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A spatial analysis of climate gentrification in Orleans Parish, Louisiana post-Hurricane Katrina

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Abstract

Background: Hurricane Katrina made landfall in New Orleans, Louisiana as a Category 3 storm in August 2005. Storm surges, levee failures, and the low-lying nature of New Orleans led to widespread flooding, damage to over 70% of occupied housing, and evacuation of 80–90% of city residents. Only 57% of the city's black population has returned. Many residents complain of gentrification following rebuilding efforts. Climate gentrification is a recently described phenomenon whereby the effects of climate change, most notably rising sea levels and more frequent flooding and storm surges, alter housing values in a way that leads to gentrification.

Objective: To examine the climate gentrification following hurricane Katrina by (1) estimating the associations between flooding severity, ground elevation, and gentrification and (2) whether these relationships are modified by neighborhood level pre- and post-storm sociodemographic factors.

Methods: Lidar data collected in 2002 were used to determine elevation. Water gauge height of Lake Ponchartrain was used to estimate flood depth. Using census tracts as a proxy for neighborhoods, demographic, housing, and economic data from the 2000 decennial census and the 2010 and 2015 American Community Survey 5-year estimates US Census records were used to determine census tracts considered eligible for gentrification (median income < 2000 Orleans Parish median income). A gentrification index was created using tract changes in education level, population above the poverty limit, and median household income. Proportional odds ordinal logistic regression was used with product terms to test for effect measure modification by sociodemographic factors.

Results: Census tracts eligible for gentrification in 2000 were 80.2% black. Median census tract flood depth was significantly lower in areas eligible to undergo gentrification (0.70 m vs. 1.03 m). Residents of gentrification-eligible tracts in 2000 were significantly more likely to be black, less educated, lower income, unemployed, and rent their home rather than own. In 2015 in these same eligible tracts, areas that underwent gentrification became significantly whiter, more educated,

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Appendix A. Supplementary data
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higher income, less unemployed, and more likely to live in a multi-unit dwelling. Gentrification was inversely associated with flood depth and directly associated with ground elevation in eligible tracts. Marginal effect modification was detected by the effect of pre-storm black race on the relationships of flood depth and elevation with gentrification.

Conclusions: Gentrification was strongly associated with higher ground elevation in New Orleans. These results provide evidence to support the idea of climate gentrification described in other low-elevation major metropolitan areas like Miami, FL. High elevation, low-income, demographically transitional areas in particular - that is areas that more closely resemble high-income area demographics, may be vulnerable to future climate gentrification.

Keywords

Climate change; Environmental gentrification; Extreme weather; Sea level rise; Elevation

1. Introduction

Hurricane Katrina made landfall in New Orleans, Louisiana as a Category 3 hurricane on August 29, 2005. The storm surge and flooding associated with the hurricane caused severe flooding that overwhelmed the levee system in New Orleans and led to widespread floodwater coverage of much of Orleans Parish. Post-storm assessments by the U.S. Department of Homeland Security found that flood elevations in some areas surpassed the 100-year flood plain by as much as 4.6 m (U.S. Department of Homeland Security, 2006). Since much of New Orleans lies below the elevation of Lake Ponchartrain to the north and the Mississippi River to the south, 80% of New Orleans was left underwater with many homes experiencing flood depths of up to 2.4 m that persisted for weeks (McCarthy et al., 2006; U.S. Department of Homeland Security, 2006). Katrina left over 1800 dead, $125 billion in economic damage in 2006, and 71% of occupied housing units in New Orleans damaged (Finch et al., 2010; Graumann et al., 2005; Knabb et al., 2005). During the disaster, Mayor Ray Nagin declared a mandatory evacuation of the city's 455,000 residents, allowing them to return in a stepwise fashion once floodwaters had receded. By the end of 2006, only 58% of pre-storm New Orleans residents had returned and there was a significant racial divide between the proportion of original black residents (51%) and non-black residents (71%) who had returned to New Orleans (Fussell et al., 2010). Though population numbers in 2009 were back to 69% of pre-hurricane levels, many original residents of New Orleans never returned and the ability of previous residents to return was largely driven by socioeconomic factors that delineated along racial lines (Finch et al., 2010). Furthermore, among those returning to the city after Katrina, only 22.3% of black residents were able to return to their original homes compared to 46% of nonblack residents (Sastry and Gregory, 2014).

The differential ability of wealthier, more educated original and new residents to return and move to New Orleans (Fussell et al., 2010) has led to anecdotal and evidence-based reports of gentrification following Katrina (Adelson, 2018; van Holm and Wyczalkowski, 2018; Williams, 2016). Specific measures of gentrification in the literature include combinations of change in income, property values, education levels, and social and employment class, but refer generally to the upward social change of a neighborhood from lower to higher socioeconomic status (Smith, 2002). The exact forces that initiate gentrification are often disputed, though research indicates factors such as family structure, rapid job growth, lack of housing, traffic congestion, and public-sector policies may all play a role (Kennedy et al., 2001). These events often occur in small scale, decade-long waves influenced by larger macroeconomic forces coupled with low housing prices that attract property developers driving a population return to newly renovated urban areas (Redfern, 2003). Conversely, large-scale events like Hurricane Katrina provide an instantaneous opportunity for redevelopment and the accompanying population regeneration can cause an immediate shift in neighborhood makeup (Boettke et al., 2007). Well-intentioned or not, post-disaster displacement can be set in motion by local authorities that merge these development prospects with previously planned economic opportunities.

