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Housing amenity and affordability shape floodplain development

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ABSTRACT

Flood damage has severe and long-term repercussions for households and communities, and continued housing development in floodplains escalates damages over time. Policies and interventions to reduce damage depend on assumptions about housing stock and residents, but assessments of flood exposure to date largely focus on community-scale characteristics at a single point in time, masking potential within-community differences and their evolution through time. We measure residential development in the floodplain nationwide over time to characterize the type and value of U.S. floodplain housing stock and to assess how new development contributes to flood exposure. Over 4M U.S. residences built from 1700 to 2019 (4.8% of all residences built during that time) are located within current regulatory floodplains. These residences are concentrated at the affordable and expensive extremes of the housing value spectrum, reflecting deep differences in the social vulnerability of floodplain residents. Floodplain housing stock often differs substantially from the local market, with coastal floodplains containing relatively expensive housing and inland floodplains containing relatively affordable housing. New housing development has not occurred equally across these contexts. In the past two decades, more floodplain development has occurred in communities with relatively expensive floodplain housing, and mobile home construction in floodplains has slowed. The bifurcated patterns in floodplain housing, across values and geographies, demonstrate the importance of considering the specific population at risk and how it may differ from the broader community when tailoring flood risk management approaches.

1. Introduction

The development of infrastructure and housing in flood-prone areas exacerbates flood damages around the world (Kim and Newman, 2019; Kakinuma et al., 2020; Tellman et al., 2021; Andreadis et al., 2022). In the United States, around 13% of the population lives in areas prone to flooding, including many vulnerable groups (Wing et al., 2018; Qiang, 2019). Nationwide, 2.1M acres of floodplain land were developed in the last two decades, particularly in suburban and rural areas (Agopian et al., In review; Iglesias et al., 2021). These developments drive damage in two ways: by placing more buildings and people directly into hazardous areas, and by worsening surface runoff and putting new areas at risk (Chen et al., 2017; Sebastian et al., 2019). Understanding and managing land use in flood-prone areas can mitigate flood risk, especially in a changing climate. Our approach builds on this literature, delving more deeply into who and what is in harm's way.

Past studies of flood exposure have often tabulated the total population or property exposed or used community-scale information to assess who is at risk. Gridded population estimates based on administrative records or satellite imagery have been combined with flood footprints or elevation data to calculate the total number of people in exposed areas (Tellman et al., 2021; Wing et al., 2018; Iglesias et al.,

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2021; Kulp and Strauss, 2017). In other studies, neighborhood- or county-scale hazard estimates are compared to Census data on the demographic and socioeconomic composition of those communities to understand potential social vulnerabilities (Sanders et al., 2023; Tate et al., 2021; Wing et al., 2022). However, these assessments can overlook substantial differences within communities, where the people at risk are not well represented by community averages.

Accurately characterizing the population at risk of flooding is particularly important since the effects of flooding are not experienced equally (Tate et al., 2021; Mazumder et al., 2022), nor are they likely to be in the future (Wing et al., 2018). Differences in wealth, for instance, can determine where people reside in relation to flood risk (Qiang, 2019). Housing type similarly influences both damage type and extent (Tate et al., 2021; Gourevitch et al., 2022; Rumbach et al., 2020; Smith et al., 2023). Furthermore, the demographic groups most at risk of flooding can vary across a single locality (Sanders et al., 2023; Chakraborty et al., 2014; Montgomery and Chakraborty, 2013).

In this paper, we use parcel-scale indicators that reflect the social vulnerability of households—housing values and housing types—in examining patterns of floodplain development in communities through time. We analyze 87 million residential parcels across the United States to create high-resolution assessments of floodplain housing stock and identify how housing development escalates exposure of people living in affordable versus expensive housing. Examining household-scale data enables more accurate characterization of risk and can inform policy promoting flood-resilient housing stock.

2. Data and methods

Our analysis consists of two main sections. First, at the national level, we characterize floodplain housing stock by housing value and housing type. In doing so, we describe the proportion of residential floodplain housing that is mobile home, multi-family, and single-family housing as well as the proportion of housing stock in the floodplain at different housing values. Second, at the local level, we compare floodplain development across communities. To evaluate local flood exposure, we determine whether floodplain housing is expensive or affordable relative to nearby housing alternatives and then measure how floodplain development patterns have changed over time across contexts of local housing prices. Below, we describe the data and methods for each of these two sections of the analysis.

