (Parrott et al., 2009). For example, some strategies, such as restrictions on coastal development, suspension of new building permissions, buffer zones, and increased insurance rates and taxes, can successfully lead to a transition to more resilient coastal land use types (Hansen, 2010) but may not receive public and political support for implementation. However, to shift the conventional planning discourse to a more innovative envisioning of coastal places, communities need tools and information that will allow them to imagine a range of scenarios. Most coastal flood models focus on physical impacts on natural and built environments (Bilskie et al., 2014; Halls and Magolan, 2019). Very few assess this issue through the lens of population mobility and relocation. Song et al. (2018) note that adaptation and land management decisions are prevalently based on remote sensing and land change information, especially if done at the scale and context useful for local policy-making. Land use modeling and simulations are becoming essential tools for examining outcomes of different land use change scenarios in response to SLR that have implications for human mobility (Hansen, 2010). Thus, having accurate quantitative information and mapping products about all flood scenarios can facilitate adaptation goals- and priority-setting, ensuring the continuation of coastal communities while at the same time addressing inevitable changes in flood regimes (Frazier et al., 2010).

This study focuses on a specific geographic area selected based on its flood risk and rural versus urban typology to illustrate differing place-based circumstances that might influence the rate and extent of flood-induced relocation. As such, the findings cannot be generalizable to other coastal rural and urban areas in their entirety but can inform policy and future research on coastal mobility by shifting the focus of risk assessments from the impacts on residential properties to more nuanced interdependencies with other place-based relocation drivers related to people s livelihoods, cultural identity, and desired quality of life. This paper can also encourage the development of new spatially-explicit methods to assess comprehensive relocation drivers on a larger geospatial scale using more detailed proxy measures such as employment and service utilization data. It can further inform novel survey designs exploring the role of critical facilities and job mobility on relocation decision-making in other coastal geographic locations. Another opportunity to advance future research on this topic is to adapt coastal vulnerability assessments to incorporate indicators relevant to relocation and measure the risk of displacement and large-scale implications on future mobility patterns.

The main limitation of this study stems from combining future flood projections with the current static LULC, socioeconomic, and assets estimates, introducing uncertainties related to flood impacts on human systems. Even though this approach is not ideal, it has been used in many research projects due to data and methodological constraints. The most significant advances were achieved in predicting future coastal populations (Neumann et al., 2015) and Urban Growth Models like Slope, Land use, Exclusion, Urban extent, Transportation, and Hillshade (SLEUTH, Votsis, 2017) and cellular automata model (Wang et al., 2021). However, these studies mostly quantify the total future populations exposed to coastal stressors and do not measure their socio-demographic profile (Hardy and Hauer, 2018). Also, urban growth simulations are computationally complex and data-specific, which limits their broader inclusion into other types of assessments, like the one in this study. Further, they extrapolate future trends from historic estimates and provide scenarios based on future policy assumptions, mostly without accounting for climate change (Al Rifat and Liu, 2022).

Estimating changes in socioeconomic patterns and nuanced spatial features is significantly more difficult, especially in coastal settings with combined development and hazard pressures. Even though some models exist looking at land use under different socioeconomic and climate scenarios, they are developed at a resolution, scale, and context less transferable to other national and global locations (Chen et al., 2020; Prestele et al., 2016). The need to account for future sociodemographic changes in parallel with coastal inundation projections has been recognized by Hardy and Hauer (2018), who used the Hamilton-Perry method and theory of demographic metabolism to develop social vulnerability projections for coastal Georgia to improve SLR assessments. However, the same authors acknowledged uncertainties mostly stemming from difficulty foreseeing future innovation and local policy efforts, especially on longer time horizons. Li et al. (2019) discuss such predictive models of natural hazard impacts on land use, their limitations, and efforts to translate human behaviors and more nuanced decisions into more dynamic models of future change.

5. Conclusions

Most studies that use a spatially explicit approach to quantifying the displacement and migration risk in coastal areas focus on residential exposure while overlooking more holistic considerations influencing mobility decision-making. Household surveys repeatedly demonstrate that the reasons prompting people to relocate are complex and driven by factors not necessarily related to flooding, such as economic opportunities and quality of life. This study comprehensively evaluates the storm surge exposure across different SLR scenarios on LULC, social vulnerability, and community features in rural and urban settings that shape economic outlook, social cohesion, and sense of place, all of which are important drivers of relocation decision-making. Our results show that flood risk significantly differs between selected rural and urban areas. Even though Norfolk and Portsmouth initially have the lower baseline of flood extent, they have the highest percentage of change in exposure and acceleration in the 2060 2090 period. Hampton and Virginia Beach have higher flood exposure baselines but a more gradual and uniform increase in future flood exposure. The studied rural counties also have differing initial exposure, with Dorchester having a higher flood baseline but a comparable increase in projected flooding with Talbot County. The exposure trend estimates are important to inform the timeline and pace of interventions and preparation time, focusing on proactive adaptation measures and relocation.