The effects of gentrification have been described by many but have produced mixed results. While gentrification often includes the benefits of a broader local tax base, lower prices of high-value goods, and lower crime (O'Sullivan, 2005), these benefits are counteracted by rising commercial and residential property values, correspondingly rising property taxes, increasing rent burden, disruption of social services, and ultimately residential displacement of original residents (Kennedy et al., 2001). While some studies have shown increases in the health of residents overall in gentrifying neighborhoods (Althoff et al., 2009; Gibbons et al., 2018; Gibbons and Barton, 2016; Morenoff et al., 2007), these improvements in health are not universally observed with significant disparities existing across racial and socioeconomic strata within gentrifying communities. This observation lead Gibbons et al. to theorize that any positive change in neighborhood health was not due to improvements in incumbent resident health, but rather due to the influx in affluent, healthier residents and the displacement of original residents (2018). Among displaced residents, gentrification has been shown to decrease access to healthy foods, transportation, healthcare, and education, and to increase injuries, violence, and crime while disrupting community cohesion (CDC, 2009; Gibbons et al., 2018; Lim et al., 2017). These changes in turn have negative effects on the health of displaced residents including decreased self-reported health, self-reported well-being and self-esteem, and mental health issues such as depression, anxiety, and stress (Desmond and Kimbro, 2015; Gibbons et al., 2018; Matthews and Yang, 2010; Oishi, 2010). However, displacement is not requirement for gentrification to result in negative health effects in incumbent residents. Disruptions in neighborhood cohesion and stability have been repeatedly shown to decrease overall as well as mental health of original residents (Anguelovski, 2015; Gibbons et al., 2018) and even fear of gentrification-caused displacement was sufficient to lead to anxiety in New York City residents (Pearsall, 2012). In the case of Hurricane Katrina, residents able to return to New Orleans but unable to return to their original home (an ability largely split along racial divisions), would have less purchasing power, due to temporary displacement and time away from work, to find a home in a market with limited healthy housing stock – circumstances that have led to displaced residents setline for unsafe housing conditions in other large cities (Desmond and Kimbro, 2015; Sastry and Gregory, 2014). In addition, a resident unable to resettle their former home after Hurricane Katrina due to gentrification can also suffer compounded negative health effects associated with being a victim of a natural disaster including physical injury or illness as well as mental health problems including anxiety, post-traumatic stress disorder, and depression (Acierno et al., 2006; Fussell and Lowe, 2014; Lonigan et al., 1994; Norris et al., 2004). While it is difficult to impossible to attribute an individual weather event to climate change, a growing interest in a phenomenon known as “climate gentrification” (Keenan et al., 2018) suggests that the social and health impacts of sociodemographic changes driven by natural disasters is of increasing importance, particularly given the impact of global climate change on the increasing frequency of extreme weather events and a predicted increase in population migrations away from vulnerable coastal areas (Albrecht et al., 2007; Portier et al., 2010; Stott, 2016).

Little research has been conducted to assess the impact of extreme weather events on gentrification. Recent studies have examined the effect of property damage due to post-Katrina flooding in New Orleans, finding that gentrification was more likely to occur in storm-damaged areas, but did not account for ground elevation (van Holm and Wyczalkowski, 2018). Other work in Miami has focused on the effect of elevation alone in its relationship to neighborhood gentrification, finding that gentrification is more likely to occur in higher elevation areas (Keenan et al., 2018). With these two opposing mechanisms of gentrification possibly at work in New Orleans (low elevation, flooded areas vs. high-elevation, unflooded areas) it is important that both be considered. Since gentrification occurs through a change in neighborhood socioeconomics, not demographics, the most widely used definitions do not include race as a measure of gentrification. However, race is often strongly tied to the economic factors influencing gentrification and the positive and negative effects of gentrification were shown to be inequitably distributed along racial and ethnic lines in other American metropolitan areas (Gibbons and Barton, 2016; Huynh and Maroko, 2014; Lim et al., 2017), providing evidence that race should be investigated as an effect modifier in New Orleans. Therefore, in this analysis we sought to explore the concept of climate gentrification following hurricane Katrina by (1) investigating the relationships between flooding severity, ground elevation, and gentrification and (2) whether these relationships were modified by neighborhood-level sociodemographic factors (pre-storm: minority population, unemployment, service occupation; post-storm: new residents, new homes constructed). We hypothesized that gentrification would be significantly associated with ground elevation and flood severity and that these associations would be significantly modified by census tract-level sociodemographic factors.

2. Materials and methods

2.1. Population data

This analysis used census tracts as a proxy for neighborhoods. Population race, ethnicity, education level, housing characteristics, and economic characteristics were obtained from US Census records from the 2000 Decennial Census, the 2006–2010 American Community Survey 5-year estimates, and the 2011–2015 American Community Survey 5-year estimates. Records were downloaded at the census tract level for Orleans Parish, Louisiana. Due to changes in census geographic units that occurred in 2010, data from 2000 were adjusted according to US Census crosswalk weighting values (U.S. Census Bureau, 2018). Three census tracts were removed as the total resident population in each survey was < 10. Race and ethnicity percentages were calculated as zero for tracts with zero total population while other percentages were considered as missing when denominator variables were zero. The 2010, 2015 and median household income values were adjusted for inflation to be comparable with 2000 values using the US Consumer Price Index (Bureau of Labor Statistics, 2019) and 2010 and 2015 median rent values were adjusted using HUD fair market rent values (U.S. Department of Housing and Urban Development, 2020).