2.1. Data

2.1.1. Floodplain maps

We use the Federal Emergency Management Agency (FEMA) Digital Flood Insurance Rate Maps (DFIRMs) in effect in spring 2018 from the FEMA Flood Map Service Center for each state. The Special Flood Hazard Area (SFHA), the area with a 1% or greater chance of flooding annually, defines our floodplain. While these maps may underestimate actual flood risk, local governments are very likely to be aware of them as they are required to be used for floodplain regulation for the National Flood Insurance Program (NFIP).

2.1.2. Communities

FEMA defines community as a “political entity having the authority to adopt and enforce floodplain ordinances for the area under its jurisdiction,” which includes tribes, states, or political subdivisions. We use the term “communities” to refer to incorporated municipalities, unincorporated areas participating in NFIP, the remaining unincorporated parts of a county, and tribal reservations. Community boundaries are defined by the 2019 Census TIGER/line shapefiles (U.S. Census Bureau, 2019). Coastal communities have a DFIRM V or VE flood zone, indicating exposure to wave action. Otherwise, a community is considered inland. Our full dataset includes 87M residential parcels across 23,612 communities in the United States. We further subset this dataset for specific analyses; these procedures are described in detail below.

2.1.3. Housing data

Nationwide housing data are from Zillow’s Transaction and Assessment Database (ZTRAX) version 2020 (Zillow, 2020), which contains detailed public records of real estate, including housing values, types, and location. We use a spatial overlay of property coordinates and community geometries to match ZTRAX residential parcels to communities. Properties that do not map to a community even after additional geocoding and buffering of 300m are excluded from the analysis. Of the 101M residential parcels matched to communities, 87M have a year built (the year of first construction, not renovation). We validate the year built records by comparing ZTRAX and Google Earth Pro data (Supplementary). Uncertainty in the reliability of ZTRAX records may increase prior to 1850 (Uhl et al., 2021), which applies to 197,280 (< 1%) of our 87M parcels records. Floodplain properties are those identified within the SFHA using a spatial overlay of property coordinates and DFIRM geometries. Because we use a point for a parcel rather than a building footprint, some parcels may be incorrectly zoned. However, building footprint data are incomplete and do not identify the primary residence if there are multiple buildings on a parcel. Using a point could either over-assign or under-assign properties to the SFHA. A point is smaller than a building footprint or parcel polygon and may be more likely to be outside the SFHA; at the same time, even if much of a parcel is in the SFHA, the building may be purposefully sited outside the SFHA.

2.1.4. Housing values

ZTRAX includes records for total assessed, market, and appraisal housing values, although not all properties have all three types of values recorded. We identify a primary property value type (market, assessed, or appraised) for each state based on the maximum property value estimate available (supplementary figure 1). Some properties in a state have a value type other than that of the state’s primary property value (e.g., an assessed value but no market value when the state’s primary value is market). To approximate the state’s primary property value for such properties, we scale them by an average ratio between the secondary and primary values from all properties in the state with both. Additional detail and further validation efforts, such as comparisons with housing values in the American Community Survey (supplementary figure 2), are provided in the Supplement. Critically, this enables comparing housing values within, but not across, state boundaries.

2.2. Methods

2.2.1. Characterizing floodplain housing stock

We subset our data to residences with housing values that could reasonably reflect the financial resources of the resident. We drop residential income properties (including apartments and duplexes), seasonal residences, timeshares, and cooperatives; they are a minority of overall housing parcels (7.3%). We also remove properties with no information on whether they are in the floodplain, leaving 77.4M residential parcels nationwide.

To assess the distribution of floodplain residences across different property values, we then place calculated housing values into percentiles from 1 (affordable) to 100 (expensive) within the state. For each housing value percentile in each state, we calculate the total residential parcels and total residential floodplain parcels. Then, we aggregate to the national scale by summing the total number of residential parcels in each percentile and the total number of *floodplain* residential parcels in each percentile of each state to calculate the share of residential floodplain properties in each percentile. This approach places the most expensive homes of each state in the 100th percentile and avoids comparing values across states, which is critical based on the property value data we use (see Section 2.1.4). We use a linear regression model to test for significant differences in the share of floodplain housing across percentiles by grouping percentiles into five categories—most affordable (1–20 percentiles), moderately affordable (21–40), a middle quintile (41–60), moderately expensive (61–80), and most expensive (81–100)—and use the middle quintile as the reference category (Table 1).