Our findings further show that some land uses, such as wetlands, military spaces, mixed-use, and critical community assets vital for livelihoods, the quality of life, safety, and security will be highly affected by coastal flooding. Cascading flooding impacts that would permeate the municipalities, from school closures or limited accessibility to permanent loss of large employers, like the federal partners or corporate offices, would have ripple effects on the population and contribute to the decision to relocate. Further, the results indicate that the studied rural and urban areas have hotspots of social vulnerability that should be addressed when considering municipal adaptation. Such an approach would help avoid disproportionate impacts on these populations (e.g., leaving residents who cannot relocate trapped in failing neighborhoods or subjecting them to gentrification). The observed impacts on critical facilities may profoundly impact the decision to move, especially if flooding leads to their closure or limited service delivery, interfering with the health and public safety. In rural areas, these impacts would have an even more prominent role in the relocation decision-making, with residents seeking more reliable services elsewhere and in urban areas. On the other hand, flood impacts the major employer in the area, and the subsequent impact on the workforce may have a more significant impact on relocation in the urban area. This study demonstrates the need for research focused on synergies between LULC and coastal adaptation/resilience planning that is often institutionally compartmentalized and spearheaded by different stakeholder groups.

Creating community visions of LULC realignment and engaging residents in reimagining their coastal places based on different flood scenarios may shift the focus on possible opportunities that could emerge from sensible spatial policy changes. Such options include accommodation space for wetlands migration, educational and recreational spaces, and integrated flood protection with win-win benefits for residents and municipalities. The ability of local governments to demonstrate they can effectively lead this fundamental transformation would boost residents confidence in the long-term resilience of the place regardless of pervasive uncertainties, attract new investment and

Table A1
Summary of projected 2% annual exceedance probability (AEP) flood elevations by year, developed from Cialone et al. (2015), Nadal-Caraballo et al. (2015), and Sweet et al. (2017).

Year	Rural Maryland		Urban Virginia	
	NOAA 2017 Intermediate sea-level change relative to 2000 at Cambridge, MD [m]	2% AEP flood elevation, median of all stations (5th & 95th percentiles) [m, NAVD88]	NOAA 2017 Intermediate sea-level change relative to 2000 at Sewells Point, VA [m]	2% AEP flood elevation, median of all stations (5th & 95th percentiles) [m, NAVD88]
1992	-0.03	1.64 (1.52, 1.86)	-0.03	2.39 (1.29, 2.88)
2000	0.00	1.67 (1.55,1.89)	0.00	2.42 (1.32, 2.91)
2030	0.28	1.93 (1.82,2.16)	0.30	2.72 (1.62, 3.19)
2060	0.65	2.29 (2.17,2.52)	0.70	3.09 (2.01,3.58)
2090	1.14	2.77 (2.65,2.98)	1.20	3.58 (2.50, 4.06)

cutting-edge human capital, and stabilize transiency that would otherwise ensue. Looking through the lens of migration theory and pull and push forces, a holistic assessment of all spatial features and LULC changes needed for resilient functions of coastal human systems, including LULC changes, is necessary to inform the discourse on flood implications on transiency and mobility. Uncertainties in the human system need to be explored using futures studies methods and simulations to identify optimal adaptive pathways combining accommodation, protection, and relocation. Soliciting stakeholders input on innovative solutions focused on broader community benefits would lead to win-win outcomes addressing other rural (e.g., economic decline and population aging) and urban (e.g., social justice and pollution) problems. Such a participatory process is even more important for the large-scale LULC transitions, such as elevation-based re-zoning already embraced by several coastal communities like Norfolk, Virginia; Charleston, South Carolina; and Mandeville, Louisiana (DeAngelis, 2018).

Statement of publication status

The content of this manuscript has not been published before in any other journal nor has it been submitted elsewhere for consideration of publishing.

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CRediT authorship contribution statement

Anamaria Bukvic: Conceptualization, methodology, resources, funding acquisition, project administration and supervision, formal analysis, writing first draft, review, and editing; **Allison Mitchell:** Formal analysis, writing methods; **Yang Shao:** Methodology, formal analysis, review, and editing; **Jennifer L. Irish:** Conceptualization, funding acquisition, methodology, formal analysis, writing review and editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Appendix

see Table A1.

F1. Calculations: Flood elevations are adjusted for sea-level change (SLC) as follows:

(A1)

where:

is new flood elevation, relative to mean sea level in the base year (1992 for NACCS).

_o is flood elevation in the base year.

SLC is sea level change, from the base year.

NNL is normalized nonlinearity index (Bilskie et al., 2014).

For the NACCS study, NNLis calculated as follows:

(A2)

where _1mis dynamically simulated flood elevation atop a 1.00-m sea-level rise, and _1m and _o are in meters.

Using Eqs. A1 and A2, flood elevations were adjusted in reference to the 1983 2001 tidal epoch Mean Sea Level datum. Datum conversion to NAVD88 was carried out using NACCS-furnished station-wise datum conversions, where these conversions are based on NOAA tide gauges and VDatum (Cialone et al. (2015); NOAA (2021a)).

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