2.2. Outcome definition

The term gentrification does not have a single, recognized definition. We adapted the concept of a neighborhood's “eligibility” to undergo gentrification from Gibbons and Barton where census tracts with a 2000 median household income below that of the entire Orleans Parish median income ($27,133) were considered eligible to undergo gentrification (“eligible”) (Gibbons and Barton, 2016). In order to address the additional contributions of education and per-capita poverty that are lacking from an income-only definition, we defined gentrification using methods described by Huynh and Maroko (2014). In short, *z-scores* were calculated for eligible tracts for the change in the percent of college educated adults older than 25, percent of individuals above the federal poverty limit, and median household income within a given census tract. These *z-scores* were then summed to create a gentrification index (GI) for 2010 and 2015 where low values represent lower degrees of gentrification and high values represent higher degrees of gentrification. Adapting these methods to the data of the present study, four categories of GI were calculated using standard deviations of the summed *z-score* as category boundaries with groups representing strongly non-gentrified (< −1 SD), moderately non-gentrified (−1SD −0), moderately gentrified (0 – 1SD), and strongly gentrified (> 1SD) (Fig. 1). In addition, a binary variable was created where gentrification was defined as any census tract with a GI > 0.

2.3. Flooding severity and elevation

Flood depth was determined using methods and data previously described by Gesch (2007). Briefly, elevation was determined using lidar prior to Hurricane Katrina. High water levels of Lake Pontchartrain after the hurricane were taken from a US Geological Survey gauge. Flood depth was calculated as the difference in meters between height of the lake and the underlying elevation of the city. The calculated extent of flooding calculated was visually verified against satellite imagery in the days of highest reported flooding. Because of the skewed distribution of flood depths and elevation, the median in each tract was selected for descriptions and analysis. All spatial calculations were performed using ArcMap version 10.5.1 (Esri, 2017).

2.4. Statistical analysis

All statistical analyses were performed using R version 3.5.2 (R Core Team, 2019). An exploratory data analysis was performed and baseline means were calculated for all variables among all census tracts and compared between those that were and were not eligible for gentrification using an independent *t*-test. Similarly, means were calculated among eligible census tracts and compared between gentrified and non-gentrified census tracts in 2010 and 2015. Proportional odds ordinal logistic regression was then performed to assess the relationship between flood depth and 2015 GI category among census tracts eligible for gentrification (N = 95). An initial unadjusted model was constructed followed by a base adjusted model that included % population black race and % population homeowners. These covariables were selected a *priori* from a directed acyclic graph based on a review of the current literature. An adjusted model was constructed using manual backward selection based on Akaike information criterion (AIC) minimization criteria that began with a fully adjusted model including % black race, % homeowners, % unemployed, % employed in management or sales occupations, % multi-unit dwellings, housing density (dwellings/hectare), median home value, median monthly rent, and sharing a tract border with an ineligible tract. Effect modification by 2000% black race, 2000% unemployment, 2000% employed in management and sales occupations, 2000% homeowners, 2015% new residents (population who moved in during previous 5 years), and 2015% newly constructed homes (homes constructed during previous 5 years) were then tested by adding a product term to the adjusted model. To limit power loss during the effect-modification analysis, modifier variables were dichotomized at the median value of all census tracts (2000% black race = 75.3%, 2000% unemployment = 8.6%, 2000% employed in management and sales occupations = 56.1%, 2000% homeowners = 42.2%, 2015% new residents = 42.4%, 2015% newly constructed homes = 40.9%) and within-group effect estimates and confidence intervals were calculated using stratified analyses. Finally, these same analyses were repeated while replacing elevation for flood depth as the dependent variable.

Because of the confounding possibility of spatial autocorrelation, spatial dependence was assessed in the primary exposures and the outcome. Spatial dependence was expected between the elevations and flood depths of nearby tracts, and gentrification is more likely to spread outward from points of origin rather than appear in islands. Therefore, weighted neighborhood matrices were constructed for all census tracts and for gentrification-eligible tracts and spatially-lagged Moran's I statistics were calculated for lags of 1–10 for each variable (Appendix). Flood depth, elevation, and gentrification were found to be spatially dependent. We then tested whether the best fitting regression models accounted for the spatial dependence in gentrification by calculating Moran's I statistics for the residuals of these regression models. These residuals were not found to be spatially dependent, demonstrating that the regression successfully accounted for spatial autocorrelation among the variables of interest and that its results can be interpreted fairly and without inclusion of spatially-lagged covariates or a spatially-dependent covariance structure.

3. Results

Ninety-five of the 174 census tracts in Orleans Parish had a median income less than the parish median income and were eligible to undergo gentrification following Hurricane Katrina. Full population demographics can be found in Table 1. Census tracts eligible to gentrify in 2000 experienced significantly lower flood depths from Hurricane Katrina and had higher elevations than tracts not eligible to gentrify. Eligible tracts also differed significantly from non-eligible tracts in racial makeup, income, housing characteristics, educational attainment, and employment characteristics. Eligible tracts that underwent gentrification experienced less flooding and were at higher elevation and by 2010 were significantly less black and more white than eligible tracts that did not undergo gentrification. They were also more likely to have changed from majority black to majority white (Fig. 2). By 2015 many of these differences remained, but gentrified neighborhoods included significantly more residents who reported moving in during the past five years. Gentrified areas also had a higher density of housing units and were more likely to be multi-unit dwellings like apartments, condominiums, and duplex homes.

Unadjusted regression estimates (Model 1) of the correlation between gentrification and median flood depth or elevation revealed opposing relationships (Table 2), with an inverse association with flood depth and a direct association with elevation. When adjusted for *a priori* selected covariables (Model 2), these relationships were slightly attenuated, but still statistically significant. AIC minimization criteria led to the addition of 2000 median income as a third covariable (Model 3), which did not significantly alter the odds of gentrification but did increase the precision of estimates. Predicted probabilities of each class of GI as predicted by the adjusted regression models for flood depth and elevation can be found in Fig. 3 and spatial distributions of elevation and gentrification indexes can be found in Fig. 4.