Next, we divide communities into inland and coastal geographies and repeat this process of assigning percentiles within states and summing based on property's relative positioning within a state. Because we reassign housing value percentiles after dividing between inland and coastal communities, we are classifying properties into percentiles in comparison to other coastal (or inland) properties within their state.

We also examine how floodplain housing types have evolved, focusing on single-family homes, multi-family homes, and mobile homes. Single-family housing includes residential properties with land uses of single family residential, rural residence, bungalow, and manufactured/modular/prefabricated homes. Multi-family housing includes townhouses, cluster homes, condominiums, row houses, and patio homes (but not income properties). Only mobile homes make up the last housing type. To differentiate single-family and multi-family housing, we group housing according to whether structures are typically attached, detached, or semi-detached. The data do not allow us to determine how many households live at a residence. However, we recognize the possibility that single-family houses can be used by many families, while multi-family housing could be a residence for a single family.

2.2.2. Comparing rates of floodplain development across communities

To assess how development contributes to flood exposure in communities, we construct a measure of floodplain housing development comparable across communities, the Floodplain Housing Index (FHI) (Agopian et al., In review). For this portion of the analysis, we limit our dataset to fully mapped communities with at least 10 residential floodplain properties (encompassing 71.5M parcels in 10,237 communities nationwide).

To compare floodplain (FP) development across communities and account for factors including community size, growth pressure, and flood hazard extent, we calculate every community's FHI:

$$FHI = \frac{\textit{Share of new homes in FP}}{\textit{Share of developable land in FP}} = \frac{\textit{Number of new FP homes}/\textit{Number of new homes}}{\textit{Area of developable FP land}/\textit{Area of developable land}}$$

Developable land in each community includes all areas other than open water (classes 11 and 12) (National Land Cover Database, 2019), non-locally protected lands (designated as "non-local") (U.S. Geological Survey, 2022), and steep slopes (LANDFIRE, 2016)—open water, protected lands, and steep land are difficult to develop. The FHI represents the ratio between the share of new floodplain houses and share of developable land in the floodplain in communities. If new housing were randomly distributed throughout a community, we would expect the share of new housing in the floodplain to be proportional to the share of developable land in the floodplain. In this case, such as a community where 50% of the developable land is in the floodplain and 50% of their new housing is in the floodplain, FHI is equal to one. In contrast, an FHI greater than one indicates disproportionately more new floodplain housing relative to the share of developable land in the floodplain (e.g., a community with 75% of new housing in the floodplain and 50% of developable land in the floodplain). An FHI less than one indicates disproportionately less new floodplain housing (e.g., a community with 25% of new housing in the floodplain and 50% of developable land in the floodplain).

For each community, we compare the median value of floodplain properties to the median value of all housing in the county where a community is located. For communities that span multiple counties, we compare a community to the county that contains most of the community's residential properties. Property prices at the community and county level are from any year through 2019, depending on when localities last recorded data, but most were recorded within the 5 years before 2019. We refer to the ratio comparing community median *floodplain* property prices with county median property prices as the "floodplain price ratio." A ratio greater than 1 indicates a community with relatively expensive floodplain, where the median housing value of floodplain properties in a community is higher than the county's median housing value; a ratio less than 1 indicates a community with relatively affordable floodplain. The ratio compares the affordability of floodplain homes to the local housing market; it is not intended to measure the effect of the floodplain on housing values. For statistical analyses on the floodplain price ratio, we use Welch's t-test to assess differences between communities with relatively affordable or expensive floodplain.

Table 1
The share of residences in the floodplain varies as a function of property value and coastal/inland geography. Results of regressions of the percentage of floodplain properties on property value quintile are shown below. The coefficients in each property value group represent the percentage point change in the share of floodplain residences compared to the middle quintile (41st-60th percentiles). The columns show the results of regressions for the full national sample, inland communities only, and coastal communities only.

Property Value Quintile	A) Nationwide	B) Inland	C) Coastal
Most Affordable (1–20)	0.988*	1.627*	-0.983
	(0.266)	(0.129)	(0.630)
Moderately Affordable (21–40)	0.275	0.518*	-0.536
	(0.266)	(0.129)	(0.630)
Moderately Expensive (61–80)	0.359	-0.118	2.239*
	(0.266)	(0.129)	(0.630)
Most Expensive (81–100)	2.529*	0.445*	9.418*
	(0.266)	(0.129)	(0.630)
Intercept	4.482*	2.715*	11.947*
	(0.188)	(0.091)	(0.445)
N	100	100	100
R-squared	0.551	0.706	0.798
Adj R-squared	0.532	0.694	0.789

Reference group is the middle quintile (41st-60th percentiles) (* $p < 0.01$)

3. Results

3.1. Characterizing floodplain housing stock

Of 87.1M residential parcels in the United States, 4.8% (4.1M parcels) are in floodplains, including 2,818,694 single-family homes, 261,186 mobile homes, and 963,043 multi-family homes. 85.3% of the 87.1M residential parcels built from 1700 to 2019 are not within the SFHA, and 9.9% are not covered by a floodplain map.

Among the 77.4M mapped properties with housing values, residences at the affordable and expensive extremes of the housing value distribution relative to the state are more likely in floodplains than residences near the average (Fig. 1). Within the most expensive quintile of residential parcels, 7% are in the floodplain, 2.5 percentage points greater than in the 41st-60th percentiles ($p < 0.01$, Table 1). In the most affordable quintile, 5.5% of properties are in floodplains, nearly one percentage point greater than the middle range ($p < 0.01$, Table 1). The unequal distribution becomes pronounced in the most expensive and most affordable 5% of residences: 9.3% and 6.2% are in the floodplain, respectively. The result is a non-linear, U-shaped distribution that deepens over time (supplementary figure 4).

The distributions differ across inland and coastal communities. In coastal communities, the most expensive residences (relative to other coastal residences within the state) contain the highest share of floodplain housing (Fig. 1(c)). The share of floodplain housing increases from 11.9% in the middle quintile to 14.2% and 21.4%, in the moderately expensive and most expensive quintiles, respectively. The share of floodplain homes among the most affordable percentiles is similar to the share in the middle quintile. By contrast, among inland communities, the share of floodplain homes is greater at both sides of the housing

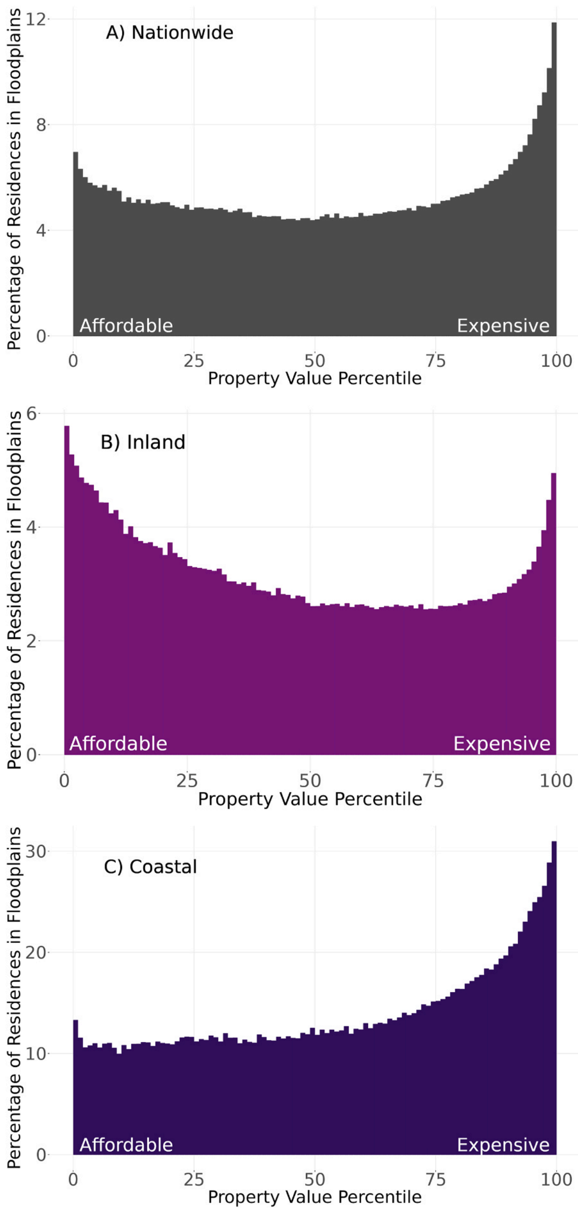

Fig. 1. Floodplain housing is concentrated in the most affordable and most expensive ends of the housing market. (A) Residential properties nationwide (n = 77,451,033) are ranked in percentiles from least to most expensive within each state; then the percentiles from each state are combined to calculate the share of floodplain residences within each percentile. (B) Residential properties in inland communities (n = 62,320,224) are ranked in percentiles relative to each state's inland properties; then the percentiles from each state are combined to calculate the share of floodplain residences within each percentile. (C) Residential properties in coastal communities (n = 15,130,809) are ranked in percentiles relative to each state's coastal properties; then the percentiles from each state are combined to calculate the share of floodplain residences within each percentile.