Of interest to this investigation were the possible modifying effects of certain baseline conditions. These results can be found in Table 3, but overall do not demonstrate any significant effect measure modification. Of note, baseline black race appears to modify the relationship between both elevation and flood depth (Fig. 5), but these effects do not reach significance. Homeownership exhibits a similar pattern, but the relatively low number of homeowners in gentrification eligible tracts led to small stratum-specific cell counts in this analysis and thus very wide confidence intervals.

4. Discussion

We hypothesized that (1) post-Katrina gentrification was significantly associated with flooding severity and ground elevation and (2) these associations were significantly modified by pre-storm race, pre-storm unemployment rate, the pre-storm percentage of residents employed in service occupations, the percentage of new residents, and the percentage of new homes constructed. We found a significant negative association between flooding severity and gentrification and a significant positive association between ground elevation and gentrification. These relationships were not significantly modified by either pre-storm black race, the percentage of residents who moved into an area post-storm, or the percentage of homes constructed in an area post-storm.

The relationship between elevation and gentrification appeared to differ in its direction according to pre-storm black race. Among gentrification-eligible census tracts, a higher percentage of black race residents decreased the probability of gentrification. Using a gentrification definition based on new housing construction and changes in the college-educated population and housing prices with gentrification eligibility based on income, van Holm and Wyczalkowski (2018) found a similar negative association between increasing black race within a tract and the odds of it gentrifying. However, it is necessary to understand that tracts eligible to undergo gentrification in the current study had much larger pre-storm black populations than non-eligible tracts. Therefore, it appears that elevation's effect on an area's probability of gentrification may be influenced by black race in a U-shaped fashion with low black race areas being unlikely to undergo gentrification due to ineligibility (since these areas had higher median incomes), moderate black race areas being likely to undergo gentrification, and high black race areas being unlikely to undergo gentrification.

Prior to Hurricane Katrina in 2000, there were many demographic and neighborhood characteristic differences between tracts that were and were not eligible to undergo gentrification. Compared to ineligible tracts, individuals living in gentrification-eligible areas were more black and less white, less educated, more likely to rent their home than own it, more likely to live in a multi-unit dwelling like an apartment than a single-unit dwelling like a single-family home, had lower household income, were less likely to be employed in a management or sales occupation, more likely to be unemployed, and more likely to earn income below the poverty limit. However, further distinctions can be made among these eligible tracts between those that were and those that were not gentrified following Hurricane Katrina. Compared to residents of census tracts that were not gentrified by 2015, residents of gentrified census tracts were less black and more white in 2000, had higher rates of high school and college graduates, were more likely to be employed in a management or sales occupation, and were less likely to be unemployed. Therefore, it seems that the U-shaped relationship observed between black race and elevation with gentrification may be applied more broadly to other demographic and neighborhood characteristics (Fig. 2). While high-income areas were unable to become gentrified, low-income areas that were demographically more similar to high-income areas were gentrified more than areas that were demographically different. Gentrified tracts were not significantly more likely to be located adjacent to high-income, gentrification-ineligible areas. However, eligible tracts next to ineligible tracts had higher proportions of white residents than eligible tracts without high-income neighboring tracts (20% vs. 6%, $p < 0.0001$) and lower proportions of black residents (75% vs. 92%, $p < 0.0001$).

Given the cost to human life and property that Hurricane Katrina caused, it seems logical that it and storms like it would have a negative effect on population and economic growth in the affected area. However, this does not appear to be the case. The housing stock vacuum associated with a catastrophic storm combined with an influx of public and private capital to rebuild and recover the affected community created an economic boost through residential and commercial construction and the availability of low-interest business loans after the four “billion dollar storms” during the 1990s in the US (Pais and Elliott, 2008). However, in an examination of counties experiencing natural disasters from 1990 to 2000, Schultz and Elliott (2013) showed that these resources are often not distributed equitably across an affected area nor are they distributed in proportion to a subcommunity's vulnerability to future storms. In fact, they tend to only intensify the disparities in vulnerability to future extreme weather events. In addition, in an analysis of US Census data from 1995 to 2000, Elliott (2015) showed that natural disasters resulted in a significant increase in migration of original residents since the recovery growth in housing stock following a disaster results in higher costs and rents. So while weather-related disasters have been shown to spur economic and population growth on the whole, this growth is actually occurring through the displacement of original residents who are replaced by influx of new residents able to afford the new, more costly housing.

Furthermore, Elliott (2015) observed that the populations most vulnerable to residential displacement following natural disasters were racial and ethnic minorities. While population migration was not explicitly measured in the current study, 11 census tracts that were originally majority black before Hurricane Katrina changed to majority white in 2015, 10 of which experienced gentrification and were located at an elevation 0.9 m above the parish median. In contrast, seven census tracts that were originally majority white before Hurricane Katrina changed to majority black in 2015, none of which experienced gentrification and were located at an elevation 0.5 m below the parish median. It is possible that these changes occurred via displacement, though it is impossible to assert this without longitudinal data to rely on. These findings support a growing idea in sociological literature regarding disaster recovery that disadvantaged residents are vulnerable not only to environmental disasters, but also to inequitable disaster recovery that often results in gentrification and residential displacement (Fothergill and Peek, 2004; Myers et al., 2008; Schultz and Elliott, 2013).