value spectrum. Homes that are more affordable (relative to other inland residences within the state) are more likely to be in the floodplain (Fig. 1 (b)): the share of floodplain residences among the most affordable quintile is 1.6 percentage points higher than that of middle quintile, and the share of floodplain residences in the moderately affordable quintile is 0.5 percentage points greater ($p < 0.01$, Table 1). For inland properties, the most expensive quintile also contains a slightly elevated share of floodplain homes.

The home types in floodplains have also shifted through time (Fig. 2). Construction of mobile homes in floodplains peaked in the 1990s, averaging 6374 per year that decade (13% of all new floodplain housing built 1990 to 2000), and declined to an average of 2787 per year from 2000 through 2019 (6% of new floodplain housing 2000 to 2019). Multi-family floodplain housing peaked in the early 2000s but declined in the past decade. Single-family homes consistently represented just over half of the annual new floodplain housing stock from the late 1980s to the late 2000s and approximately three-quarters of all new floodplain housing built in the 2010s.

3.2. Comparing rates of floodplain development across communities

Using the floodplain price ratio, which compares a community's median floodplain property value to the median property value of the surrounding county, we group communities based on the relative affordability of the floodplain housing stock. We refer to communities with a floodplain price ratio < 1 as "affordable" and < 0.5 as "very affordable." Conversely, communities with a floodplain price ratio > 1 are "expensive" and > 2 are "very expensive." Here, we focus on 71.5M residential properties in 10,237 communities nationwide. Overall, communities are roughly equally divided into those with relatively affordable floodplains and those with relatively expensive floodplains (Fig. 3). 5613 communities (55%) are affordable, and of those, 932 are very affordable; 4616 communities (45%) have expensive floodplains, and of those, 655 have very expensive floodplains.

In many communities, floodplain residences differ substantially from the local housing stock, illustrating how community-scale statistics may mask important features of the population at risk. 112 communities have a floodplain price ratio of less than 0.25, such that floodplain residences are very inexpensive relative to the local market. In those communities, which occur across the United States, 38% of the floodplain housing stock is mobile homes. As floodplain housing values approach values of the surrounding county (i.e., as the floodplain price ratio approaches 1), the share of mobile homes in the floodplain decreases to less than 10%. Unsurprisingly, coastal communities are more likely to have relatively expensive floodplains. Coastal communities average a floodplain price ratio of 2.13 (n = 816, sd = 8.19), and 69% have a floodplain price ratio > 1. By contrast, inland communities have an average floodplain price ratio of 1.06 (n = 9421, sd = 1.26) and 43% have a floodplain price ratio > 1. The difference in floodplain price ratios across coastal versus inland communities is statistically significant ($p < 0.001$; CI = 0.51–1.64; Welch's t-test).

In the past two decades, communities with expensive floodplains have built more housing than communities with affordable floodplains, both within and outside of flood hazard areas. Communities with very expensive floodplain had an average of 105 (sd= 456, median of 10) new residences built in the floodplain from 2001 to 2019, compared with an average of 15 new properties (sd = 72, median of 3) for communities with very affordable floodplain ($p < 0.001$, CI = 55–126; Welch's t-test). This result mirrors differences in overall development rates, as expensive floodplain communities have built an average of 1762 new residences (median = 463) total compared to 1351 (median = 138) in affordable floodplain communities.

To account for differences in growth pressure and flood hazard and test whether expensive floodplain communities have developed *disproportionately* in the floodplain, we compare FHI values across communities. For the 2001 to 2019 period, FHI increased with the floodplain price ratio. The median FHI was 0.46 among communities with very expensive floodplain, followed by 0.3, 0.27, and 0.24 for expensive, affordable, and very affordable floodplain communities (Fig. 4). (The mean FHI values are affected by extremely large outliers in FHI values, so we focus on the median here.) The share of communities with FHI values above one shows similar results: 24% of very expensive floodplain communities had FHI values above 1, indicating that development was concentrated in the floodplain, compared to 21% of very affordable floodplain communities. Expensive floodplain and affordable floodplain

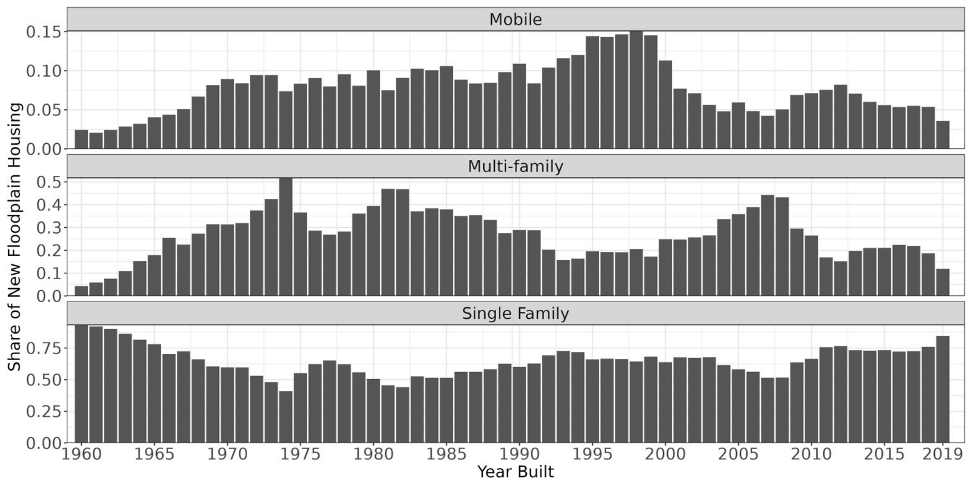

Fig. 2. The types of residences built in the floodplain change over time. The share of floodplain housing for each year from 1960 through 2019 is plotted for mobile (n = 256,427), multi-family (n = 929,873), and single-family (n = 1,968,240) residences in the floodplain. Each housing type represents a share of floodplain housing for a given year. Since 2000, mobile and multifamily floodplain homes have become less prevalent, while single-family homes represent a larger share of floodplain housing.

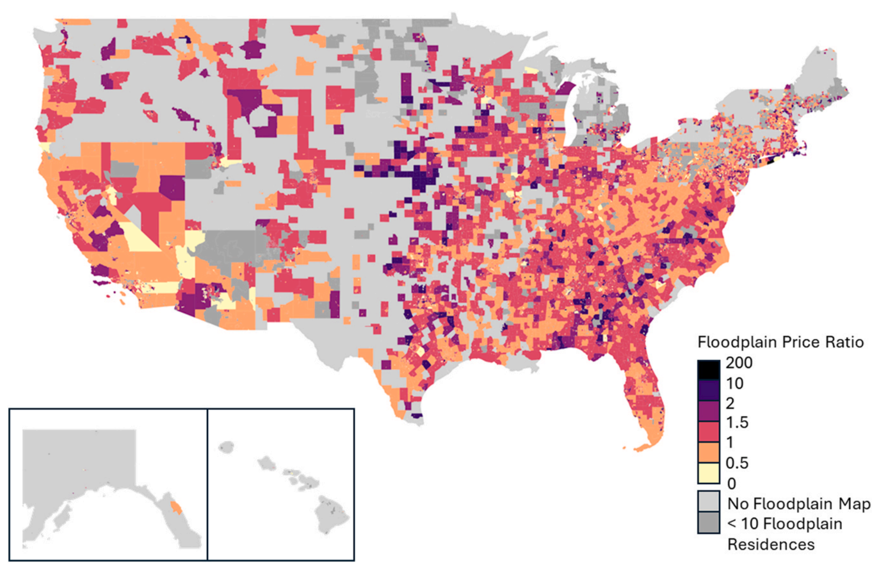

Fig. 3. Values of floodplain houses often diverge substantially from values in the surrounding area. The median value of floodplain residences in communities (n = 10,237) is compared with the median housing value of all residences in the county where a community is located, creating a floodplain price ratio. Communities with relatively affordable floodplains (n = 5613) have floodplain housing with a median value less than the median housing value in the surrounding county (floodplain price ratio <1, light colors) and communities with relatively expensive floodplains (n = 4616) have a higher median value of floodplain housing (floodplain price ratio >1, dark colors).

communities, the middle two bins, had 15% and 16% of communities with FHI above 1.