Our results appear to contrast with findings by van Holm and Wyczalkowski (2018) in their exploration of physical damage from Hurricane Katrina in New Orleans. These authors found a positive relationship between property damage and gentrification following the storm, while we found that increased flood depth was negatively associated with gentrification. However, several methodological distinctions exist between that may explain this difference. First, the definitions of gentrification in these two studies differed. Van Holm and Wyczalkowski based their definition on one by Freeman (2005) using income, housing age, education, and housing prices while the current study incorporated poverty (a proxy for per capita income in a household) and did no account for housing age. Second, flood depth may not necessarily correlate well with flooding damage to property as there may be a threshold of flood depth above which a total loss of property could be declared. Third, total storm damage as used by van Holm and Wyczalkowski may include other sources of damage such as wind in addition to flooding. Finally, the use of city-conducted property damage estimates by Van Holm and Wyczalkowski may carry neighborhood bias that could systematically over- or underestimate subjective damage estimates according to socioeconomic status, race, age of buildings, or other neighborhood characteristics (Friedland, 2009; Martin and Teles, 2018). At the same time, our results echo similar findings by Keenan et al. (2018) in their exploration of climate gentrification in Miami, FL. These authors explored the impact of future coastal flooding under predicted climate change conditions on residential home value appreciation over time, with an assumption that residential displacement, was ultimately responsible for gentrification. A primary finding of this investigation was that home prices appreciated over time at higher rates in areas with higher elevation. As such, social gentrification in the form of increasing education and income levels would be more likely to occur in these high-elevation areas. Keenan et al. also propose three primary mechanisms for climate gentrification in Miami, the Superior Investment Pathway, the Cost-Burden Pathway, and the Resilience Investment Pathway (Keenan et al., 2018), and we find support for each of the pathways contributing to the sociodemographic changes noted in New Orleans following Hurricane Katrina.

These findings are especially important given the timeline of predicted future climate conditions. With current carbon emissions, sea level rise of 0.1–0.2 m is expected by 2030, 0.2–04 m by 2050, and 0.3–1.2 m by 2100 (Hayhoe et al., 2018). Coupled with a predicted increase in the intensity of tropical storms and precipitation events leading to coastal flooding and storm surge (Camargo and Wing, 2016; Easterling et al., 2017; Walsh et al., 2016), coastal areas of the United States are particularly vulnerable to climate gentrification and climate displacement. In 2010, 39% of the U.S. population, or 123.3 million individuals, lived in coastal shoreline counties (NOAA, 2013). Even with adaptation measures, it is likely that many of these people will be relocated either within their communities or into new areas (Hauer, 2017). These challenges carry the potential to worsen existing social inequality issues and, according to the Fourth National Climate Assessment, “coastal communities will be among the first in the Nation to test existing climate-relevant legal frameworks and policies against these impacts and, thus, will establish precedents that will affect both coastal and non-coastal regions” (Fleming et al., 2018). A governmental review panel required the language here to not reflect an attempt to influence any specific policy position. As a result, the findings represented here and by Keenan et al. (2018) will be vitally important to those decision-makers developing climate policy and adaptation strategies to ensure that resources and opportunities are distributed equitably and justly in the future.

This study is not without limitations. Our methodology of measuring gentrification relies on an assumption that neighborhood demographic changes occur through residential migration and not on improving the socioeconomic status of original residents. Secondly, the geographic units in which gentrification was assessed, census tracts, do not necessarily represent neighborhood boundaries, so gentrification in an area spanning multiple tracts may have been washed out by non-gentrification in the remainder of those tracts. Similarly, census tracts encompassing multiple neighborhoods may hide gentrification if residents forced to relocate from their home in one neighborhood move into an adjacent neighborhood in the same tract. Census tracts may also be too large to capture finer-scale variation in elevation or flood depth within a tract. However, census tracts are the most commonly used areal unit in neighborhood health studies (Arcaya et al., 2016), are a good approximation for neighborhoods (Freeman, 2005), and their use allows direct comparison with the many studies of gentrification at the census tract level that exist in the literature (Ellen and O'Regan, 2008; Hwang and Sampson, 2014; McKinnish et al., 2010; Schnake-Mahl et al., 2019; van Holm and Wyczalkowski, 2018). Finally, many gentrification definitions incorporate some measure of construction or renovation as the means by which property is improved. However, in older cities like New Orleans property improvement often occurs through renovation of existing structures rather than through new construction, a practice that is not captured in census records.

5. Conclusions

Climate gentrification occurred in Orleans Parish following Hurricane Katrina. The degree of gentrification was significantly impacted by an area's ground elevation and thus its likelihood of future flooding with higher elevation areas being more gentrified. High elevation, low-income, demographically transitional areas are at highest risk for future climate gentrification. These findings are particularly important given the vulnerability of coastal cities to predicted increased coastal flooding from more intense rainfall and coastal storms and rising sea levels.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Declaration of competing interest

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Abbreviations:

GI	gentrification index
lidar	light detecting and ranging
AIC	Akaike information criterion

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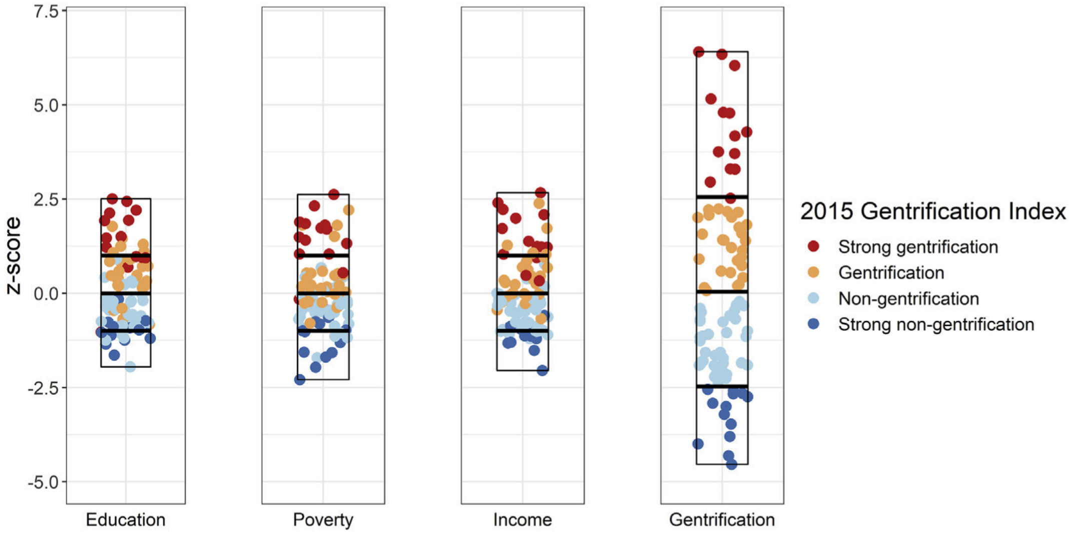

Fig. 1.