While communities with expensive floodplains have developed more than communities with affordable floodplains in recent decades, results differ when examining older development. Communities with very affordable floodplains today experienced disproportionately more floodplain development before 2001, with a median FHI for that time period of 0.52 (Fig. 4). The floodplain price ratios are calculated using housing values generally recorded between 2015 and 2019, so the relative pricing today may differ from what was the case when the housing was initially built. Nonetheless, the median of 0.52 among the very affordable communities was greater than any other category. Affordable floodplain communities had an FHI of 0.47, expensive 0.37, and very expensive 0.43. Between the pre- and post-2001 periods, there is a notable shift in floodplain development rates in communities with very affordable floodplains: the median FHI decreased from 0.52 to 0.24, and the share of communities with FHI > 1 decreased from 27% to 21%. The median FHI also decreased for affordable communities, from 0.47 to 0.27. The only category where FHI increased between the two time periods is communities with very expensive floodplains. These overall patterns hold when using more granular bins across the floodplain price distribution (supplementary figure 3).

4. Discussion

Our nationwide analysis points to two distinct housing patterns within floodplains: one where floodplain housing is relatively affordable and more likely to include mobile homes, and another where floodplain housing is relatively expensive and more likely to be comprised of single-family homes. In considering the geography of floodplain housing patterns, we find that floodplain housing is more prevalent among the most expensive housing in coastal areas and most affordable housing in

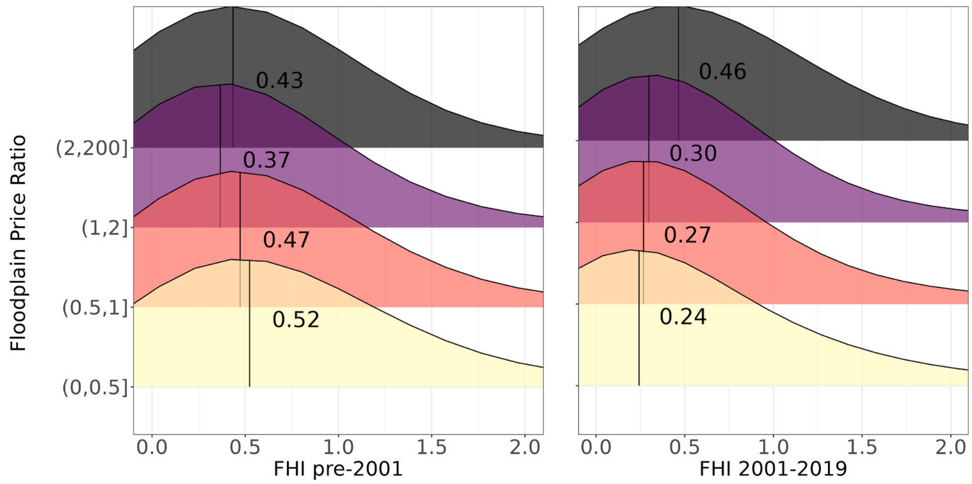

Fig. 4. Communities with affordable floodplain developed more in the floodplain before 2001, while communities with expensive floodplain developed the floodplain at higher rates in 2001–2019. The floodplain price ratio is compared against FHI (A) before 2001 (n = 9732) and (B) from 2001 to 2019 (n = 9571) to evaluate differences between the cost of floodplain housing and rates of floodplain development over time. Median floodplain development rates measured through FHI (vertical black line) are shown in communities with relatively expensive floodplains (dark colors) and relatively affordable floodplains (light colors).

inland areas. Residences in floodplains are often quite different in housing type and value than residences in the community more broadly, underscoring the importance of distinguishing between community characteristics and the characteristics of the flood-prone population.

This bifurcation in housing types and values may represent a similar bifurcation in the financial assets of the residents and therefore has significant implications regarding the ability of residents to self-finance flood preparedness measures, afford flood insurance, and respond to and recover from flooding. Previous neighborhood-scale analyses have highlighted convergence of social vulnerability with high flood hazard in inland, rural areas and in the U.S. South (Tate et al., 2021; Wing et al., 2022) and documented that disadvantaged populations more often live in inland flood zones (Qiang, 2019). However, in other settings wealthier and more privileged communities face disproportionate flood risk (Montgomery and Chakraborty, 2013; Collins et al., 2018) and tend to occupy coastal flood zones, valuing amenities such as viewsheds (Bin et al., 2008). Our analysis demonstrates that not only are both scenarios present in the United States, but they are more common than other, less extreme, combinations of wealth and exposure: both affordable and expensive housing are over-represented in the U.S. floodplain.

Focusing on the past two decades, floodplain development rates are higher in communities where floodplains contain relatively expensive housing, often in coastal, high-amenity areas. In this light, new floodplain residents occupying the most expensive housing might have the financial resources to prepare for, mitigate, respond to, and recover from floods; access public funds due to increased local government capacity (Smith, 2023); or have lower barriers to proving the cost-effectiveness of flood mitigation structures (Martinich et al., 2013; Siders and Keenan, 2020; Tate et al., 2016). That people purchase floodplain residences at the extreme expensive end of the housing market, however, also raises questions about their awareness of the risk (Gomez-Cunya et al., 2022) and the ethics of potentially using public funds to protect expensive private properties (Frank, 2022). Development of expensive housing in coastal floodplains also raises concerns about potential gentrification (Keenan et al., 2018) and private flood mitigation actions reducing public access to coasts (Caldwell and Segall, 2007). Our results focus solely on new construction, so they do not speak to redevelopment or potential gentrification.

The bifurcated floodplain development we observe provides valuable context for ongoing debates over public investment in flood-prone areas. Increasing exposure in both the most affluent and most affordable areas suggests that national or even state-level policies designed to address either, but not both, housing patterns will underserve communities. For instance, expanding public funding for elevating or flood-proofing private property may result in an equitable distribution of resources in some communities and a highly inequitable distribution in others. As another example, there have been numerous calls to modify pricing of the NFIP. Yet NFIP reforms face the challenge of pricing premiums to both signal risk to the coast's most affluent residents, while still being cost-effective for residents in affordable inland floodplains (Elliott, 2023). Further complicating matters, wealthy buyers who purchase a house without a mortgage can also avoid the mandatory flood insurance purchase requirements of federally backed mortgages. Lack of take-up among wealthy buyers both limits the ability of NFIP to signal risk for high-income groups and makes it much more difficult to meet fiscal balance and affordability goals.

In debating the public sector's role in managing flood risk, it is critical to recognize the different populations we identify in this analysis: those who perhaps cannot afford to live in safer areas or purchase additional protections, and those who choose to take on risk due to floodplain amenities, despite having the financial resources to make other choices or mitigate risk. Not all populations have equal access to disaster assistance (Wilson et al., 2021), and unequal distribution of federal aid can have long-term effects on wealth inequality in race, education, and home ownership (Howell and Elliott, 2019). Moreover, historical race relations underpin residential development (Pettigrew, 1979) and can further ostracize populations in rebuilding efforts (Gotham, 2014) and mitigation strategies such as managed retreat and floodplain buyouts (Marino, 2018; Siders, 2019; Elliott et al., 2020). Accounting for resource disparities between floodplain populations can enable public policy supporting vulnerable households with climate-smart spending on infrastructure and reconstruction.

Previous work highlights how FEMA floodplains often underestimate flood risk (Wing et al., 2018; Sanders et al., 2023; Ferguson and Ashley, 2017), but we considered only the SFHA as "floodplain." Therefore, our estimates of new floodplain housing are likely lower than estimates using other floodplain definitions. We also exclude residential income properties (e.g., apartments, duplexes), so our housing count totals are likely a lower bound too. However, renters are among the groups most vulnerable to floods (Wilson et al., 2021), and attention to rental properties is necessary for a fuller scope of local flooding effects. Also, our assessment of floodplain housing and associated values draws on tax assessor data, with varied levels of completeness and accuracy, and though we clean and process the data, the raw data shape communities in our sample and results. Last, our study does not evaluate risk on a parcel-by-parcel basis, and not all new development similarly contributes to risk. Adaptation strategies such as applying building-level protection, elevating buildings, flood-proofing ground windows, and altering landscape design can lessen flooding effects (Attems et al., 2020; Nofal and van de Lindt, 2020). While our analysis focuses solely on exposure, considering disparities in adaptation would enhance understanding of the risks faced by various communities.

5. Conclusion

Where people live—either by choice or by necessity—is a key factor shaping exposure to natural hazards. We find that floodplain housing is more prevalent in the most affordable and most expensive homes, emphasizing the importance of considering diverse populations in planning and implementing policy for local development and flood risk management. It is unlikely that a single solution can reduce flooding effects for all populations in a community. Instead, tailoring approaches to the needs of different populations within and across communities offers pathways to promote equitable development at the local level.

CRediT authorship contribution statement

Katharine J. Mach: Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **A.R. Siders:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Armen Agopian:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Christopher Samoray:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Miyuki Hino:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

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

Processed data and accompanying code are available on the DesignSafe Data Depot at https://www.designsafe-ci.org/data/browser/public/.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2024.107216.

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