2000–2015 Census tract characteristic changes among gentrification-eligible tracts Z-scores calculated from the 2015–2000 change in each measurement. Gentrification index calculated as sum of education, poverty, and income z-scores. Horizontal bars in each boxplot represent the minimum, mean − 1 standard deviation, mean, mean + 1 standard deviation, and maximum.

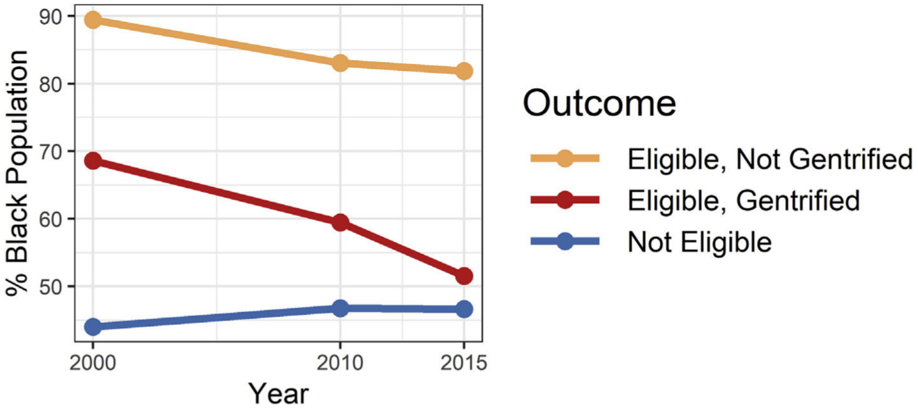

Fig. 2.

Change in census tract black race according to gentrification status gentrification eligibility determined by 2000 median income below 2000 parish median ($27,133). Gentrification defined as 2015 gentrification index > 0. Gentrified tracts experienced a significant decrease in black population and a corresponding increase in white population. Gentrified tracts also displayed pre-hurricane racial makeups more similar to higher income, non-eligible tracts.

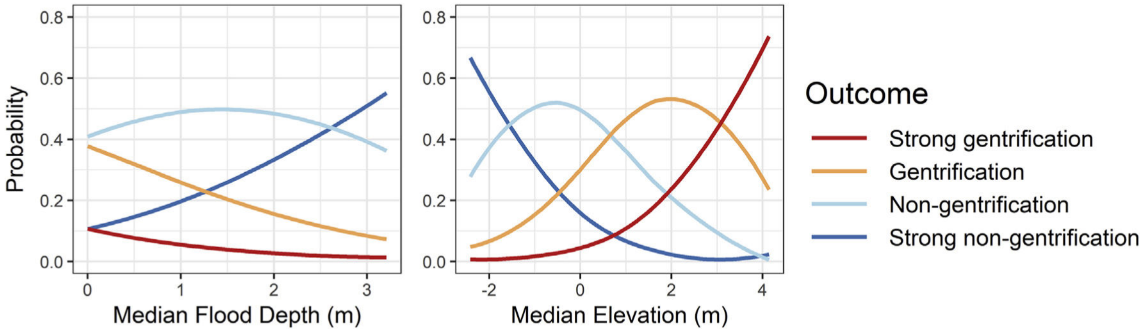

Fig. 3.

Predicted probabilities of 2015 gentrification classification fully adjusted model proportional logistic odds regression predicted probabilities of gentrification index category according to median flood depth and median elevation. Models adjusted for 2000% black race, 2000% home owner, 2000 median home value.

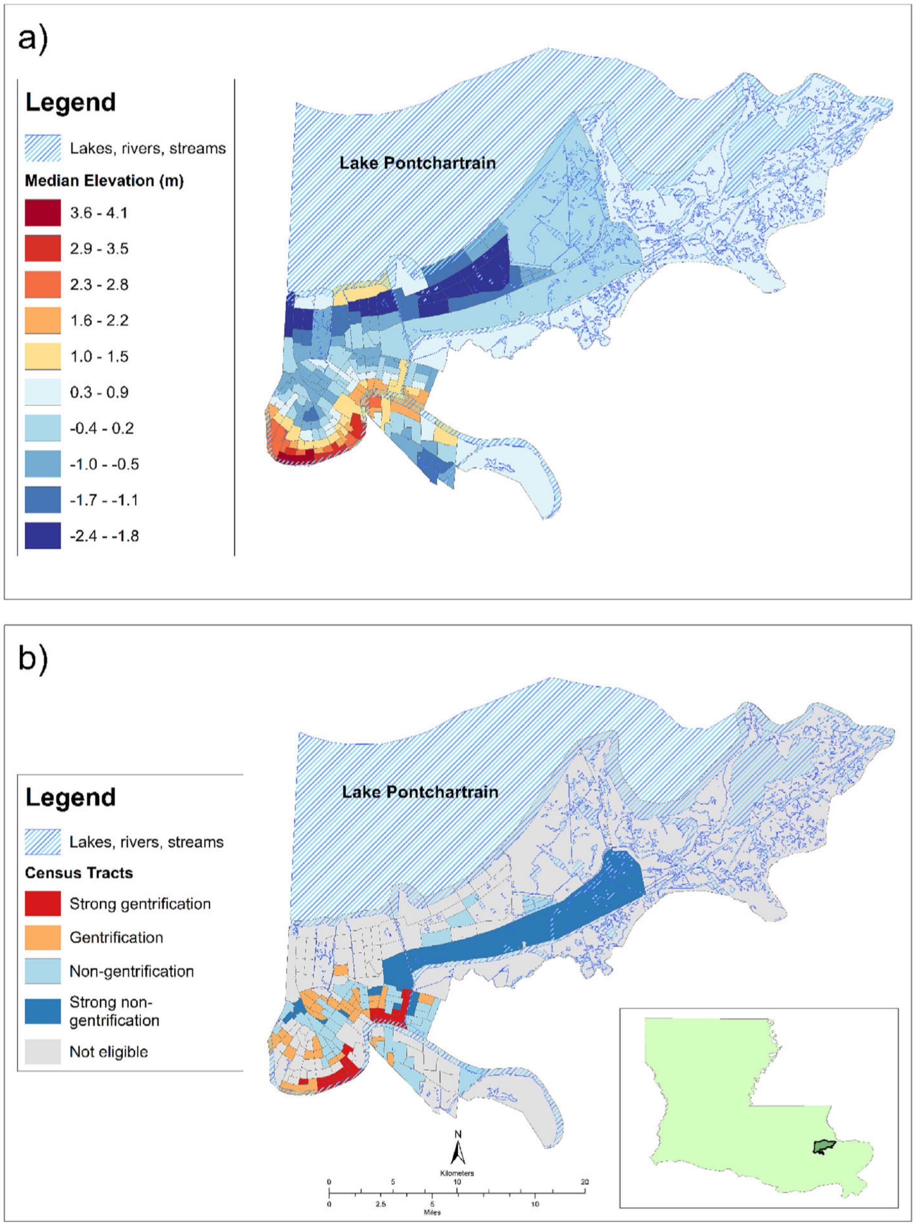

Fig. 4.

Elevation and gentrification in Orleans Parish, Louisiana a) Census tract median elevation in meters circa 2002. b) Gentrification index categories representing changes from 2000 to 2015. Gentrification eligibility determined as below 2000 parish median income ($27,133).

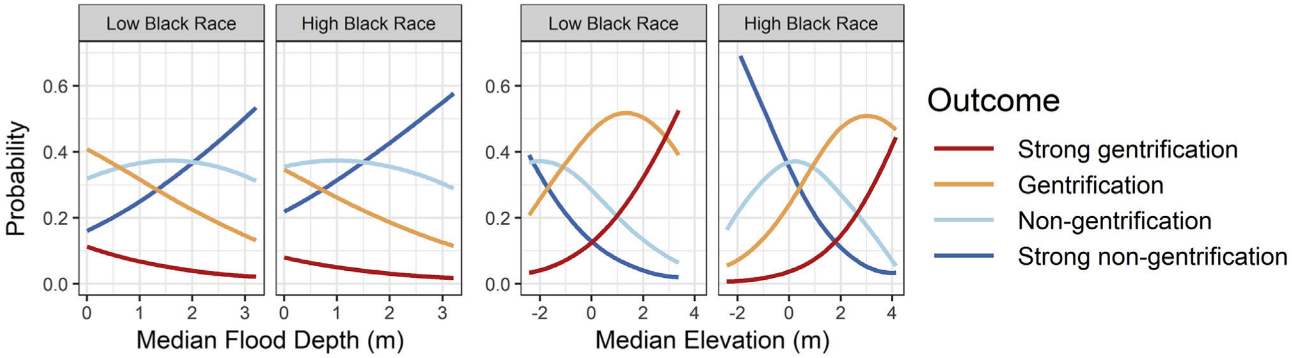

Fig. 5.

Predicted probabilities of gentrification according to flood depth and elevation stratified by black race Adjusted model proportional logistic odds regression predicted probabilities of gentrification index category according to median flood depth and median elevation. Models adjusted for 2000% black race, 2000% home owner, 2000 median home value. Population split at parish median % black population (75.3%) in low % black race (≤75.3%) and high % black race (> 75.3%).

Table 1

Population demographics, Orleans Parish, 2000–2015.

	2000			**2006–2010**			**2011–2015**		
	Not Eligible (N = 79)	**Eligible (N = 95)**	**P**	**Eligible**					
				Gentrified (N = 44)	**Not Gentrified (N = 51)**	**P**	**Gentrified (N = 53)**	**Not Gentrified (N = 42)**	**P**
Median flood depth (m)	1.03 (1.05)	0.70 (0.72)	**0.0194**	0.44 (0.56)	0.93 (0.76)	**0.0007**	0.44 (0.61)	0.91 (0.74)	**0.0009**
Elevation (m)	−0.17 (1.42)	0.21 (1.12)	0.0541	0.74 (1.24)	−0.24 (0.78)	< **0.0001**	0.79 (1.24)	−0.25 (0.77)	< **0.0001**
Population (N)	3007.3 (1356.6)	2601.0 (1130.9)	**0.0357**	1400.5 (746.2)	1478.0 (891.2)	0.6458	1692.4 (673.8)	1728.7 (1045.4)	0.8380
Race (%)									
Black	44.0 (33.3)	80.2 (22.5)	< **0.0001**	65.9 (31.2)	78.4 (25.5)	**0.0373**	51.5 (28.0)	81.8 (19.5)	< **0.0001**
White	51.1 (33.3)	15.6 (20.3)	< **0.0001**	30.1 (29.0)	11.5 (14.1)	**0.0003**	43.2 (25.9)	10.5 (10.4)	< **0.0001**
Other	4.9 (3.5)	4.2 (7.4)	0.3921	4.0 (5.2)	6.2 (14.0)	0.3109	5.2 (4.0)	5.8 (11.0)	0.7470
Hispanic (%)	3.5 (1.6)	3.0 (3.3)	0.1855	5.5 (7.6)	4.5 (7.6)	0.5234	6.6 (5.2)	5.7 (7.9)	0.4976
Education (%)									
High school diploma or higher	86.1 (7.0)	63.0 (12.5)	< **0.0001**	77.5 (14.0)	72.2 (9.9)	**0.0415**	83.3 (10.3)	72.6 (9.9)	< **0.0001**
Bachelor’s degree or higher	39.9 (17.9)	14.4 (12.4)	< **0.0001**	26.4 (18.0)	12.0 (11.5)	< **0.0001**	38.2 (18.4)	12.4 (8.0)	< **0.0001**
Home renter (%)	41.6 (20.0)	66.2 (15.1)	< **0.0001**	59.1 (19.5)	63.0 (19.1)	0.3341	63.8 (14.6)	65.6 (18.1)	0.5976
Dwelling (%)									
Single unit	67.0 (21.6)	55.3 (23.9)	**0.0009**	53.0 (22.0)	57.4 (25.4)	0.3620	48.2 (17.1)	57.9 (22.2)	**0.0190**
Multi unit	29.4 (18.3)	38.6 (20.7)	**0.0024**	41.3 (18.5)	36.2 (22.3)	0.2195	46.4 (14.7)	36.9 (19.0)	**0.0080**
Housing unit density (units/Ha)	12.5 (7.5)	19.8 (10.2)	< **0.0001**	14.3 (9.0)	13.7 (10.0)	0.7634	19.8 (9.6)	12.8 (8.2)	**0.0003**
Moved in last 5 years (%)				52.6 (15.6)	60.2 (16.1)	**0.0234**	48.5 (10.0)	43.2 (13.4)	**0.0345**
Home constructed in last 5 years (%)				4.3 (5.8)	7.7 (19.6)	0.2335	46.3 (9.9)	41.9 (12.9)	0.0664
Median income ($1000)	43.03 (19.27)	18.15 (5.31)	< **0.0001**	36.78 (17.70)	19.39 (6.26)	< **0.0001**	25.87 (9.39)	14.94 (4.86)	< **0.0001**
Unemployment (%)	5.7 (3.0)	15.3 (9.4)	< **0.0001**	14.8 (11.2)	19.0 (12.9)	0.0948	10.7 (5.2)	15.8 (7.8)	**0.0003**
Employment in management/sales (%)	69.9 (12.6)	48.0 (11.4)	< **0.0001**	49.2 (19.3)	41.7 (18.4)	0.0592	61.7 (12.3)	43.1 (13.7)	< **0.0001**
Population below poverty line (%)	15.1 (7.4)	40.7 (14.0)	< **0.0001**	24.5 (14.2)	41.6 (13.9)	< **0.0001**	27.5 (11.9)	45.1 (15.2)	< **0.0001**

Values reported as mean (standard deviation). Eligibility defined as census tracts with median household income below Parish median ($27,133). Gentrification defined as census tracts with gentrification index > 0. Median income in 2010 and 2015 adjusted for inflation to 2000 levels. P-values represent independent t-test within each time period (not measures of change within tracts over time).

Table 2

Odds ratios for proportional odds ordinal logistic regression models of post-Hurricane Katrina Flood Depth and Elevation on Gentrification in Orleans Parish, Louisiana, 2000–2015.

Model	**Flood Depth**	**Elevation**
	OR[a] (95% CI)	**OR[b] (95% CI)**
Model 1	0.40 (0.24–0.69)	2.97 (1.95–4.52)
Model 2[c]	0.50 (0.29–0.88)	2.55 (1.65–3.94)
Model 3[d]	0.49 (0.28–0.85)	2.58 (1.67–3.97)

[a] Odds of increasing gentrification classification per 1 m increase in flood depth.

[b] Odds of increasing gentrification classification per 1 m increase in elevation.

[c] Adjusted for 2000% black race and 2000% home owner.

[d] Further adjusted for 2000 median home value.

Table 3

Effect measure modification.

Modifier	Flood Depth		Interaction P	Elevation		Interaction P
	OR[a] (95% CI)			OR[b] (95% CI)		
	Bottom 50%	**Top 50%**		**Bottom 50%**	**Top 50%**	
2000% Black race[c]	0.09 (0.02–0.40)	0.59 (0.30–1.15)	0.0982	6.56 (2.18–19.72)	1.88 (1.04–3.39)	0.2770
2000% Unemployment	0.24 (0.06–0.87)	0.43 (0.22–0.84)	0.4470	4.41 (1.46–13.31)	2.67 (1.61–4.41)	0.2274
2000% Service occupation	0.50 (0.26–0.97)	0.05 (0.003–0.79)	0.4283	2.58 (1.50–4.42)	3.72 (1.35–10.23)	0.7220
2000% Home owner[d]	0.29 (0.14–0.59)	8.01 (1.27–50.67)	0.0766	3.72 (2.10–6.60)	0.90 (0.30–2.69)	0.3812
Home constructed within last 5 years	0.55 (0.21–1.41)	0.43 (0.19–0.95)	0.8773	2.68 (1.25–5.71)	2.84 (1.57–5.15)	0.4944
Moved in within last 5 years	0.51 (0.20–1.31)	0.53 (0.24–1.17)	0.4055	2.79 (1.30–5.99)	2.51 (1.40–4.48)	0.1735

All models adjusted for 2000% black race, 2000% home owner, 2000 median home value unless otherwise specified.

[a] Odds of increased gentrification classification with each meter of flood depth.

[b] Odds of increased gentrification classification with each meter of elevation.

[c] Not adjusted for 2000% black race.

[d] Not adjusted for 2000% home owner.